Assessment of Integrated Pond-Cage System for the Production of Nile Tilapia for Improved Livelihood of Small-Scale Fish Farmers in Kenya

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ABSTRACT

The study analyzed the effects of three different stocking densities of tilapia in cages on growth and yield in an integrated cage-pond system and compared alternate feeding regimens on growth and yield performance under the three different stocking densities. The costs of producing tilapia at the different stocking densities and feeding regimens in the integrated system were also compared. The results from this study indicate that stocking density considerably influences the growth performance, survival, yield and economic performance of *O. niloticus* in cages under a cage-cum-pond culture system. The stocking density of 50 fish m^{-3} gave the best growth, survival and economic benefits but the lowest yield. This suggests that a cage-cum-pond culture system of *O. niloticus* with stocking density of 50 fish m^{-3} for larger size of fish in a short period and 100 fish m^{-3} provide the highest production. Integration of cage and pond culture therefore increases yield and thus farmers stand a chance of benefiting from two crops in the same facility. It is recommended that the appropriate stocking density in a cage-cum-pond culture system for larger fish in a short period of time should be 50 fish m^{-3}. On the other hand, for higher production, stocking cages at 100 fish m^{-3} is recommended.

INTRODUCTION

In the recent past, integrated cage-cum- ponds culture system has been developed and practiced using combination of catfish-tilapia and tilapia-tilapia (Yi et al., 1996 and Yi, 1997a, Yi 1997b). Integrated cage-cum- ponds culture is a system in which fish are fed with artificial diets in cages suspended in ponds, while same species or others low value fish are stocked in open pond water to utilize natural foods derived from cage wastes. The technique uses the niche optimization concept for feeding; the fish in cages are fed while those in open waters are either fed at lower rates or not fed at all. Pond fish, therefore, derive their nutrients from uneaten foods from the cages or from autotrophic and heterotrophic food chains (Yi et al., 1996). The aim is to rear fish in a cage while the pond fish utilize the uneaten cage feeds and the plankton generated in the pond to satisfy the bio-energetic needs. In such practices, the nutrient utilization efficiency could reach more than 50%, compared to about 30% in most intensive culture systems (Coche 1979). To limit competition for food, raise pond carrying capacity, increase pond fish production, higher supply of artificial feed is required. This systems, provides small-scale farmers an opportunity to use their limited resources to increase fish yield, generate more income.

Rural pond culture in Kenya is moving from subsistence to small-scale commercial culture of fish. The aquaculture industry is transitioning from the rural subsistence enterprise to commercial profit-oriented aquaculture business. Small-scale commercial farmers are utilizing improved management practices such as stocking densities, feeding regimens, and feed nutrient to enhance their economic returns (Quagrainie et al., 2009). The current major production system is pond culture with an average size of 400m^2 stocked with Nile tilapia (Oreocrhomis niloticus) and the African catfish (Clarias gariepinus).

Feeding issues appear to be one of the challenges facing Kenyan small-scale commercial farmers. Studies in Southeast Asia have suggested improvements in growth and yields of Nile Tilapia in integrated cage-cum-pond systems (Yi and Lin, 2001; Yi, Lin and Diana, 1996). The integrated system allows the open pond water to utilize cage wastes as fertilizers, generating natural food in the pond. The integrated system is environmentally friendly because less waste nutrients are released to the public water systems. Profitability from such venture is highly dependent on fish performance in the cage and static ponds. Yi and Lin (2001) concluded that an appropriate integrated cage-cum-pond system depends on appropriate stocking densities for tilapia rotation culture. The underlying hypothesis is that greater amount of wastes from increased biomass in the cages would enhance the productivity in the open ponds. The specific objectives of this study are:

1. To analyze the effects of three different stocking densities of tilapia in cages on growth and yield in an integrated cage-pond system
2. To compare alternate feeding regimens on growth and yield performance under the three different stocking densities.
3. To compare the costs of producing tilapia at the different stocking densities and feeding regimens in the integrated system
4. Conduct on-farm trials to test integrated cage-pond system technologies developed in this study and evaluate costs and benefits to local fish farmers through on-farm trials

Hypotheses

1. H_0: Different stocking densities have no effect on growth of *O. niloticus* in cages suspended in static ponds in an integrated cage-cum-pond culture system.
2. H_0: Different stocking densities have no effect on survival rates of *O. niloticus* in cages suspended in static ponds in an integrated cage-cum-pond culture system.
3. H_0: Different stocking densities have no effect on yield of *O. niloticus* in cages suspended in static ponds in an integrated cage-cum-pond culture system.
4. H_0: Integrated cage-cum-pond culture system has no effect on the growth and yield of *O. niloticus* in the pond.
5. H_0: Different stocking densities have no effect on economic benefits of *O. niloticus* in cages suspended in static ponds in an integrated cage-cum-pond culture system.

