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Effect of stocking density on growth, production and economic benefits of mixed sex Nile tilapia (*Oreochromis niloticus*) and African sharptooth catfish (*Clarias gariepinus*) in polyculture and monoculture

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Abstract

On-farm fish production experiments were conducted for 240 days to investigate the effect of stocking density on growth, yield and economic benefits of Nile tilapia (*Oreochromis niloticus*) in monoculture and polyculture with African sharptooth catfish (*Clarias gariepinus*). Low stocking density (LSD), medium stocking density (MSD) and high stocking density (HSD) of 30 000, 60 000 and 90 000 fish ha^{-1} respectively, were tested. *O. niloticus* cultured in polyculture attained significantly higher mean weight gain than those cultured in monoculture. *O. niloticus* and *C. gariepinus* raised together in polyculture attained significantly higher net annual yield than *O. niloticus* cultured alone in monoculture. Profitability analysis using partial enterprise budgets revealed that polyculture is a more profitable system than monoculture. The highest growth, yield and economic benefits were achieved at HSD and MSD than at LSD with no significant difference between HSD and MSD. Results demonstrate that farmers can achieve the highest net yield and economic benefits by culturing *O. niloticus* and *C. gariepinus* in polyculture at HSD and MSD, preferably MSD for economic reasons.

Keywords: polyculture, Nile tilapia, African sharptooth catfish, stocking density, growth, yield

Introduction

Nile tilapia (*Oreochromis niloticus*) is the most important cultured fish species worldwide (Yue & Zhou 2008). Its suitability in aquaculture revolves around its ability to tolerate a wide range of environmental conditions as well as high plasticity in its food habits. The fish also accepts a wide range of foods including those at lowest trophic level and the detrital food chain (Bowen 1982; Maitipe & De Silva 1985; Welcomme, 1996 cited in Offem, Ikpi & Ayotunde 2009) and tolerates stress induced by handling (Yue & Zhou 2008).

Tilapia farming in developing countries is generally practised either at extensive or semi-intensive levels (Liti, Mac'Were & Veverica 2002). While extensive culture is mostly undertaken at small scale by cash-poor farmers, to some extent semi-intensive culture is practised at commercial scale (Liti *et al.* 2002). The semi-intensive culture of tilapias is particularly ideal in developing countries because it provides a wide variety of options in management and capital investments. Semi-intensive production of *O. niloticus* is mostly, practised in monoculture system. In the monoculture of *O. niloticus*, females mature and reproduce early at small size leading to fish production of poor market value (Hepher & Pruginin 1981; Coleman 2001). This has remained a major biological constraint to improving yields and profitability in *O. niloticus* farming (de Graaf, Galemoni & Banzoussi 1996).

For many years monoculture of *O. niloticus* has been the most important culture system in Tanzania (Balarin 1985; Bjoneseth 1992; Shoko, Hoza & Mgaya 2005; Shoko, Matola, Mzighani & Mahika 2011b). However, this type of culture system has always been poorly managed in the country. This has resulted into early reproduction of *O. niloticus* leading to overpopulation in ponds causing 'stunted' growth and consequently low yields (Shoko *et al.* 2005, 2011b). Different attempts have been made to control overpopulation in the culture of *O. niloticus*, and these include culture in cages, intermittent harvesting, hybridization, hormone-induced sex reversal, induction of sterility and production of super male fish (Mair & Little 1991). However, these methods are not within the reach of local fish farmers in Tanzania and therefore increase the production cost, limiting the expansion of aquaculture industry (Carlberg, Olst & Massingi 2000).

The use of proper predatory fish is considered a safe biological method for checking *O. niloticus* overpopulation in ponds without affecting the big size stocked fish (Abdel-Tawwab 2005). *O. niloticus* cultured with predators has been practised worldwide and different predatory fish species have been used with varying degrees of success in combination with different tilapia species depending on their availability (Offem *et al.* 2009). The following are examples of different fish species that have been used in combination with tilapias: Tarpon (*Megalops cyprinoides*), *Micropterus salmoides* (McGinty 1985), Tucunare (*Cichla monoculus*) (Fischer & Grant 1994), *Lates niloticus* (El Gamal 1992), *L. niloticus* and *Clarias gariepinus* (El Gamal, Abdel-Halim, Abdel-Razek & Solomon 1998), Snake head (*Channa striata*) (Yi, Diana, Shrestha & Lin 2004) and European catfish (*Sirulus glanis*) (Wysujack & Mehner 2005).

Clarias gariepinus is used in polyculture technology as a predator to control tilapia prolific breeding and improve growth rate and fish yields (El Gamal *et al.* 1998). The use of polyculture technology maximizes production of fish from different levels of the food chain (Akpaniteaku, Weimin & Xinhua 2005). The technology also enhances nutrient utilization efficiency in the culture unit with consequent maximum fish growth and yields (Lin, Teichert-Coddington, Green & Veverica 1997). Despite the technical viability of *O. niloticus* and *C. gariepinus* polyculture, this production strategy is not commonly practised in Tanzania. This is due to lack of knowledge to the farmers on the benefits associated with this technology (Kaliba, Osewe, Senkondo, Mnembuka & Quagrainie 2006; Wetengere 2009).

Optimum aquaculture production can be achieved if stocking density among other factors is addressed (FAO 1995). Higher growth rate and yield of aquaculture species can be attained when farmers culture fish at an optimum stocking density, which will eventually result into high growth for economic benefits. Although Suresh (2003) indicated that *O. niloticus* is suitable for culturing at high stocking densities (5–10 fish m^{-2}) for achieving high productivity, however, such densities are commonly known from cages and tanks (Liti, Fulanda, Munguti, Straif, Waidbacher & Winkler 2005; Osofero, Otubusin & Daramola 2009). Experimental culture of tilapias in earthen ponds at stocking densities of 5–10 fish m^{-2} has demonstrated that intensive tilapia farming is feasible in earthen ponds (Suresh 2003). Despite the suitability of *O. niloticus* culture at high densities, limited studies have demonstrated stocking densities as high as 9 fish m^{-2} at production level in earthen ponds (Diana, Lin & Yi 1996).

