Effects of open-pond density and caged biomass of Nile Tilapia (*Oreochromis niloticus* L.) on growth, feed utilization, economic returns and water quality in fertilized ponds

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Abstract

The effects of open-water and caged fish density on growth, feed utilization, water quality and profitability were investigated to assess the feasibility of a small-scale rotational system for production of *Oreochromis niloticus* (L.) in fertilized ponds. Hand-sexed male fingerlings averaging 18.6 and 29.9 g were stocked in open water and cages, respectively in four treatments with open-pond:caged tilapia ratios of 300:0 (control), 150:150 (L), 300:150 (H1) and 300:300 (H2). The ponds in L and H1 contained one cage, two cages in H2, and the control ponds had no cages. Each cage contained 150 fish, which were fed daily at 1.5% body weight for 125 days. All fish in the open water except the control fish were not fed. Growth of open water tilapia was significantly ($P<0.05$) higher in L than in control. Feed utilization, dawn DO and economic returns were significantly better ($P<0.05$) in caged than control ponds. Growth of tilapia in L was significantly lower ($P<0.05$) in cages than in open water. Fingerling production was significantly lower ($P<0.05$) in L than in other treatments. In conclusion, cage-cum-open-pond integrated treatment (L) was optimal for *O. niloticus* production in fertilized ponds. However, the system could not rotate and needed further fine-tuning to rotate.

Keywords: *Oreochromis niloticus*, cage, fertilized ponds, integration, density

Introduction

Nile tilapia (*Oreochromis niloticus* L.) production occurs primarily in semi-intensive ponds where fertilizers are used to increase fish yields at low levels of production (Green, Phelps & Alvarenga 1989; Knud-Hansen, Mcnabb & Batterson 1991). At higher levels, more rigorous management practices are applied to optimize production (Diana, Lin & Schneeberger 1991). One such management practice involves the application of supplemental feeding (Hepher 1988; Diana, Lin & Jaiyen 1994). However, supplemental feeding not only increases the costs of production but also degrades pond water quality (Boyd 1990). Poor water quality, especially low dissolved oxygen (DO), depresses fish growth (Diana *et al*. 1991), while chronic levels of unionized ammonia often lead to reduced fish growth and eventual fish mortalities (Boyd 1990; Hargreaves & Kucuk 2001).

A number of studies have focused on the evaluation of various management strategies for reducing feed and therefore input costs, and also to improve pond water quality in semi-intensive production of *O. niloticus*. Among these studies, Diana *et al*. (1994)

demonstrated that ponds receiving a combination of feed and fertilizer were more cost effective in *O. niloticus* production than those receiving feed alone. With such combination, fish growth, efficiency of feed utilization and pond water quality were significantly improved compared with fish in the fed-only ponds (Diana *et al.* 1994). Diana *et al.* (1994) reported that feeding rate could be reduced by 50% of satiation level without deleterious effects on tilapia growth. They further reported that feed input could be reduced by 42% without adverse effects on fish growth. Another technique that was evaluated for feed input reduction in tilapia production was based on the concept of staged feeding (Diana, Lin & Yi 1996). Feeding was initiated at various tilapia sizes and production was optimized when supplemental feeding was initiated at sizes between 100 and 150 g (Diana *et al.* 1996).

A more recent management strategy for optimization of tilapia production, which is still under development, is based on the concept of cage-pond integration. Part of the fish biomass is fed in cages, while the other part is held in the open water (McGinty 1991; Lin & Diana 1995). Fish in the open water are not fed and derive their nutrition from the cage wastes: either directly as uneaten food or faeces, or indirectly through the autotrophic and heterotrophic food chain (Yi, Lin & Diana 1996). Larger size tilapia in cages have been raised to 500 g within a period of 90 days, which is relatively shorter than in the conventional semi-intensive culture techniques (Yi *et al.* 1996). Previous studies have focused on the effects of both caged and open-pond fish density on growth of tilapia. Yi *et al.* (1996) observed that cage-cum-open pond integration improved growth of tilapia and pond water quality while Lin, Jaiyen and Muthuwan (1989) reported that high open-pond fish density reduced the growth of caged tilapia but improved the growth of open-pond tilapia. Yi *et al.* (1996) also reported a decrease in growth performance of both caged and open water tilapia.