METHODOLOGY

Study Area

The study was conducted at Mwea Aquafish Farm (MAF). The warm water fish farm is located 110km North East of Nairobi on the Nairobi-Embu highway and 1.5km from Kimbimbi town. The study area lies at 0˚36.73'S, 37˚22.84'E and 1208m above the sea level. Daily temperatures range from 16.9˚C to

29˚C with cool seasons ranging between 16.9 - 23˚C and warm seasons between 19 - 29˚C. Rainfall ranges between 18.5mm – 223mm in rainy months and 0mm in dry months.

Experimental Design

The study was done in a 1300m^2 earthen pond using 9 cages each with a volume of 1 m^3. The cages had a frame made from 2-inch diameter PVC pipes covered with a 1-inch netting material. The tubing of the upper frame was completely sealed to offer a self-floating mechanism, while the lower frame was perforated to allow it to sink once water filled the tubing. Floating feed rings with a diameter of 50cm made from flexible 15mm PVC tubing were installed to minimize the amount of floating feeds that would slip out of the sides of the cage during feeding.

Hand sexed male *O. niloticus* fingerlings (Mean weight 65.57g ± 0.766; Total length 15.74cm ± 0.076) and *O. niloticus* fry from the M.A.F. hatchery were stocked in the cages and the open pond water respectively (the pond was stocked six weeks after stocking of cages). Fish were reared for a period of 180 days with close monitoring and sampling between 2nd September, 2010 and 2nd March, 2011. Cages were randomly allotted three treatments and stocked at varying densities of 50, 75 and 100 fish per m^3. Each treatment had three replicates to increase data accuracy and reduce cases of bias. Fish were fed with commercial floating feeds.

Feeding was done through hand feeding to caged fish at 4% body weight for the first month and reduced as the fish grew to 1.5 in the sixth month. Fish were fed twice a day at 10.00 hrs and 16.00 hrs. Fish in the experimental pond were not fed with the commercial diet but browsed on the plankton material in the pond; however, they were allowed to feed on feeds that slipped from the sides of the cages. Feeds were adjusted every month based on calculated biomass.

The experimental pond was stocked with $4m^{-2}$ *O. niloticus* as is the practice by small scale commercial fish farmers for static pond culture in this region. Prior to stocking, the pond was fertilized with 20kgN ha^{-1} wk^{-1} and 5kg P ha^{-1} wk^{-1} using Urea and Di-ammonium phosphate (DAP); which is a standard procedure. After 30 days, the rate of Urea application was lowered to 10kgN ha^{-1} wk^{-1} as measures to correct ammonia build up in the pond. Due to evaporation and pond seepage, the pond was topped up every two weeks to maintain the water level at 1.3m.

Sampling

Dip and seine nets were used to sample fish in cages and in the pond respectively. 30 fish from every cage and 100 from the open pond were sampled during each sampling occasion. On completion of the experiment, all fish were harvested from both the cages and the experimental pond. Their mean weights were recorded and their yields computed. Plankton net was used to sample plankton in the pond. Stomach content analysis of fish (both from the cages and from the pond) was also done.

At the end of the experiment, fish were harvested using repeated netting, and total yield determined. Minitab statistical software was used for analysis. The effects of the three stocking densities on growth, survival, yield performance and economic benefits were analysed using Ordinal Logistic Regression with time in months as the response variable and the different stocking densities and the factors. ANOVA was also used to test significance differences among the treatments. The following parameters were calculated as indicated. Mortalities were recorded as they occurred. Their numbers were also determined by counting the remaining fish in the cages at each sampling date.

A full enterprise budgeting analysis was used to compare the relative profitability of the different stocking densities by estimating all income and expenditures of each treatment.

Dissolved oxygen (DO), temperature and pH were measured *in situ* twice a week. DO and temperature were measured using DO meter (model: YSI 550A) while pH was measured using a pH meter (model: HI 98127). Water samples were also collected monthly in the morning and afternoon from the pond between 0800 and 1800 h for analysis of nitrite-nitrogen (NO_2-N), total nitrogen (TN), soluble reactive phosphorus (SRP), and total phosphorus (TP). All the analyses were conducted following the standard analytical procedures detailed in Boyd and Tucker (1992).

RESULTS

Fish Growth

The overall growth performance attributes of *O. niloticus* in cages are presented in Table 2. The stocking weights of *O. niloticus* among the treatments were statistically similar (p=0.992). The same case applied for the stocking weights (p=0.995). After the study period of 180 days, the largest fish in cages weighed 590g recorded in fish stocked at 50 fish m^{-3} as shown in Table 2 while the smallest fish was found in the treatment with the highest stocking density of 100 fish m^{-3} weighing 180g. Fish reared at the lowest stocking density were more uniform in sizes during harvest; however, fish reared at the highest stocking density were less uniform despite being stocked at the same size.

The SGR of fish stocked at 50 fish m^{-3} was higher than that of fish stocked at 75 fish m^{-3} as well as those stocked at 100 fish m^{-3} which showed the lowest SGR. The condition factor of fish stocked at 50 fish m^{-3} was higher than observed in the other two treatments with fish stocked at 100 fish m^{-3} having the least condition factor. Fish stocked at 100 fish m^{-3} had the highest total yield as compared to the other two treatments.