Aquaculture in many African countries is performed for subsistence, with little surplus production marketed (Omondi, Gichuri & Veverica 2001). Economic analysis in fish farming is a relatively recent practice in Africa with only a handful studies reporting economic impacts (Omondi *et al.* 2001; Kaliba *et al.* 2006; Shoko, Getabu, Mwayuli & Mgaya 2011a). Economic benefit analysis in aquaculture is crucial to evaluate the profitability of the culture system, to determine efficiency of resource allocation and management practices. Despite the importance of economic aspects, this area has not been given priority in many aquaculture studies. Particularly in Tanzania, few studies have addressed the economic aspects of aquaculture. Kaliba *et al.* (2006) evaluated economic profitability of small-scale Nile tilapia production in Tanzania using a model, Wetengere (2009) assessed the socio-economic factors critical for adoption of fish farming technology. Moreover, Shoko *et al.* (2011a) determined the growth performance, yields and economic benefits of Nile tilapia *O. niloticus* and Kales *Brassica oleracea* cultured under vegetable-fish culture integration. There are no studies that have evaluated economic benefits of *O. niloticus* in monoculture and polyculture with *C. gariepinus* with stocking densities particularly beyond 3 fish m^{-2} in Tanzania.

The objective of this study was to evaluate the growth rate, yield and economic performance of *O. niloticus* in monoculture and polyculture with *C. gariepinus* under three different stocking densities. The performance at low stocking density (LSD) (30 000 fish ha^{-1}), medium stocking density (MSD) (60 000 fish ha^{-1}) and high stocking density (HSD) (90 000 fish ha^{-1}) was investigated.

To address the above objective, the following hypotheses were tested:

i. *O. niloticus* reared at different stocking densities in monoculture will attain higher growth rate, yield and economic benefits than those reared at the same densities in polyculture with *C. gariepinus*.
ii. *O. niloticus* polycultured with *C. gariepinus* will attain higher growth rate, yield and economic benefits than *O. niloticus* cultured in monoculture.

Materials and methods

Description of the study site

This study was carried out from April to November, 2010 at Kimusi village, Tarime District, Mara Region in the Lake Victoria basin, Tanzania (Fig. 1). Tarime is one of the six districts of Mara Region which lies in the north of Tanzania East of Lake Victoria. It is situated between latitudes 1°10″–1°36″ South of the Equator and longitudes 34°08″–35°01″ East of Greenwich Meridian (URT 1998). The district has bimodal rainfall that starts in September to December (short rainy season) and March to May (long rainy season). It has a total land area of 1936.9 square kilometres and the land surface is divided into two zones (i.e. highland and midland zones). The highland zone has an altitude that ranges from 1500 to 1800 m above sea level (asl). This zone receives an average annual rainfall of 1200–1500 mm and average annual temperature is between 14 and 20°C. The lowland zone lies between 1200 and 1500 m asl and has average annual rainfall and temperature of 900–1200 mm and 20–25°C respectively. Kimusi village is located in the highland zone of Tarime District (URT 1998).

Experimental design

This on-farm study was carried out in ponds owned and managed by a community of 15 different farmers to ensure that the results depict the actual practice of fish farming in Tanzania. Before the start of the experiment, the ponds were rehabilitated to ensure that they had similar dimensions. To ascertain proper feeding regimes and sampling frequencies as per set-up of the experiment, scientists provided close supervision to farmers in a collaborative way. Supervision was important so as to avoid variation caused by daily management regimes in different farmers' ponds. The ponds were randomly assigned to different monoculture and polyculture treatments.

A factorial experimental design was set-up to test the effect of stocking density on weight gain of *O. niloticus* in monoculture and *C. gariepinus* in polyculture systems. A monoculture system was used as a control in which fingerlings of

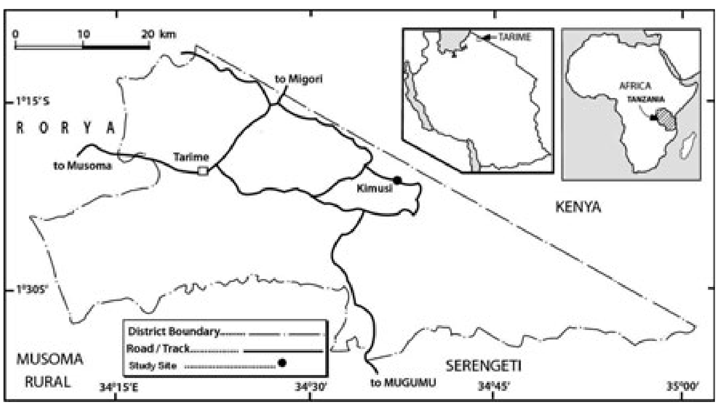

Figure 1 Map of Tarime, Tanzania showing study site (source: University of Dar es Salaam Cartographic Unit).

O. niloticus were stocked. The polyculture system was stocked with *O. niloticus* and *C. gariepinus*. In total, 18 ponds each having an area of 150 m^2 and mean depth of 1.25 m where for each culture system, nine ponds were used. Of the nine ponds for each system, triplicates (three ponds) were stocked at LSD, MSD and HSD. In both culture systems, fingerlings of mean (±SE) initial weight of 5.01 ± 0.01 g were stocked. However, stocking of *C. gariepinus* in the polyculture ponds was intentionally delayed for 30 days to allow *O. niloticus* to grow to a size that *C. gariepinus* would be unable to prey on.