During the studies for optimization of the caged and open-water fish density (Lin *et al.* 1989; Yi *et al.* 1996), only caged fish were fed while fish in the open water were not fed and ponds were not fertilized to stimulate natural food items. Despite the fact that feed and fertilizer combination has successfully been applied to increase tilapia growth and improve pond water quality in conventional culture ponds (Diana *et al.* 1994), the management technique has not yet been tested for pond–cage tilapia integration. This is because it is feared that the extra nutrients from fertilizer may cause accelerated eutrophication of the pond water, and the recipient water bodies (Lin *et al.* 1989). However, the technique may find useful application in small-scale cage-cum-pond integrated rotational systems, where draining of ponds between tilapia harvests is not required. There is, therefore, a need to gather data on the feed-fertilizer combination in the optimization of caged and open water fish density of the rotational system. Also, data on economic feasibility of cage–pond tilapia integration in the East African region are scarce or lacking. The present study was designed to address these gaps.

The objectives of the present study were to evaluate open-water and caged fish density on growth, feed utilization, water quality and profitability, and to assess the feasibility of a small-scale rotational system for production of *O. niloticus* in fertilized ponds.

Material and methods

The study was conducted at the Sagana Fish Farm (0°39′S, 37°12′E and 1230 m above mean sea level). Sixteen 150 m^2 earthen ponds and 16 cages, each with a volume of 2.8 m^3 and consisting of a wooden frame ($2 \times 1.4 \times 1\,m^3$) covered with 1.4cm wire mesh, were used in the study. Hand-sexed male *O. niloticus* fingerlings averaging 29.9 and 18.6 g were stocked in cages and in the open water respectively. The ponds were randomly allocated to four treatments with four replicates per treatment. One treatment represented the normal Nile tilapia culture practice at Sagana; 2 fish m^{-2} in fertilizer-fed ponds and acted as a control. The three other treatments represented cage/pond-integrated systems with either low or high open water fish density. In the low-density treatment, the open water was stocked at 1 fish m^{-2}, while at high-density fish were stocked at 2 fish m^{-2}. All the integrated treatments had one or two cages containing 150 fish each. The low-density treatment (L) had one cage, while other two treatments representing high fish density, H1 and H2, had one cage and two cages respectively. The ratios of open water to caged tilapia in the treatments were 300:0 (control), 150:150 (L), 300:150 (H1) and 300:300 (H2). Fish were fed a diet with the following chemical composition (dry weight): 241 g kg^{-1} crude protein (CP), 75 g kg^{-1} ether extract, 122 g kg^{-1} crude fibre, 483 g kg^{-1} nitrogen free extract and 76 g kg^{-1} ash. The diet was formulated from three ingredients; 12% fresh water shrimp meal (600 g kg^{-1} CP, 60 g kg^{-1} ether extract, 70 g kg^{-1} crude fibre, 40 g kg^{-1} nitrogen free extract and 231 g kg^{-1} ash), 24% cottonseed meal (350 g kg^{-1} CP, 67 g kg^{-1} ether extract, 71 g kg^{-1} crude fibre, 420 g kg^{-1} nitrogen free extract and 58 g kg^{-1} ash) and 64% wheat bran (140 g kg^{-1} CP, 65 g kg^{-1} ether extract, 160 g kg^{-1} crude fibre, 395 g kg^{-1} nitrogen free extract and 40 g kg^{-1} ash). Feed was offered to caged fish only at 1.5% body weight, except for the control, where fish were fed directly in the open ponds. Floating rings of 30 cm diameter, which were made of polyvinyl chloride tubing (15 mm diameter), were placed inside the cages to prevent spillage of feed out of the cages. Also, fine-meshed nylon traps were fitted in the cages 50 cm directly below the floating rings to prevent feed from sinking out of the cages. The study took 125 days. Limestone ($CaCO_3$) was applied at 2500 kg ha^{-1} to all the experimental ponds once at the beginning of the experiment. The ponds were fertilized at 20 kg ha^{-1} week^{-1} N and 8 kg P ha^{-1} week^{-1} using DAP and urea.

Samples for monitoring fish growth and making feeding adjustments were taken bi-weekly. Dip and seine nets were used to sample fish in the cages and open ponds respectively. Daily feed ration was calculated and adjusted after each sampling. On termination of the experiment, mean fish weights were computed for cage, open pond and for both cage/open-pond combined. Extrapolated net fish yields (NFY) were computed for combined pond and cage fish biomass at the end of the culture period.