Mean length of fish stocked at 50 fish m^{-3} was higher as compared to the other two treatments. Fish stocked at 100 fish m^{-3} had the least length as shown in figure 1. The same was observed for the mean weight. Both the lengths and the weights showed a statistical significant difference (p=0.000).

There was a significance difference (p = 0.000) in the growth of fish among the different treatments. Both the weights and the lengths showed this difference. As shown in figure 2, fish stocked at 50 fish m^{-3} had the best growth as compared to the other two treatments. After the first month, the lengths of *O. niloticus* among the treatments showed no significance difference (p=0.434) as did the weights (p=0.854). At the second month, the length of fish stocked at 50 fish m^{-3} showed statistical difference (p=0.000) from the rest, however, the lengths of fish stocked at 75 fish m^{-3} and 100 fish m^{-3} still remained statistically similar (p=0.833). The same was observed in weights between fish stocked at 75 fish m^{-3} and 100 fish m^{-3} (p=0.212). At the third month, all treatments showed statistical difference (p=0.000) which was maintained to the end of the experiment.

Table 1: A summary of the various experimental parameters (Mean ± SE)

Growth parameter	50 fish m^{-3}	75 fish m^{-3}	100 fish m^{-3}
Stocking Length (cm)	15.72 ± 0.12[a]	15.74 ± 0.13[a]	15.74 ± 0.15[a]
Stocking Weight (g)	65.47 ± 1.07[a]	65.59 ± 1.24[a]	65.67 ± 1.65[a]
Mean Harvest Length (cm)	25.57 ±0.137[a]	24.03 ± 0.139[b]	23.15 ± 0.156[c]
Mean Harvest Weight (g)	360.00 ± 7.34[a]	281.28 ± 4.73[b]	247.94 ± 4.64[c]
Harvest maximum Length (cm)	30.0	26.8	26.4
Harvest minimum Length (cm)	23.0	21.1	20.3
Harvest maximum Weight (g)	590.0	390.0	350.0
Harvest minimum Weight (g)	260.0	200.0	180.0

Growth parameter	50 fish m^{-3}	75 fish m^{-3}	100 fish m^{-3}
Mean Yield (kg)	17.35^a	18.58^a	20.91^b
SGR (% day^{-1})	0.41	0.35	0.32
FCR	1.9^a	2.6^b	3.1^c
Condition factor	2.15^a	2.03^b	2.00^c
Survival (%)	96.67^a	89.78^b	83.00^c

NB: For every parameter and treatment, means with different letters as superscripts are statistically different.

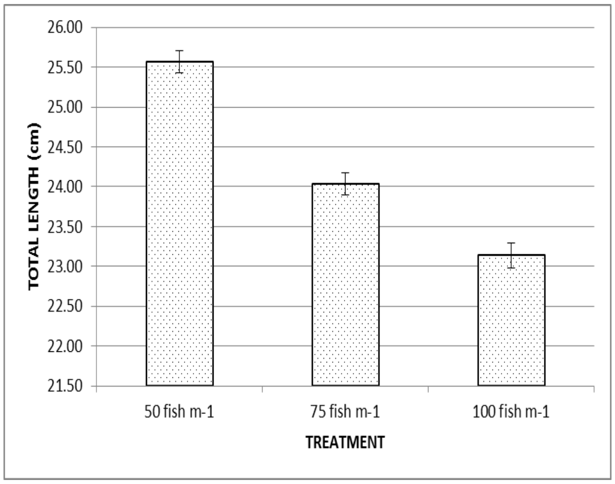

Figure 1: Total Length (Mean ± SE) for each treatment

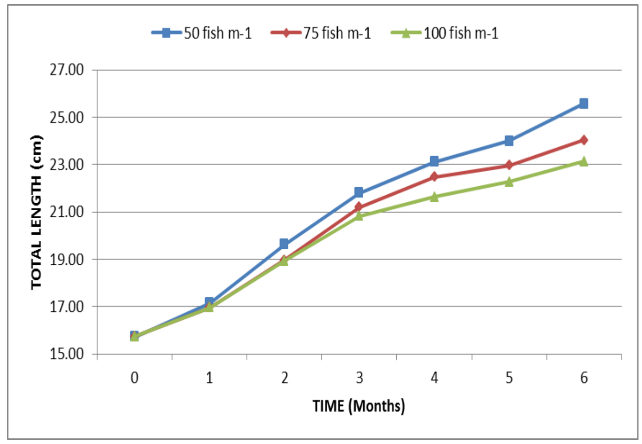

Figure 2: Total Length of fish over a period of 6 months for the three treatments.