The main source of water to the ponds was a permanent stream originating from Mori River, one of the main rivers that supply water to Lake Victoria. Water levels in each pond were monitored weekly and maintained at the same level to avoid effect of water level fluctuations. Any decrease in water level in the ponds due to evaporation and/or leakage was offset by abstraction of water from Mori River, which flows nearby the site of the ponds. During weekly monitoring, about 30 per cent of water was exchanged to remove organic debris accumulated on the pond bottom to improve water quality parameters. Before stocking, ponds were drained and limed with dolomite at a rate of 0.25 kg m^{-2} (Engle & Neira 2005) to regulate pond water pH and water chemistry in general.

A stocking ratio of 1:3 for *C. gariepinus* to *O. niloticus* in polyculture as recommended by Uddin, Rahman, Azim, Wahab, Verdegem and Verreth (2007) was adopted in this study. The duration of each experiment was 240 days. Fish were fed on a 297.50 g kg^{-1} crude protein diet made using locally available cotton seed cake 683.40 g kg^{-1} and maize bran 316.60 g kg^{-1} of dry feed (Table 1). The ingredients were separately ground using a hammer mill with a screen size of 0.8 mm, weighed and mixed in the required proportions to form a mash. The resulting mash was applied at a daily ration of 5% average body weight of *O. niloticus* or of the combined body weights of *O. niloticus* and *C. gariepinus* in the case of polyculture. The ration was divided into two portions and fed using hands by broadcasting at the periphery of each pond, twice a day in the morning between 09:00 and 10:00 hours and evening between 15:00 and 16:00 hours. Pond fertilization by using cattle manure was done at a rate of 10 kg 100 m^{-2} $week^{-1}$ (Isyagi 2005). The chemical composition of the cattle manure used in the present study is shown in Table 2.

Table 1 Formulation and proximate composition (dry matter basis) of feed used in the study

Ingredients	Composition (g kg^{-1}) dry feed
Cotton seed cake meal	683.40
Maize bran meal	316.60
Total	1000.00
Proximate composition of feed	
Dry matter	924.70
Crude protein	297.50
Crude fibre	136.70
Crude fat	109.60
Ash	68.10
Carbohydrate	388.10

Data collection

During data collection, all measurements were done by scientists in collaboration with the farmers. Before stocking, 30 fish of both species were randomly sampled and their individual total weights (g) and lengths (cm) recorded to the nearest 0.01 g and 0.01 cm by using a sensitive weighing balance (Electronic Precision Balance Model EJB-KD-3000 g, Endel Global Weighing Company) and a ruler respectively. Before weighing, the specimens were blot dried to ensure accuracy (El-Naggar 2008). Thereafter, fish sampling was conducted every 30 days by using a seine net (12.7 mm mesh size) and their weights and lengths measured. However, during the first two sampling months catfish was rarely caught from one of the *O. niloticus* – *C. gariepinus* polyculture pond. Thus, during this period it was necessary to assume that the weight of *C. gariepinus* was equal to the weight of sampled *O. niloticus* (de Graaf *et al.* 1996).

Table 2 Proximate composition (dry matter basis) of cattle manure used in the study

Chemical component	Composition (g kg^{-1}) dry manure
Moisture	755.00
Organic matter	222.00
Total nitrogen (N)	9.20
Total phosphorus (P_2O_5)	4.30
Potassium	4.00
Calcium	5.50

Feeding allowances were calculated on the basis of expected average weight of adult fish on monthly basis. Reproduced fingerlings were ignored during the calculation of feed allowances because the study intended to compare growth, production and economic benefits of adult fish and difficulties in establishing the fingerlings number and size. Revised feeding regimes were re-computed every 30 days. Thus, the total amount of feed provided was according to the total number and weight of the fish in a given pond.

Water quality parameters were monitored to gain an insight into the prevailing environmental conditions in the fish ponds. Temperature, pH and dissolved oxygen (DO) measurements were taken twice daily in the morning (08:30–09:00 hours) and in the afternoon (16:30–17:00 hours) by using a conductivity metre kit (model KTO, HQ, 40D PHC 101-LD 101-01 by Hach Company, Loveland, CO, USA). The percentage of un-ionized ammonia (UIA) was calculated from the following relationship:

$$\text{UIA} = \frac{100}{1 + \text{anti}\log\,(\text{pKa-pH})}$$

where: pH = −log (H+); pKa = −logKa (which is a constant) = 9.25

At the end of the experiment, water was completely drained out of the ponds and all fish including the under-sized from each pond were collected, counted and sorted according to species and size (fingerlings and adults). The fish were then weighed for determination of yield. A random sample of 30 fish of each species was collected from each pond and measured individually to determine the mean weight at the time of harvesting. Mean weight gain was calculated by subtracting the mean initial weight from the mean final weight. Gross Fish Yield (GFY) was determined by weighing the total weights (kg) of all fish harvested from each pond by using a kitchen weighing scale (maximum 15 kg, graduation 50 g, Made in China). Net Fish Yields (NFY), Net Annual Yield (NAY), Specific Growth Rates (SGR), Feed Conversion Ratio (FCR), Percentage Survival (%) and Relative Condition Factor (K) were calculated using the following formulae:

i $$\text{NFY} = \frac{W_h - W_s}{P}$$

where W_h = Total weight of fish harvested (kg); W_s = Total weight of fish stocked (kg); P = Pond area (ha)

ii $$\text{NAY} = \frac{\text{NFY} \times 365}{t}$$

where t = Growth period (days)

iii $$\text{SGR} = \frac{\ln W_f - \ln W_i}{t} \times 100$$

where W_f = Final mean weight (g); Wi = Initial mean weight (g)

iv $$\text{FCR} = \frac{\text{TFC}}{\text{TWG}}$$

where TFC = Total feed consumed (dry) (kg); TWG = Total weight gained by fish (wet) (kg)

v $$\text{Percentage Survival} = \frac{N_h}{N_s} \times 100$$

where N_h = Total number of fish harvested; N_s = Total number of fingerlings stocked

vi $$K = \frac{W}{L^3} \times 100$$

where W and L are final weight (g) and total length (cm) respectively.