Samples for pond water quality were taken bi-weekly. Integrated water samples were collected from 06:00 to 07:00 hours in the morning using a 1.12 m-long column sampler developed by Boyd and Tucker (1992). The samples were filtered through Whatman glass filter paper GF/F and analysed for total alkalinity, total hardness, inorganic nutrients (nitrite-nitrogen, total ammonia-nitrogen (TAN)), soluble reactive phosphorus and total phosphorus and chlorophyll *a*. Total ammonia-nitrogen diurnal samples were taken at a 2-hourly interval. Water quality analyses were done according to procedures adopted from the American Public Health Association standard methods (APHA 1995) and also as modified by Boyd and Tucker (1992). Temperature and DO were measured with a YSI model 58 oxygen meter (Yellow Springs Instruments, Yellow Springs, OH, USA). Complete and partial enterprise budgets were used to evaluate the economic performance of the treatments. Diurnal sampling for monitoring TAN was done once at a 6 h interval.

Data were analysed by single classification analysis of variance (ANOVA), using the methods described by Sokal and Rohlf (1981). When significance was demonstrated, Duncan's multiple range test (Duncan 1955) was used to identify which means were different from each other. Significance was declared at $P \leq 0.05$.

Results

Data on growth performance of *O. niloticus* and fingerling production are presented in Table 1. Growth rate for the open water fish and the combined growth rate for cage and open-pond fish were significantly higher ($P<0.05$) in L than the other treatments. The growth rate of the caged fish was not significantly ($P>0.05$) different from that of the control treatment. The individual mean harvest weight followed a similar trend to that of growth rates. At the same stocking rate (i.e. control and L), NFY were significantly higher ($P<0.05$) in the integrated treatments than the con-

Table 1 Data for ponds and cages on fish performance and fingerling production under different treatments (mean ± SE)

Parameter	Treatments: Control	L1	H1	H2
Pond mean weight (g)	65.3 ± 2.3[a]	91.7 ± 2.3[b]	57.0 ± 2.3[a]	58.6 ± 2.3[a]
Cage mean weight (g)	65.3 ± 2.00[a*]	67.8 ± 2.00 [a]	71.5 ± 2.12[a]	72.1 ± 1.51[a]
Combined mean weight (g)	65.3 ± 1.08[a*]	76.9 ± 1.08[b]	64.1 ± 1.08[a]	67.2 ± 1.08[a]
Pond daily growth rate (g day^{-1})	0.34 ± 0.018[a]	0.60 ± 0.018[b]	0.32 ± 0.018[a]	0.33 ± 0.018[a]
Cage daily fish growth rate (g day^{-1})	0.34 ± 0.015[a*]	0.31 ± 0.015[a]	0.34 ± 0.015[a]	0. 33 ± 0.015[a]
Combined daily growth rate (g day^{-1})	0.33 ± 0.01[a*]	0.43 ± 0.01[b]	0.34 ± 0.01[a]	0.34 ± 0.01[a]
Survival (%)	70.2 ± 2.37[a]	71.6 ± 9.29[a]	59.3 ± 10.72[b]	69.8 ± 8.13[a]
Recruitment as % of control	100 ± 5.35[a]	40.1 ± 2.10[b]	106.2 ± 13.72[a]	102.8 ± 6.44[a]
Net field yield (kg ha^{-1} year)$^{-1}$	8,856 ± 622[a]	13,283 ± 622[c]	11,360 ± 622[b]	18,795 ± 622[d]
Food conversion ratio (cage only)	2.9 ± 0.12[b*]	2.8 ± 0.12[b]	2.3 ± 0.12[a]	2.3 ± 0.12[a]
Food conversion ratio (pond and cage)	2.9 ± 0.10[c*]	1.0 ± 0.10[a]	1.1 ± 0.10[a]	1.5 ± 0.10[b]

*No cages included for comparison, values within a row with the same letter are not significantly different.

trol. H1 had significantly ($P<0.05$) the lowest NFY among the integrated treatments. Survival was significantly lower ($P<0.05$) in H1 than the rest of the treatments. All other treatments had similar ($P>0.05$) survival. Although fish were hand-sexed before stocking, there was substantial reproduction in ponds. Treatment L had significantly lower ($P<0.05$) fingerling production than all the other treatments, all of which had similar values ($P>0.05$).

Feed conversion ratio (FCR) for caged fish (Table 1) was similar ($P>0.05$) in L and control but significantly higher ($P<0.05$) than in H1 and H2; however, the latter pair had similar ($P>0.05$) values. The overall FCR for pond and cage fish was significantly higher ($P<0.05$) in H2 than L and H1, but similar ($P>0.05$) in L and H1. Fish in the control treatment had significantly higher ($P<0.05$) FCR than the overall FCR for the integrated treatments. Fingerling production was significantly lower ($P<0.05$) in L than in the other treatments, and constituted 40% of the total number produced in the control treatment. The rest of the treatments, which contained 300 fish in the open pond, had level of fingerling production a similar ($P>0.05$) to the control.