The SGR of fish in all treatments had a continued decline. Reduction in the SGR was highest in fish stocked at 100 fish m^{-3} and lowest in fish stocked at 50 fish m^{-3} with fish stocked at 75 fish m^{-3} remaining as the intermediate. These trends were maintained throughout the experimental period. The SGR corresponded to cage biomass such that, as the cage biomass increased, SGR continually declined towards stagnation.

At a stocking density of 50 fish m^{-3}, the general equation of Log W versus Log L indicated a slope (b) value of 3.3191; a slope of 2.7734 for the fish stocked at 75 fish m^{-3}; and 2.6689 for fish stocked at 100 fish m^{-3}. This shows a decrease in the slope as the stocking density increased. The lowest stocking density of 50 fish m^{-3} had the highest condition factor (K) as compared to fish stocked at 75 and 100 fish m^{-3}. The fish stocked at 100 fish m^{-3} had the lowest condition factor.

Food Conversion Ratio of *O. niloticus* stocked in cages suspended in a pond decreased with decrease in stocking density. Fish stocked at 100 fish m^{-3} had the highest FCR of 3.1 followed by fish stocked at 75 fish m^{-3} with FCR of 2.6 and finally fish stocked at 50 fish m^{-3} had the least FCR of 1.9 as shown in figure 3. FCR among the three different treatment was statistically different (P= 0.000).

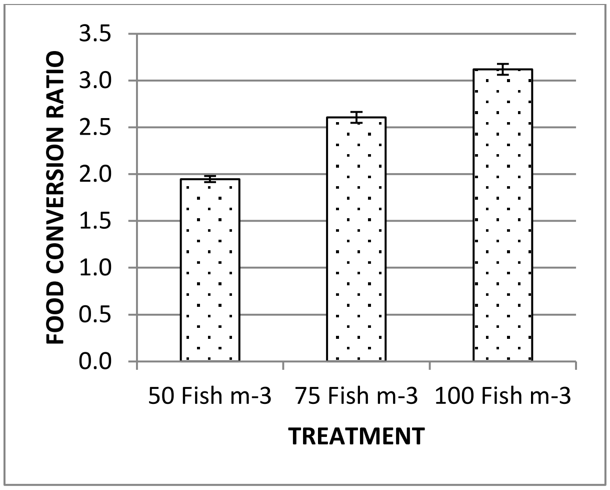

Figure 3: FCR of *O. niloticus* reared in cages suspended in a pond under 3 different stocking densities.

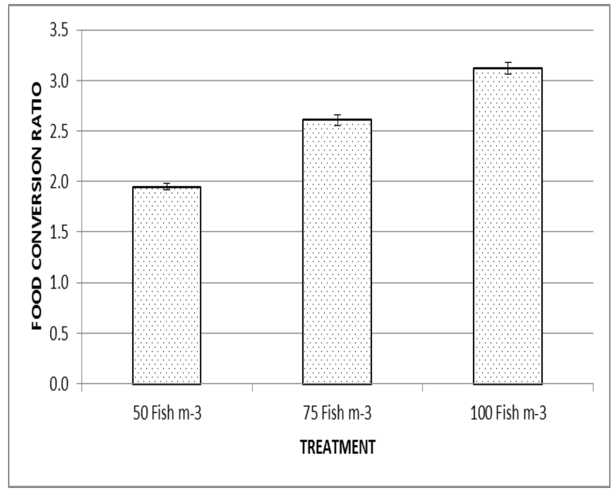

Figure 4: Percentage Survival of *O. niloticus* in cages under three different stocking densities

Fish Survival

Percentage survival of *O. niloticus* stocked in cages suspended in a static-water pond increased with a decrease in the stocking density. Fish stocked at 50 fish m^{-3} had the highest survival rate of 96.67% followed by fish stocked at 75 fish m^{-3} at 89.78% and finally 100 fish m^{-3} with the least survival rate at 83.00% as shown in figure 7. Mortalities were first experienced on the fifth day when feeding started and remained high for the first two weeks before the fish acclimatised to the new environment. Mortalities were also experienced after every sampling occasion.

Yield

Yields of fish increased with increase in the stocking density. The highest stocking density (100 fish m^{-3}) yielded higher than treatments where fish were stocked at 50 and 75 fish m^{-3}. Fish stocked at 50 fish m^{-3} had the lowest yield as shown in figure 5. Mean yield of fish stocked at 100 fish m^{-3} had a significance difference (p=0.000) from the other two treatment. Mean yields of fish stocked at 50 fish m^{-3} and 75 fish m^{-3} showed no significance difference (p=0.050).