Partial enterprise budgets were used to compare the relative profitability of *O. niloticus* and *C. gariepinus* reared at different stocking densities under monoculture and polyculture systems. Costs were defined in terms of inputs categorized into variable costs (expenses that vary with the level of production) and fixed costs (costs that do not vary with the level of production). Variable costs included costs of inputs such as fingerlings, feeds, lime, casual labour, interest on operating costs and transport costs whereas fixed costs included fish pond construction and family labour costs. The actual values of revenues generated by farmers after selling their fish were used in the analysis. All costs and revenues were converted to monetary values, and the net returns on investments were determined. The analysis was based on local market retail prices and expressed in USD (USD 1 = TZS 1572.4). Interest rate of 20% per annum as adopted from the local branch of National

Microfinance Bank where farmers can easily obtain a loan was used in the analysis.

Statistical analysis

Multivariate Analysis of Variance (MANOVA) with fixed effect: stocking density (three levels), culture system (two levels) and sampling time (nine levels) was used to evaluate if there were any significant differences in the final and mean weight gains, SGR, K and FCR of the fish among the treatments. Any significant differences within and among treatments were analysed using a Student–Newman–Keuls test (SNK). The data were tested for homogeneity of variance using Levene's test. Percentage data on survival of *O. niloticus* and *C. gariepinus* were arcsine-transformed prior to statistical analysis (Zar 1999) but per cent values were reported. Data on percentage survival and yields were analysed by using one way analysis of variance (ANOVA). The stocking density and NFYs were correlated by using simple polynomial regression. Statistical analyses were performed using Stat View 5 (SAS Int., Carry, NC, USA).

Comparison of economic profitability between polyculture and monoculture system was done by using Wilcoxon test to remove the effects of density within culture system. Confidence intervals (95% CI) around estimates were used in depicting significance of difference between the stocking densities (Gardner & Altman 1986). Statistical analyses for economic comparisons were performed using SPSS 13 for Windows (Landau & Everit 2004). Significant differences were judged at a probability level of $P < 0.05$ (Zar 1999). Means of all individual values were presented with the standard error of the mean (SE) or 95% confidence intervals (CI) as may be applicable.

Results

Mean weight gains

The results showed significant difference in mean weight gain over time for Nile tilapia (*O. niloticus*) cultured under different stocking densities from both monoculture and polyculture systems (ANOVA, $F = 3141.932$, $P < 0.0001$). Overall results showed that *O. niloticus* reared under MSD attained the highest mean weight gain over time followed by LSD and finally HSD from both monoculture and polyculture systems (ANOVA, $F = 635.043$, $P < 0.0001$). *O. niloticus* cultured under polyculture systems attained significantly higher mean weight gain than those cultured under monoculture systems (ANOVA, $F = 259.701$, $P < 0.0001$; Table 3).

In terms of stocking density, *O. niloticus* cultured in polyculture at LSD attained the highest total mean weight gain (204.69 ± 2.84) followed by HSD (141.57 ± 3.56) and MSD (131.95 ± 2.91). Conversely, *O. niloticus* cultured under monoculture at MSD attained the highest total mean weight gain (191.34 ± 5.00) followed by HSD (118.63 ± 2.58) and LSD (92.79 ± 1.17) (Fig. 2).

Growth variables and percentage survival

O. niloticus polycultured with *C. gariepinus* at LSD attained significantly higher mean SGR (ANOVA, $F = 38.868$, $P < 0.0001$) and mean final weights (ANOVA, $F = 48.561$, $P < 0.0001$) than those cultured at MSD and HSD (Table 4). In monoculture, it attained significantly higher mean SGR and mean final weights at MSD than LSD and HSD. There was no significant difference in FCR among stocking densities in both polyculture and monoculture systems (ANOVA, $F = 2.314$, $P = 0.103$; Table 4). *O. niloticus* cultured at LSD attained significantly lower K than those reared at MSD and HSD (ANOVA, $F = 24.029$, $P < 0.0001$; Table 4). The highest mean final weight for *C. gariepinus* was attained from LSD, followed by MSD and HSD (ANOVA, $F = 34.827$, $P < 0.0001$). Similarly, the highest mean SGR for *C. gariepinus* was attained at LSD followed by MSD and HSD (ANOVA, $F = 92.262$, $P < 0.0001$; Table 4).