Water quality data are presented in Table 2. With the exception of the dawn DO, other measured water quality parameters were not significantly different ($P>0.05$) among treatments. Dawn DO was significantly higher ($P<0.05$) in L and H1 than in the control and H2. The control and H2 had similar ($P>0.05$) DO levels. Although there were no significant differences in mean TAN among treatments, there was a wide variation among and within experimental ponds. TAN values ranged from 0 to 2.18 mg L^{-1} from the beginning to the end of the experiment respectively. Diurnal trends for TAN in cages and open ponds under different treatments are presented in Fig. 1. Higher ($P<0.05$) concentrations were recorded in the cages than in the open ponds. In all the treatments, levels of TAN were highest in the morning, but progressively declined to values below 0.08 mg L^{-1} between 14:00 and 18:00 hours. The trends for chlorophyll *a* depicted in Fig. 2 demonstrated a steady but gradual increase during the culture period.

Economic data on different treatments are depicted in Table 3. Net revenues over variable costs were lower in the control than in the integrated treatments. However, among the integrated treatments, H1 posted negative net returns over the variable costs. Treatments L1 and H2 generated positive return

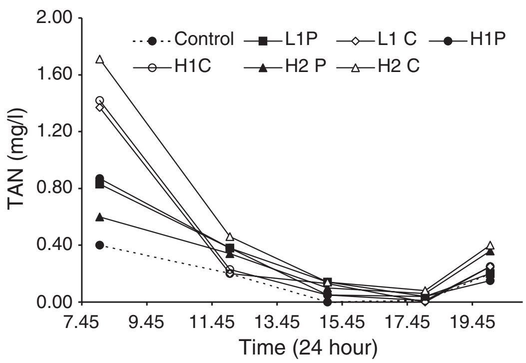

Figure 1 Diurnal variation of total ammonia-nitrogen under different treatments.

Table 2 Data on water quality quality variables and nutrients in ponds and cages for different treatments (mean ± SE)

	Treatments			
Variable	Control	L1	H1	H2
Total hardness (mg L^{-1})	54.9 ± 2.62[a]	47.2 ± 2.17[a]	47.3 ± 2.94[a]	54.3 ± 2.27[a]
Total alkalinity (mg L^{-1})	70.8 ± 3.7[a]	70.0 ± 4.6[a]	65.9 ± 4.1[a]	64.6 ± 4.2[a]
pH	8.6 ± 0.10[a]	8.5 ± 0.10[a]	8.4 ± 0.08[a]	8.3 ± 0.06[a]
Orthophosphate-P (mg L^{-1})	0.09 ± 0.015[a]	0.18 ± 0.03[a]	0.27 ± 0.04[a]	0.16 ± 0.03[a]
Mean pond TAN (mg L^{-1})*	1.46 ± 0.25[a]	1.16 ± 0.12[a]	1.75 ± 0.25[a]	1.06 ± 0.25[a]
Mean cage TAN (mg L^{-1})*	1.37 ± 0.24[a]	1.37 ± 0.24[a]	1.42 ± 0.24[a]	1.71 ± 0.24[a]
TAN (mg L^{-1})	0.7 ± 0.10[a]	0.6 ± 0.12[a]	0.5 ± 0.12[a]	0.4 ± 0.12[a]
NO_2-N (mg L^{-1})	0.06 ± 0.04[a]	0.04 ± 0.004[a]	0.04 ± 0.006[a]	0.03 ± 0.004[a]
Total phosphorus (mg L^{-1})	0.99 ± 0.21[a]	0.81 ± 0.89[a]	1.2 ± 0.24[a]	1.0 ± 0.18[a]
Chlorophyll *a* (mg L^{-1})	193 ± 25[a]	141 ± 25[a]	169 ± 25[a]	181 ± 25[a]
Temperature (°C)	24.0 ± 2.81[a]	23.5 ± 2.5[a]	23.4 ± 2.45[a]	23.6 ± 2.40[a]
Dawn DO (mg L^{-1})	1.9 ± 0.31[a]	2.6 ± 0.31[ab]	3.2 ± 0.31[b]	1.6 ± 0.31[a]
Secchi depth (cm)	16.4 ± 6.19[a]	18.1 ± 7.58[a]	16.8 ± 6.79[a]	15.6 ± 5.43[a]

*Maximum values, TAN, total ammonia nitrogen; DO, dissolved oxygen; SE, standard error of mean.

above variable costs with L1 recording the highest returns.