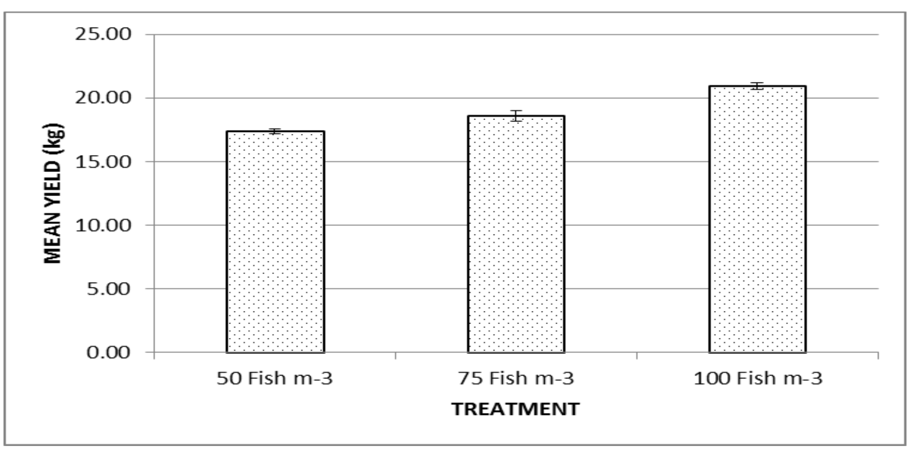

Figure 5: Mean yield of *O. niloticus* stocked in cages at different stocking densities.

Pond Fish

Fish in ponds ranged in their weights between 1g and 190.0 g. They showed division in five classes which included fish between below 6g (fry – 28,500); 6.6 – 38.7g (3751 pieces); 43.9 – 69.4 g (1386 pieces); 71.70 – 98.9g (342 pieces); and 103.9g – 190.0g (151 pieces) as shown in table 2.

Plankton Composition

Both the phytoplankton and zooplankton were available in the pond water where the cages were suspended. Phytoplankton dominated with *Volvox spp* (60%) as the dominant species found. Others include: *Scenedesmus, Pandorina, Aphanocapsa, Tetraedron, Euglena spirogyra.* Zooplankton were dominated by *Daphnia spp* (55%); others include: *Flagaria capucina, Nauplius*

Table 2: A table showing the various classes of fish harvested in the pond

	Minimum		Maximum		Mean		
Class	TL (cm)	WT (g)	TL (cm)	WT (g)	TL (cm)	WT (g)	Yield (kg)
6 - 40g	7.00	6.60	13.30	38.70	10.32	21.47	80.53
40-70g	13.10	43.90	16.20	69.40	14.63	55.47	76.88
70 – 100 g	15.50	71.70	19.00	98.90	16.79	87.73	30.00
> 100g	18.5	103.90	22.30	190.00	19.47	129.31	19.53

Stomach Content Analysis

Analysis of the stomach content of fish in cages for the three different stocking densities (i.e. 50, 75 & 100 fish m^{-3}) showed that fish in cages, highly depended on the commercial feed given to them with percentages of 95%, 93% and 93% respectively. On the other hand, fish in the open pond, consumed 88% plankton material and 12% commercial feed.

Table 3: Mean, Min and Max water quality parameters measured during the study period.

PARAMETER	MEAN ± SE	MINIMUM	MAXIMUM
Dawn DO (mg l^{-1})	3.023 ± 0.0496	1.9900	3.5600
Evening DO (mg l^{-1})	6.827 ± 0.0998	5.2200	8.4400
Dawn pH	8.279 ± 0.0232	7.9000	8.7000
Evening pH	8.815 ± 0.0222	8.4000	9.3000
Dawn Temperature (°C)	22.750 ± 0.111	21.100	24.300
Evening Temperature (°C)	26.798 ± 0.111	25.000	28.800
Total phosphorous (mg l^{-1})	0.085 ± 0.0034	0.0800	0.1000
SRP (mg l^{-1})	0.036 ± 0.0008	0.0330	0.0390
Total nitrogen (mg l^{-1})	0.287 ± 0.0061	0.2700	0.3100
NO_2-N (mg l^{-1})	0.009 ± 0.0004	0.0080	0.0110

Water Quality Parameters
The water quality parameters in the pond where the cages were suspended remained within the tolerable ranges for the optimal growth of *O. niloticus* as shown in table 3.

Economic Benefits
Returns decreased with increase in stocking density. The highest stocking density (100 fish m^{-3}) had the lowest returns as compared to the other two treatments where fish were stocked at 50 and 75 fish m^{-3}. Fish stocked at 50 fish m^{-3} had the highest returns as shown in figure 6. Mean returns of fish stocked at 50 fish m^{-3} had a significance difference ($p=0.003$) from the other two treatment. However, mean returns of fish stocked at 75 fish m^{-3} and 100 fish m^{-3} showed no significance difference ($p= 0.735$). Fish from the pond