Percentage survival of *O. niloticus* and *C. gariepinus* in the different treatments were generally high (with a range from 86.62 ± 3.97% to

Table 3 Overall results of mean weight gain over time during the study

	Mean weight gain ± SE (g)
Stocking density	
LSD	73.286 ± 1.683
MSD	84.052 ± 1.562
HSD	56.286 ± 1.296
Culture system	
Monoculture	66.879 ± 1.202
Polyculture	75.460 ± 1.313

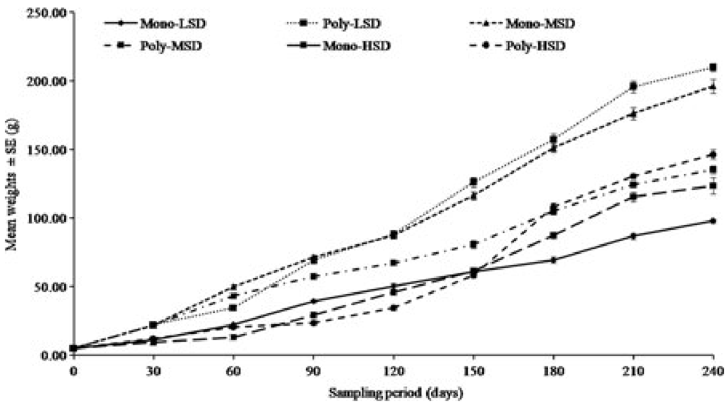

Figure 2 Growth trends showing change in mean weights of Nile tilapia (*Oreochromis niloticus*) cultured at low (LSD) (30 000 fish ha^{-1}), medium (MSD) (60 000 fish ha^{-1}) and high (HSD) (90 000 fish ha^{-1}) stocking densities under polyculture (Poly) and monoculture (Mono) systems (Error bars show ± SE).

Table 4 Growth parameters of Nile tilapia (*Oreochromis niloticus*) and African sharptooth catfish (*Clarias gariepinus*) polyculture and monoculture systems under low (LSD), Medium (MSD) and high (HSD) stocking densities

Culture system	Cultured species	Parameters	LSD	MSD	HSD
Monoculture	Nile tilapia	Initial weight (g)	5.01 ± 0.05^{a}	5.01 ± 0.05^{a}	5.01 ± 0.05^{a}
		Final weight (g)	97.80 ± 1.17^{a}	196.35 ± 4.50^{b}	123.64 ± 2.37^{c}
		Total weight gain (g)	92.79 ± 1.17^{a}	191.34 ± 5.00^{b}	118.63 ± 2.58^{c}
		Survival (%)	97.56 ± 0.26^{a}	92.69 ± 0.44^{b}	92.13 ± 1.70^{b}
		SGR (%)	1.24 ± 0.01^{a}	1.52 ± 0.01^{b}	1.33 ± 0.01^{c}
		K	1.58 ± 0.03^{a}	1.77 ± 0.02^{b}	1.82 ± 0.02^{c}
		FCR	3.55 ± 0.39^{a}	3.33 ± 0.31^{a}	2.83 ± 0.31^{a}
Polyculture	Nile tilapia	Initial weight (g)	5.01 ± 0.05^{a}	5.01 ± 0.05^{a}	5.01 ± 0.05^{a}
		Final weight (g)	209.70 ± 2.84^{a}	136.96 ± 2.91^{b}	146.56 ± 3.56^{c}
		Total weight gain	204.69 ± 2.84^{a}	131.95 ± 2.91^{b}	141.57 ± 3.56^{c}
		Survival (%)	98.08 ± 0.28^{a}	89.26 ± 3.30^{b}	86.62 ± 3.97^{b}
		SGR (%)	1.55 ± 0.01^{a}	1.37 ± 0.01^{b}	1.40 ± 0.01^{c}
		K	1.74 ± 0.03^{a}	2.36 ± 0.10^{b}	1.89 ± 0.02^{c}
		FCR	3.52 ± 0.32^{a}	3.10 ± 0.28^{a}	2.63 ± 0.25^{a}
	African catfish	Initial weight (g)	5.01 ± 0.05^{a}	5.01 ± 0.05^{a}	5.01 ± 0.05^{a}
		Final weight (g)	584.52 ± 40.26^{a}	524.21 ± 15.50^{b}	346.32 ± 8.593^{c}
		Total weight gain	579.51 ± 40.26^{a}	519.19 ± 15.50^{b}	341.31 ± 8.60^{c}
		Survival (%)	97.90 ± 0.21^{a}	96.56 ± 2.21^{b}	89.45 ± 2.77^{b}
		SGR (%)	2.21 ± 0.02^{a}	2.20 ± 0.01^{b}	2.00 ± 0.01^{c}
		K	0.63 ± 0.01^{a}	0.64 ± 0.01^{b}	0.76 ± 0.01^{c}
		FCR	3.52 ± 0.32^{a}	3.10 ± 0.28^{a}	2.63 ± 0.25^{a}

Data are presented as mean ± SE. Different superscripts in each row indicate significant differences among stocking densities (ANOVA) ($P < 0.05$).

98.08 ± 0.28%). In all treatments, percentage survival of the fish decreased with increasing stocking density (Fig. 3). However, there was no significant difference found in percentage survival among stocking densities from both polyculture and monoculture systems (ANOVA, $F = 5.874$, $P > 0.05$).

Fish yield variables

O. niloticus and *C. gariepinus* raised together in polyculture attained higher GFY and NFY than *O. niloticus* cultured in monoculture (Table 5). Similarly, fish raised in polyculture attained significantly higher NAY (18 472.82 ± 1986.65 kg ha^{-1} $year^{-1}$) than

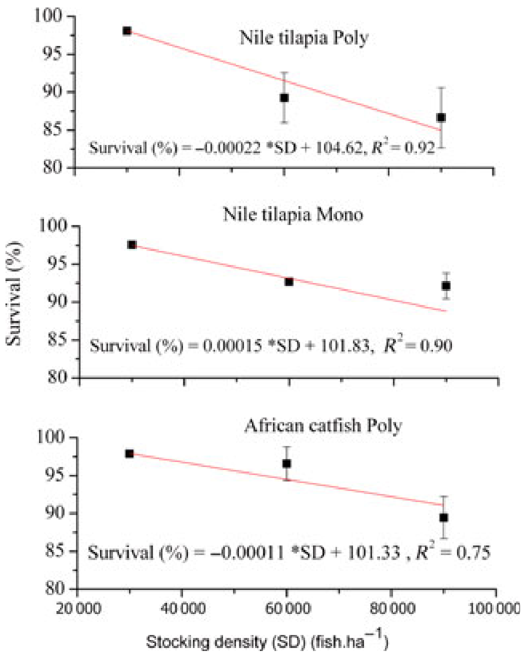

Figure 3 Percentage survival of *Oreochromis niloticus* (Nile tilapia Poly and Mono) and *C. gariepinus* (African catfish Poly) reared under monoculture and polyculture systems under different stocking densities (Vertical bars indicate SE).