Discussion

At the same stocking rate, harvest mean weight, daily weight gain and net yields for the combined cage and open-water fish were significantly better in the treatment L than those in control. The better performance of tilapia in treatment L was probably because of utilization of uneaten residues of feed and faeces from the cage waste by fish in the open water and also because of higher levels of DO, which were observed in that treatment. This observation agrees with the findings of Yi and Lin (2001), who reported better growth of *O. niloticus* in integrated than in non-integrated systems.

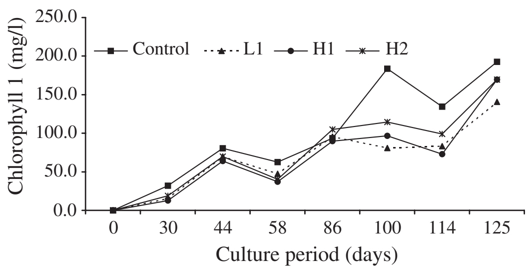

Figure 2 Trends in chlorophyll *a* (mg L^{-1}) during the culture period.

Among the integrated treatments, the harvest mean weight and daily weight gain of the open-pond fish were reduced when the stocking density of fish in the open water was increased from 1 (treatment L) to 2 fish m^{-2} (treatment H1). Similar reductions in growth performance measures also occurred for combined cage and open water fish. Feed input was similar in the two treatments, as each had one cage with 150 fish, but the amount of cage waste per fish in the open water in L was more than that in H1, because the former had fewer fish in the open water than the latter. The growth of open water tilapia in a pond–cage integrated system has been shown to be positively correlated to the amount of feed waste generated from the cages (Yi & Lin 2001); thus, it is possible that the reduced cage waste loading per individual fish in H1 was the cause of the poor fish performance. Similar results were reported by Yi and Lin (1996), where a decline in growth occurred when the open-pond density of tilapia was increased from 1.4 to 2 fish m^{-2}. This observation supports reports from previous studies that high densities in open water reduce the performance of open-pond fish in integrated systems (McGinty 1991; Yi *et al.* 1996).

Further increase in the number of caged fish from 150 (one cage) to 300 fish (two cages) within the high-density treatments (H1 and H2) did not significantly influence the growth of *O. niloticus* in the open ponds. This lack of response occurred despite the fact

Table 3 Data on economic analysis for different treatments

		Treatment			
Item	Unit	Control	L1	H1	H2
Gross receipts					
Total revenue	US$	17.65	21.27	21.53	33.61
Variable costs	US$				
Tilapia fingerling costs	US$	3.85	3.85	5.77	7.69
Sagana pelleted feed	US$	3.58	1.89	1.80	5.80
Urea	US$	1.99	1.99	1.99	1.99
DAP	US$	2.63	2.63	2.63	2.63
Agricultural lime	US$	2.24	2.24	2.24	2.24
Field labour (feeding, etc.)	US$	2.00	2.00	2.00	2.00
Field labour (stocking, harvest, repair)	US$	1.38	1.38	1.38	1.38
Sub-total variable costs	US$	17.67	15.98	17.82	23.74
Interest operating costs	US$	4.24	3.84	4.28	5.70
Total variable cost (TVC)	US$	21.92	19.82	22.10	29.44
Fixed costs					
Amortization	US$	19.23	19.23	19.23	19.23
Interest on fixed costs	US$	4.62	4.62	4.62	4.62
Total fixed costs (TC) (years)	US$	23.85	23.85	23.85	23.85
Net returns above TVC	US$	−4.26	1.45	−0.56	4.17
Breakeven price at TVC	US$	1.52	1.32	1.38	1.28

that the open water fish in H2 received double the amount of cage waste received by the open water fish in H1. The lack of improvement in fish growth was probably because the carrying capacity of the ponds for that management practice might have been exceeded in H2. The significant decline in some water quality parameters like dawn DO in H2 might have also have caused the lack of growth response as the number of cages was increased from one to two. The results of the present study are different from those of Yi and Lin (2001), who observed better growth of open water tilapia in a cage–pond-integrated system when the number of cages was increased from one to two. The differences between the results of the two studies might be explained by the differences in the feeding rate. The feeding rate in the present study was restricted to 1.5% of the body weight while a range of 2–3% was applied in the previous study (Yi & Lin 2001). Thus, at higher feeding rates, more cage waste was available to promote higher fish growth. Survival was significantly lowest in the high-density treatment, H1. This result agrees with that of Yi and Lin (2001), who observed lower survival in treatment with one cage. The reason for this lower survival is not clear.