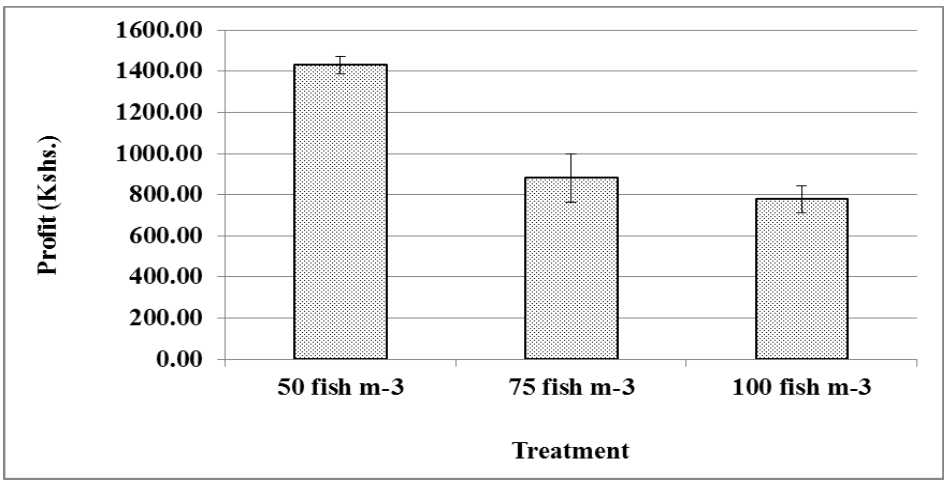

Figure 6: Mean returns accrued from the different stocking densities

were sold at different prices depending on their size. Fish above 120g were sold as broodstock. Individual cost and revenue are shown in Tables 4. Enterprise budget for *O. niloticus* stocked at 100 fish m^{-3}shown in Table 5.

On-Farm Trials
Preparatory contacts with farmers in Central Province – Kenya began immediately after the research work on cage-cum-pond culture started. Three groups of farmers were identified i.e. Ruiru Youth for Development and Environment Conservation group – Thika; Rugita Youth Development group – Kikuyu; and Karunda Whiteland Youth Development Group – Nyeri. A workshop to introduce the farmers to cage culture was held on 16th October, 2010 at Mwea Aquafish Farm. Farmers were taught the importance of cage culture, cage construction, site selection for placement of the cages, feeding, record keeping, and stocking densities among other cage management practices. They were also introduced to pond management practices. In addition to the farmers who participated in the workshop, extension officers, AquaFish CRSP personnel, Mwea Aquafish Farm staff and a student involved in the cage culture research work were involved. A more intensive training was conducted from 23rd November to 5th December, 2010 at Mwea Aquafish Farm where two farmers from each group attended. During this training, the farmers constructed cage frames and also learnt how to make a complete cage. After the training, farmers were given materials for cage construction which they started from 6th December, 2010 at their respective sites. Each group constructed six cages.

On-farm trials of cages in ponds and of cages in dams were conducted by the group members between December 2010 and July 2011. A post-trial workshop was held on 8th July, 2011 at MAF. The three groups of farmers participated in the workshop, along with extension officers who have been working with the various groups, AquaFish CRSP personnel, MAF staff, representatives from the Ministry of Youth Affairs, and a student involved in the cage culture research work.
Each group made a presentation of how they have progressed in cage farming, their experiences in fish farming and the challenges they are facing. Farmers were given a chance to ask questions and discuss the impacts they have had on the community around them.

Challenges faced

<u>Twiga dam</u>

- High fish mortalities
- Theft of fish
- Accessibility of the cages – inefficient boat
- Uncommitted members
- Poor record keeping

<u>Gathathi-ini dam</u>

- Accessibility of the cages – inefficient boat (heavy)
- Uncommitted members
- Insufficient funds
- Destruction of hapa nets by predators (leading to loss of fish)
- High water turbidity

<u>Rungiri dam</u>

- Uncommitted members
- Water resource conflict
- Poor security
- Drug trafficking by the community within the vicinity of the dam
- Crime (Murder and suicide) – dumping of murdered people in the dam
- Leadership problem (which is now resolved)

DISCUSSION

Fish Growth

Growth trends of fish in this study indicated that there was uniform growth pattern in length and weight of fish stocked at the three different densities for the first month of the rearing period. This could be attributed to the fact that fish transferred to a new environment take time to acclimatize. This condition, however, changed in the subsequent months based on the different stocking densities. The growth performance of tilapia is significantly related with the stocking density of the fish (Chakraborty *et al.*, 2010).

In this study, the growth of *O. niloticus* in cages was found to be density dependent with increased stocking density having a negative effect on final mean body weight, final mean total length, SGR, FCR and condition factor. Similar observations were made by Yi and Lin (2001), where increased fish biomass of Nile tilapia in cages has a significant negative effect on the final mean body weight. Increased rearing density negatively affected the mean body weight, final mean total length, SGR and weight gain of *O. niloticus* fry reared in glass tanks (Opiyo, 2010). This is in agreement with previous studies by: Yi *et al*., (1996); Gibtan *et al*., (2008); Mokoro, (2008). However, some researchers have found out a positive effect on growth of fish with increased stocking densities (Baker and Ayles, 1990; Petit *et al.,* 2001).