those raised in monoculture (13 543.95 ± 2819.33 kg ha^{-1} year^{-1}) (ANOVA, F = 12.391, P = 0.0042; Table 5). Relatively, *O. niloticus* cultured in polyculture system at HSD attained the higher NAY (12 562.41 ± 879.89 kg ha^{-1}year^{-1}) than those cultured at MSD (8117.12 ± 1041.29 kg ha^{-1} year^{-1}) and LSD (2624.42 ± 241.96 kg ha^{-1} year^{-1}). The NAY values for the different stocking densities, irrespective of the culture systems were significantly different (ANOVA, F = 59.281, P < 0.0001; Table 6). SNK *post hoc* test revealed a significant difference in NAY between LSD and the other two stocking densities (MSD and HSD).

Table 5 The combined yield from polyculture [Nile tilapia (*Oreochromis niloticus*)/African sharptooth catfish (*Clarias gariepinus*)] and monoculture [Nile tilapia (*Oreochromis niloticus*)]

Yield parameters	Polyculture	Monoculture
GFY (kg ha^{-1})	12 151.785 ± 1307.028^{a}	9155.088 ± 1819.683^{b}
NFY (kg ha^{-1})	12 059.974 ± 1294.471^{a}	9149.837 ± 1819.067^{b}
NAY (kg ha^{-1} year^{-1})	18 472.824 ± 1986.649^{a}	13 543.949 ± 2819.325^{b}

Data are presented as mean ± SE. Different superscripts in each row indicate significant differences between culture systems (ANOVA) (P < 0.05).

The combined yield of *O. niloticus* and *C. gariepinus* from polyculture treatments and their relative contribution to the NAY (kg ha^{-1} year^{-1}) is shown in Figure 4. In polyculture, NAY estimates were significantly different among stocking densities (ANOVA, F = 44.297, P < 0.0001). As shown under the different stocking densities above, SNK *post hoc* test showed that the combined NAY in HSD and MSD was significantly higher than in LSD.

Economic benefit analysis

Results of partial enterprise budget analysis showed that polyculture of *O. niloticus* and *C. gariepinus* was significantly a more profitable treatment in terms of income above variable cost and net return than monoculture (z = −2.666, P < 0.05). Indeed, the net returns from all stocking densities tested under monoculture system were negative. It was further noted that polyculture treatments had significantly lower break-even price based on variable and total cost than monoculture (z = −2.666, P < 0.05; Table 7).

Economic comparison among different stocking densities of *O. niloticus* and *C. gariepinus* polyculture and *O. niloticus* monoculture are shown in Figure 5 and Table 8. Polyculture had positive net returns from *O. niloticus* and *C. gariepinus* at MSD and HSD, while a negative return was obtained from the same at LSD. The net returns of USD 94.50 (95% CI = 77.8, 111.2) obtained from MSD were not significantly different from a net return of USD 110.70 (95% CI = 92.10, 129.30) obtained from HSD. Income above variable cost obtained in MSD (USD 291.40; 95% CI = 247.70, 308.10) and HSD (USD 307.60; 95% CI = 289.00, 326.20) were both significantly higher than in LSD (USD 120.30; 95% CI = 103.70, 136.90). Income above variable cost of USD 291.40 (95% CI = 247.70, 308.10) obtained in MSD was not significantly different from that of USD 307.60 (95% CI = 289.00, 326.20) obtained in HSD.

Break-even price based on variable cost estimated for HSD (USD 1.50, 95% CI = 14.90, 15.10) and MSD (USD 1.50, 95% CI = 14.90,

Table 6 Yield parameters of Nile tilapia (*Oreochromis niloticus*) and African sharptooth catfish (*Clarias gariepinus*) polyculture and monoculture systems under low (LSD), medium (MSD) and high (HSD) stocking densities

Culture system	Cultured species	Yield parameters	LSD	MSD	HSD
Monoculture	Nile tilapia	GFY (kg ha^{-1})	2624.42 ± 241.96^{a}	14 575.03 ± 1658.28^{b}	10 265.81 ± 544.99^{b}
		NFY (kg ha^{-1})	2622.23 ± 241.95^{a}	14 569.00 ± 1658.28^{b}	10 258.28 ± 544.75^{b}
		NAY (kg ha^{-1} year^{-1})	3987.97 ± 367.97^{a}	22 157.02 ± 252.97^{b}	15 601.14 ± 828.47^{b}
Polyculture	Nile tilapia	GFY (kg ha^{-1})	3907.86 ± 610.54^{a}	5341.80 ± 684.69^{b}	8265.87 ± 578.81^{b}
		NFY (kg ha^{-1})	3906.17 ± 610.55^{a}	5337.28 ± 684.69^{b}	8260.22 ± 578.56^{b}
		NAY (kg ha^{-1} year^{-1})	2624.42 ± 241.96^{a}	8117.12 ± 1041.29^{b}	12 562.41 ± 879.89^{b}
	African catfish	GFY (kg ha^{-1})	3552.29 ± 262.42^{a}	8398.99 ± 707.39^{b}	6988.75 ± 479.58^{b}
		NFY (kg ha^{-1})	3551.74 ± 262.42^{a}	8397.28 ± 707.39^{b}	6986.86 ± 479.47^{b}
		NAY (kg ha^{-1} year^{-1})	5401.59 ± 399.09^{a}	12 770.86 ± 1075.83^{b}	10 625.86 ± 729.20^{b}

Data are presented as mean ± SE. Different superscripts in each row indicate significant differences among stocking density treatments (ANOVA) ($P < 0.05$).