In the present study, growth performance measures (individual mean weight and daily weight gain) of the caged tilapia was similar or significantly lower than those for fish raised in the open water and in the control ponds. The experimental ponds in the present study were heavily fertilized with urea, while those in similar previous studies were not fertilized (Yi *et al.* 1996). Reports in the literature indicate that urea and the associated ammonia depress fish growth at chronic levels above 0.08 mg L^{-1} unionized ammonia (Meade 1969; Daud, Hasbollah & Law 1988; Abdalla, Mcnabb & Batterson 1996; Hargreaves & Kucuk 2001). In the open water, there are microzones of safe water quality, which are lacking in cages; thus, the growth of caged fish is likely to be limited by unfavourable conditions within the cages. The finding of the present study differs somewhat from that of Yi *et al.* (1996), who reported better growth of caged tilapia in integrated treatments than in the open water. The differences in the results of the two studies may be attributed to differences in the experimental conditions and the nutritional quality of the diets. In the previous study, the ponds were not fertilized with urea and a nutritionally superior diet with 30% CP was used, while in the present study, urea and a diet with lower nutrition, 25% CP and without vitamin or mineral premixes was used.

From the present work, a significant improvement in the overall pond FCR in the integrated ponds over the non-caged ponds was observed. This result suggested that a significant portion of the feed in the control was lost into the sediments. The cage waste consists of solid (uneaten feed, faeces) and dissolved nutrients. Thus, in the integrated system, the open water tilapia were able to consume a large part of the solid matter with increased efficiency in feed utilization, while in the non-caged ponds, the whole solid matter of the cage waste was lost into the sediments. Fish could only recover the sedimented solid feed waste after mineralization and recycling through the autotrophic and heterotrophic pathways. Trophic transformations are usually accompanied by energy losses, which might be recovered through cage-open-pond integration. Although the open water tilapia in H1 received lower cage waste loading than those in the other integrated treatments, FCR was similar to the value recorded in the L treatment. This observation suggested that a significant contribution to the fish growth originated from the natural food. The FCR values observed in the present study (1.0–1.5) are comparable with the range (1.22–1.70) obtained by Yi and Lin (2001), and confirmed the reports that feed utilization is more efficient in caged than in non-caged ponds.

Most of the water quality variables were not significantly different among treatments with the exception of the dawn DO that was lower in control and H2 than in the other treatments. The integrated treatments in the present study received feed based on the biomass of the caged fish. In both control and H2, a higher biomass (300) of fish were fed compared with 150 tilapia in L and H1 treatments. Thus, the lower dawn DO levels in treatments with 300 fed fish were because of higher organic matter loading from the feed. Unionized ammonia fluctuated widely (0–0.9 mg L^{-1}) during the course of the study. The range observed in the present study was more than 10 times (0–0.05 mg L^{-1}) that observed in a previous study by Yi *et al.* (1996). The higher levels of unionized ammonia observed in the present study might have resulted from urea, which decomposes in water to form ammonia (Boyd 1990). The diurnal TAN trends depicted in Fig. 1 demonstrated higher levels in the cages than in the open ponds. Also in the early morning, TAN levels were as high as 1.75 mg L^{-1}, but declined to levels below 0.1 mgL^{-1} in the early afternoon. The higher concentration of TAN in the cages was probably because of ammonia secretion by fish. Fish excrete nitrogenous products mainly in the form of ammonia, and because of the concentration of fish in cages, the level of ammonia would be higher in cages than in the ponds. Moreover, feeding was concentrated in the cages adding to the concentration of ammonia through decomposition of protein. The decline in TAN as the day progressed was probably because of assimilation of the nutrient by algae as photosynthesis increased with light intensity.

The diurnal fluctuations of TAN observed in the present study might have positive implications for tilapia culture in urea-fertilized ponds. The percentage of unionized ammonia, the toxic component is largely depended on pH, and increases with increase in pH (Tomasso, Goudie, Simco & Davis 1980; Erickson 1985). High pH values are prevalent in heavily fertilized ponds as a result of intense photosynthesis in the early afternoon. Therefore, the coincidence of low concentrations of total ammonia with high afternoon pH levels may be beneficial to fish health.