Table 4: Enterprise budget for *O. niloticus* in a cage-cum-pond culture system

Item	Number	Unit	Cost / unit (Kshs.)	Total cost (Kshs.)	Total cost (US$)
Revenue					
Cage fish	170.52	kg	300	51156	639.45
Pond fish 7 - 40g	3751	piece	15	56265	703.31
Pond fish 40 – 70g	1386	piece	40	55440	693.00
Pond fish 70 - 100g	342	piece	80	27360	342.00
Pond fish > 100g	151	piece	200	30200	377.50
Fry	28500	piece	7	199500	2493.75
Total revenue				**419921**	**5249.01**
Costs					
Variable costs					
Fingerlings	675	piece	15	10125	126.56
Fry	5200	piece	5	26000	325.00
Feed	322.96	kg	60	19377.41	242.22
Labor	23	man/8hr	200	4600	57.50
Fertilizer					
Urea	10.4	kg	50	520	6.50
DAP	2.6	kg	60	156	1.95
Fuel	23	Litres	100	2300	28.75
Total variable costs (TVC)				**63078.41**	**788.48**
Fixed costs					
Cage rent	9	Piece	750	6750	84.38
Pond rent	6	Month	500	3000	37.50
Total fixed costs				**9750**	**121.88**
Total costs (TC)				**72828.41**	**910.36**
Net returns above TVC				356842.59	4460.53
Net returns above TC				347092.59	4338.66

The observed final mean body weight and final mean total length in this study were poor in the high stocking density of 100 fish m^{-3}. The lower growth performance of tilapia at higher stocking density could have been caused by voluntary appetite suppression, more expenditure of energy because of intense antagonistic behavioural interaction (Chakraborty *et al.,* 2010), competition for food and living space (Diana *et al*., 2004) and permanent stress caused by crowding (Ellis *et al*., 2002). Boujard *et al*., (2002) also reported that appetite of fish can be impaired by increase in density. High stocking densities impair visual location of food by making it difficult for fish to follow a trajectory towards the food pellets (Silva *et al.,* 2000) and might have prevented the physical access of pellets by the fish stocked at 100 fish m^{-3}. Poor feeding might also explain the poor performance of fish stocked at high density.

Table 5: Enterprise budget for *O. niloticus* stocked at 100 fish m^{-3}

Item		Quantity	Unit	Unit Cost (Kshs.)	Total cost (Kshs.)	Total cost (US $)
Revenue						
	Cage Fish	20.91	kg	300	6272.00	78.40
Total revenue					6272.00	78.40
Costs						
Variable costs						
	Fingerlings	100	piece	15	1500.00	18.75
	Feed	43.64	kg	60	2618.36	32.73
	Labor				383.33	4.79
	Fertilizer				16.00	0.20
	Fuel				144.44	1.81
Total variable costs (TVC)			Kshs.		4662.13	58.28
Fixed costs						
	Cage rent				750.00	9.38
	Pond rent				83.33	1.04
Total fixed costs			Kshs./US $		833.33	10.42
Total costs (TC)			Kshs./US $		5495.46	68.69
Net returns above TVC			Kshs./US $		1609.87	20.12
Net returns above TC			Kshs./US $		776.54	9.71
Breakeven price (BEP)			Kshs./US $		155.29	1.94
Breakeven yield (BEY)			kg		10.82	

The fish attained the highest length and achieved maximum body weight when reared at 50 fish m^{-3}. This could be due to the fewer fish per unit space (Sahoo *et al*., 2004) in the cages. Similar results were reported by Gibtan *et al.,* (2008) who recommended 50 fish m^{-3} as the optimal stocking density of *O. niloticus* in cages in Lake Kuriftu in Ethiopia. The average weight for the low stocking density at harvest was 360g. The weights obtained in this study confirm the results obtained in experiments conducted at IAAS which showed that intensive culture of Nile tilapia in cage within pond with feeding can efficiently produce large fish (250-300 g) (Shrestha, 2002). In spite of rearing the fish in cages for 180 days, they did not attain an average weight of 500g which was reported by Yi *et al.,* (1996) within a period of 90 days. This could have resulted from poor quality feeds as the diet used in this study had 17% crude protein which was lower than the recommended 28 - 32% CP for Tilapia above 25g (McGinty and Rakocy, 1989; Ofori *et al.,* 2009).

Fish stocked at a high density were less uniform in sizes during harvest despite being stocked at the same size. Among other factors the food accessibility is one of the most difficult parameter to set identical for each fish when density increases (Boujard *et al*., 2002). This could probably be the reason for the varied sizes in fish stocked at a high density of 100 fish m^{-3}.

Specific growth rate of *O. niloticus* in cages under the current study was density dependent with low stocking density performing better than the other two treatments. The trend in this parameter over the

180-day period showed reduction with increase in biomass after the second month. However, despite this reduction, low stocking density maintained the highest SGR throughout the study. The high SGR observed in low stocking density could be attributed to by better accessibility of feeds due to adequate space.