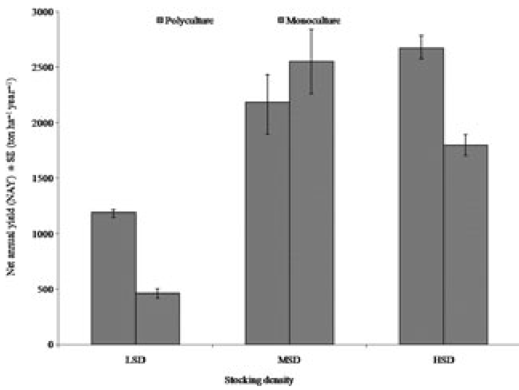

Figure 4 Mean Net Annual Yield (NAY) (tonnes ha^{-1} year^{-1}) at low (LSD), medium (MSD) and high (HSD) stocking densities (SD) (Vertical bars indicate SE).

Table 7 Overall economic comparison between polyculture and monoculture treatments

Item	Unit	Polyculture	Monoculture
Gross revenue	USD	683.92^{a}	501.17^{a}
Total variable cost	USD	444.16^{a}	493.00^{a}
Income above variable cost	USD	239.75^{a}	8.15^{b}
Fixed	USD	196.87^{a}	196.87^{a}
Total cost	USD	641.02^{a}	689.87^{a}
Net return	USD	42.89^{a}	−188.71^{b}
Break-even yield	kg	251.99^{a}	271.19^{a}
Break-even price (variable cost)	USD kg^{-1}	1.68^{a}	3.36^{b}
Break-even price (total cost)	USD kg^{-1}	2.42^{a}	4.93^{b}

1 USD = TZS 1572.40. Different superscripts in each row indicate significant differences between culture system treatments (Wilcoxon) ($P < 0.05$).

15.10) were both significantly lower than for LSD (USD 2.00 (95% CI = 1.90, 2.10). Break-even price above variable cost of USD 1.50 (95% CI = 14.90, 15.10) estimated in MSD was not significantly different from that of USD 1.50 (95% CI = 14.90, 15.10) for HSD. Similarly, break-even price based on total cost estimated for HSD (USD 2.20, 95% CI = 2.10, 2.30) and MSD (USD 2.20, 95% CI = 2.10, 2.30) were both significantly lower than for LSD (USD 2.90, 95% CI = 2.80, 3.00). Break-even price above total cost (USD 2.20, 95% CI = 2.10, 2.30) estimated in MSD was not significantly different from that of USD 2.20 (95% CI = 2.10, 2.30) calculated for HSD. In monoculture system, income above variable cost from MSD (USD 98.30, 95% CI = 55.20, 141.40) and HSD (USD 107.50, 95% CI = 92.00, 123.00) were both significantly higher than that of LSD (USD −222.60, 95% CI = −191.60; −253.60). Income above variable cost of USD 98.30 (95% CI = 55.20, 141.40) estimated from MSD was not significantly different from that of USD 107.50 (95% CI = 92.00, 123.00) obtained in HSD.

Break-even price based on variable cost estimated from HSD (USD 2.10 (95% CI = 2.00, 2.20) and MSD (USD 2.20, 95% CI = 2.10, 2.30) were both significantly lower than from LSD (USD 6.20 (95% CI = 5.60, 6.80). However, break-even price above variable cost of USD 2.20 (95% CI = 2.10, 2.30) obtained from MSD was not significantly different from that of USD 2.10 (95% CI = 2.00, 2.20) in HSD. Likewise, break-even price based on total cost obtained from HSD (USD 2.90 (95% CI = 2.80, 3.00) and MSD (USD 2.90 (95% CI = 2.80, 3.00) were both significantly