Hand sexing is one of the common methods for producing male tilapia fingerlings to stock production ponds. However, the method is not 100% efficient, and the presence of a few females may lead to substantial fingerling production. Thus, despite stocking hand-sexed males in the present study, substantial fingerling production occurred in the ponds by the conclusion of the experiment. Treatments containing 300 fish in the open water had a similar level of fingerling production to the control. However, when the number of fish in the open ponds was reduced to 150 fish, as was the case in treatment L, fingerling production dropped by more than 50%. An increase in the number of caged fish from 150 (H1) to 300 (H2) did not significantly influence fingerling production. These observations suggested that the open-pond fish mainly produced fingerlings in the experimental ponds and that fish in cages did not contribute significantly to the fingerling production. The low or lack of reproduction within the cages may be attributed to reduced spawning because of a lack of a suitable substrate for nest building, and also because of overcrowding in the cages. One of the major problems in semi-intensive production of *O. niloticus* is the prolific reproduction in culture ponds. Overpopulation of fishponds often leads to a general decline in fish growth as a result of stiff food competition and other density-growth-related factors. The application of the present result is fairly obvious; caging might serve as a complimentary means of reducing the reproduction of the females of *O. niloticus* that might have been confused for males during hand sexing.

Economic analysis indicated that production of *O. niloticus* was more profitable in integrated treatments than in the control. Also, comparison between control and treatment L indicated that the latter was more profitable than the former despite having the same initial biomass of stocked tilapia. The better economic performance in treatment L might be attributed to the 47% reduction in feed input and improvement in feed utilization in the treatment. Feed is a major cost item in fish production and its reduction can significantly improve profitability. Treatment H1 posted negative returns among the integrated systems, possibly because of the low survival and low fish yields. These present results demonstrated that caging is an effective means of maximizing profits in the production of *O. niloticus* in fertilized ponds. Among the issues of concern by farmers is the question of the minimum size of a fishpond, which is just profitable in semi-intensive production of *O. niloticus*. Although the present study was not designed to answer this question, it can be stated that semi-intensive culture of *O. niloticus* in a 150 m^2 pond at a stocking density of 2 fish m^{-2} under the present dietary regiment is not profitable. However, caging half of the fish biomass made the enterprise profitable. The integration system has also an added advantage of providing a constant supply of fish to the market with continuous generation of revenue.

The cage-cum-open-pond integrated system has been developed as a rotational system to produce large tilapia in cages and grow smaller tilapia in the open ponds to restock the cages (Diana *et al.* 1994; Yi *et al.* 1996). However, in the present study, the system could not rotate because the growth of caged tilapia was similar to or lower than that in the open ponds. One strategy to increase the growth of caged tilapia and make the system rotate is to improve the nutrition of the feed used in the present study. This diet was developed for production of *O. niloticus* in semi-intensive ponds. Although the diet performed better in ponds, and did not require any vitamin or mineral supplementation (Liti, Cherop, Munguti & Chhorn 2005), it may not be nutritionally adequate for fish in cages where they are confined and cannot effectively scavenge for different available natural food organisms in the ponds. Also, the system could rotate if the feeding rate is increased from 1.5 to higher levels than in the present study.

In conclusion, the results of the present study demonstrated that *O. niloticus* growth, efficiency of feed utilization, pond water quality and profitability were significantly improved by integration of cages into fertilized fishponds. Production was optimized at an open-pond density of 1 fish m^{-2} and open-pond to cage ratio of 1:1 tilapia in which feed input was reduced by 47% of the control. Cage integration did not significantly improve tilapia growth when the open–pond tilapia density was raised to 2 fish m^{-2}. The present results also indicated that cagepond integration could control the prolific reproduction of tilapia in semi-intensive culture ponds. The growth of the caged fish was not significantly faster than that of the control or the open water fish, thus restricting the rotation of the present integrated system. The integrated system may rotate in fertilized ponds, if the nutrition of the diet and the feeding rate of the caged fish are improved.

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References

Abdalla A.A.F., McNabb C.D. & Batterson T.R. (1996) Ammonia dynamics in fertilized fishponds stocked with Nile tilapia. *Progressive Fish Culturist* **58**, 117–123.

APHA (American Public Health Association) (1995) *Standard Methods for the Examination of Water and Wastewater*, 16th edn. American Water Works Association and Water Quality Control Federation, Washington, DC, USA, p. 1268.