The regression coefficient (r) for length-weight relationship of *O. niloticus* in cages for the three different stocking densities was high (above 80%). This indicates that the weight of fish increases with increase in length. The length-weight relationship within a species differs according to the robustness of individual fish, however, similar findings have been reported in previous studies on different fish species by: Layèyè (2006), Ayoade and Ikulala (2007); Ndimele *et al*., (2010). The condition factor for *O. niloticus* in cages was greater than 1 for all the treatments and this shows that all fish were above average condition. The low stocking density had the highest condition factor as compared to the other two treatments. The observed condition might have been caused by the low density of fish in the cage thus better feeding conditions, good appetite, reduced competition for space and reduced stress. Similar findings were reported by Mokoro, (2008).

In this study, FCR was density dependent and higher stocking density resulted to significantly higher FCR compared to the low stocking density. High FCR is an indicator of low food efficiency and has been attributed to the decreasing efficiency in searching for food, poor water quality (Abou *et al*., 2007) and impaired visual location of food (Silva *et al.,* 2000). This finding confirms observations made by Gibtan *et al*., 2008; Opiyo, 2010. However, some authors (Yi *et al.,* 2005; Osofero *et al.,* 2009) have reported no significant difference on FCR. In this study, fish were fed to satiation since the amount of feed given to the fish was based on the rearing density. Therefore, the higher FCR at 100 fish m^{-3} could be attributed to lower growth rates (Yi *et al.,* 1996), poor feeding and poor appetite. Another probable reason is the fact that overcrowding resulted to stress thus food consumed was used to curb stress instead of being converted to somatic growth. FCR in this study was lower than that reported by Gibtan *et al*., 2008 of up to 7.22 in a study to evaluate the effect of stocking density on the growth performance and yield of Nile tilapia in a cage culture system in Lake Kuriftu, Ethiopia.

Fish Survival

The highest stocking density had the lowest percentage survival indicating that survival rate is density dependant which confirms observations made by Huang and Chiu, (1997). This agrees with findings of other fish as illustrated by Aksungur *et al.,* (2007) who reported that stocking density had a significant effect on survival rates of turbot. However this contradicts findings by other authors (Yi *et al*., 2005; Abou *et al*., 2007; Gibtan *et al.,* 2008; Osofero *et al.,* 2009) who noted that survival of *O. niloticus* was not density dependent. The reduced survival rate at high stocking density might have been caused by the crowding of fish stocked at 100 fish m^{-3} which caused stress and voluntary appetite suppression. This might have had a negative effect on the immune system thus the high mortalities. Another probable explanation for the high mortalities in the highly stocked cages is the intense antagonistic behavioural interaction (Chakraborty *et al.,* 2010) which might have increased stress in the fish.

Mortalities were first experienced on the fifth day which coincided with the introduction of supplemental feeds. Increased metabolic rate due to feeding might have been the cause of the mortalities. Mortalities remained high for the first two weeks. This is because fish were not yet acclimatised to the new environment. Another cause could be handling during stocking. Survival of fish has a significant role to play in increasing the revenue and thus profitability of a culture unit and according to Ofori *et al.,* (2009), extreme care must be taken in transportation, holding and handling of fish to avoid heavy mortalities. Mortalities were also experienced after every sampling occasion. This could have resulted from handling during sampling which increased stress in fish and led to mortalities. Percentage survival in all treatments was above 80% and higher than that reported by Ofori *et al.,* (2009) of 30% but lower than that reported by Osofero *et al.,* (2009) of 98.5 – 99.5%.

Yield

In this study, highest yields were recorded in the high stocking density. This indicates that yield is density dependant. Similar findings were reported by Gibtan *et al.,* (2008). Yield was high in the high stocking density due to the high number of fish in the cage as compared to the other stocking densities.

Additional yield was obtained from the pond which added to the revenue accrued from the cages. Fish stocked in the pond showed differentiation in sizes during harvest. This might have been caused by the fact that some fish are fast growers. Another probable reason could have been recruitment. Fish in the pond showed high recruitment since the fish stocked in the pond were mixed sex. Production of fish from the two systems i.e. pond and the cages, can help the farmers to stay in production throughout the year. This can be achieved by stocking the fast growers from the pond in the cage once those in cages attain market size and since there is recruitment in the pond, continued cycle is guaranteed. From this culture system, farmers can diversify in their final products such that they can sell both table size fish and fingerlings to other farmers at the same time.

Water Quality

Measured water quality parameters i.e. D.O., pH, temperature, total phosphorus, SRP, total nitrogen and NO_2-N were within the optimal limits for the growth of *O. niloticus* as recommended by Popma and Masser, (1999). Therefore, the growth rates recorded were not affected by the water quality.

Economic Benefits

The highest returns were recorded in the low stocking density i.e. 50 fish m^{-3} in spite of the low yield and revenue accrued from this treatment. This might have been as a result of the low amount of feeds and fingerlings used in this stocking density as compared to the other two treatments. Returns decreased with increase in stocking density indicating a negative relationship. Breakeven price and breakeven yield increased with increase in stocking density. This could have resulted from the increased variable costs as the stocking density increased. This clearly shows the efficiency of the low stocking density.

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