Boyd C.E. (1990) *Water Quality in Ponds for Aquaculture Alabama Agricultural Experiment Station.* Auburn University, AL, Birmingham Publishing, p. 482.

Boyd C.E. & Tucker C.S. (1992) *Water Quality and Pond Soil Analyses for Aquaculture. Alabama Agricultural Experiment Station.* Auburn University, AL, Birmingham Publishing, p. 482.

Daud S.K., Hasbollah D. & Law A.T. (1988) Effects of unionized ammonia on red tilapia, *Oreochromis mossambicus* and *O. niloticus* hybrid fry. In: *The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings*, Vol. 15 (Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Manila, Philippines (ed. by R.S.V. Pullin, T. Bhukaswan, K. Tonguthai & L.Ž. MacLean), pp. 411–413.

Diana J.S., Lin C.K. & Schneeberger P.J. (1991) Relationships among nutrient inputs, water nutrient concentrations, primary production, and yield of *Oreochromis niloticus* in ponds. *Aquaculture* **92**, 323–341.

Diana J.S., Lin C.K. & Jaiyen K. (1994) Supplemental feeding of tilapia in fertilized ponds. *Journal of World Aquaculture Society* **25**, 497–506.

Diana J.S., Lin C.K. & Yi Y. (1996) Timing of supplemental feed for tilapia in production. *Journal of World Aquaculture Society* **27**, 410–419.

Duncan D.B. (1955) Multiple range and multiple F-tests. *Biometrics* **11**, 1–42.

Erickson R.J. (1985) An evaluation of mathematical models for the effects of pH and temperature on ammonia toxicity to aquatic organisms. *Water Resources* **19**, 1047–1058.

Green B.W., Phelps R. & Alvarenga H.R. (1989) The effect of manures and chemical fertilizers on the production of *Oreochromis niloticus* in earthen ponds. *Aquaculture* **76**, 37–42.

Hargreaves J.A. & Kucuk S. (2001) Effects of diel un-ionized ammonia fluctuation on juvenile hybrid striped bass, channel catfish and blue tilapia. *Aquaculture* **195**, 163–181.

Hepher B. (1988) Principles of fish Nutrition. In: *Fish Culture in Warm Water Systems, Problems & Trends* (ed. by M. Shilo & S. Sarig), pp. 121–142. CRC Press, New York, USA.

Knud-Hansen C.F., Mcnabb C.D. & Batterson T.R. (1991) Application of limnology for efficient nutrient utilization in tropical pond aquaculture. *Proceedings of the Iinternational Association of Theoretical and Applied Limnologist* **24**, 2541–2543.

Liti D.M., Cherop L., Munguti J.M. & Chhorn L. (2005) Growth and economic performance of Nile tilapia (*Oreochromis niloticus*) fed on two formulated diets and two locally available feeds in fertilized ponds. *Aquaculture Research* **36**, 746–752.

Lin C.K. & Diana J.S. (1995) Co- culture of catfish (*Clarias macrocephalus* × *Clarias gariepinus*) and tilapia (*Oreochromis niloticus*) in ponds. *Aquatic Living Resources* **8**, 449–454.

Lin C.K., Jaiyen K. & Muthuwan V. (1989) Integration of intensive and semi-intensive aquaculture: concept and example. *Thai Fisheries Gazette* **43**, 425–430.

McGinty A.S. (1991) Tilapia production in cages: effects of cage size and number of non-caged fish. *Progressive Fish Culturist* **53**, 246–249.

Meade J.W. (1969) Allowable ammonia for fish culture. *Progressive Fish Culturist* **47**, 135–145.

Sokal R.R. & Rohlf F.J. (1981) *Biometry. The Principles and Practice of Statistics in Biological Research*. W.H. Freeman and Company, San Francisco, USA, pp. 181–318.

Tomasso J.R., Goudie C.A., Simco B.A. & Davis K.B. (1980) Effects of environmental pH and calcium on ammonia toxicity in channel catfish. *Transactions of the American Fisheries Society* **109**, 229–234.

Yi Y. & Lin C.K. (2001) Effects of biomass of caged Nile tilapia (*Oreochromis niloticus*) and aeration on the growth and yields in an integrated cage cum-pond system. *Aquaculture* **195**, 253–267.

Yi Y., Lin C.K. & Diana J.S. (1996) Effects of stocking densities on growth of caged adult Nile tilapia (*Oreochromis niloticus*) and on yield of small tilapia in open pond water in earthen ponds. *Aquaculture* **146**, 205–215.