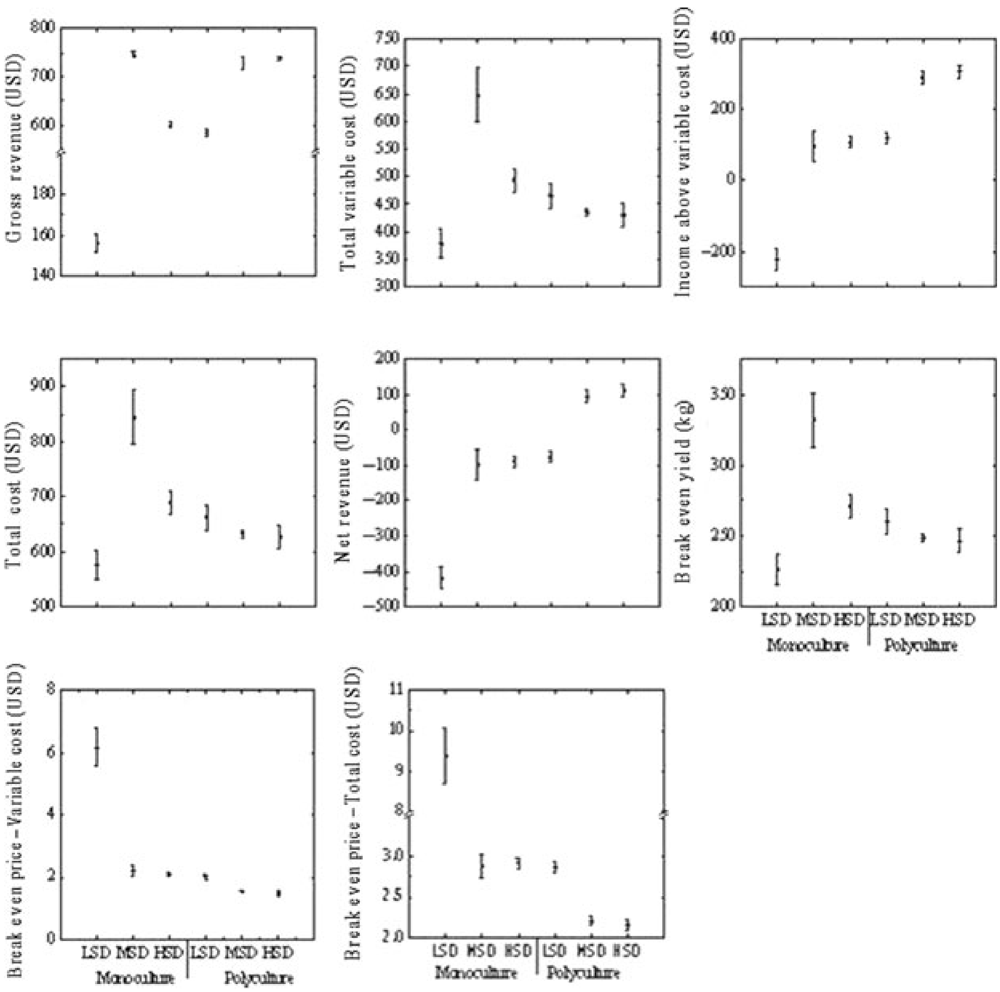

Figure 5 Confidence Intervals (95% CI) depicting statistical significance of difference of economic estimates among the stocking densities.

lower than that of LSD (USD 9.40 (95% C = 8.70, 10.10). Break-even price above total cost of USD 2.90 (95% CI = 2.80, 3.00) obtained from MSD was not significantly different from that of USD 2.90 (95% CI = 2.80, 3.00) from HSD.

Water quality parameters

Results of water quality parameters from both monoculture and polyculture pond systems were within acceptable ranges. The results showed that, DO ranged from 6.20 ± 0.76 to 13.70 ± 0.74 mg L^{-1}, temperature varied from 20.27 ± 0.50 to 25.68 ± 0.28°C whereas pH ranged from 6.49 ± 0.07 to 7.80 ± 0.24 and UIA ranged from 0.21 ± 0.03% to 0.68 ± 0.04%.

Discussion

The present study investigated the growth, yield and economic performance of *O. niloticus* and *C. gariepinus* polyculture and *O. niloticus* monoculture reared at LSD, MSD and HSD. The results partly negate and support the hypotheses set for this study. It was predicted in one of the hypotheses that, low stocking densities in both systems will attain higher growth, yield and economic benefits than medium and high stocking densities as reported elsewhere (Rurangwa 1997; Shoko, Urasa & Ndaro 2003; Uddin *et al.* 2007). However, this turned out not to be the case. Interestingly, the results support the hypothesis that *O. niloticus* cultured in polyculture system with

Table 8 Economic comparison among different stocking densities of *Oreochromis niloticus/Clarias gariepinus* polyculture and *O. niloticus* monoculture

	Item	Unit	LSD	MSD	HSD
Polyculture	Gross revenue	USD	585.90 ± 6.60[a]	727.90 ± 14.50[b]	737.90 ± 4.40[b]
	Total variable cost	USD	465.60 ± 23.30[a]	436.60 ± 6.60[a]	430.30 ± 20.90[a]
	Income above variable cost	USD	120.30 ± 16.60[a]	291.40 ± 16.70[b]	307.60 ± 18.60[b]
	Total cost	USD	662.50 ± 23.30[a]	633.40 ± 6.60[a]	627.10 ± 20.90[a]
	Net return	USD	−76.60 ± 16.60[a]	94.50 ± 16.70[b]	110.70 ± 18.60[b]
	Break-even yields	kg	260.40 ± 9.10[a]	249.00 ± 2.60[a]	246.50 ± 8.20[a]
	Break-even price (variable cost)	USD	2.00 ± 0.10[a]	1.50 ± 0.10[b]	1.50 ± 0.10[b]
	Break-even price (total cost)	USD	2.90 ± 0.10[a]	2.20 ± 0.10[b]	2.20 ± 0.10[b]
Monoculture	Gross revenue	USD	156.30 ± 4.40[a]	745.90 ± 5.80[b]	601.30 ± 6.00[c]
	Total variable cost	USD	378.90 ± 26.60[a]	647.60 ± 48.80[b]	493.70 ± 21.20[c]
	Income above variable cost	USD	−222.60 ± 31.00[a]	98.30 ± 43.10[b]	107.50 ± 15.50[b]
	Total cost	USD	575.80 ± 26.60[a]	844.50 ± 48.80[b]	690.60 ± 21.20[c]
	Net return	USD	−419.40 ± 31.00[a]	−98.60 ± 43.10[b]	−89.30 ± 15.50[b]
	Break-even yields	kg	226.30 ± 10.40[a]	332.00 ± 19.20[b]	271.50 ± 8.30[c]
	Break-even price (variable cost)	USD	6.20 ± 0.60[a]	2.20 ± 0.10[b]	2.10 ± 0.10[b]
	Break-even price (total cost)	USD	9.40 ± 0.70[a]	2.90 ± 0.10[b]	2.90 ± 0.10[b]

USD 1 = TZS 1572.40. Data are presented as mean ± CI. Different superscripts in each row indicate significant differences among stocking density treatments (95% CI).

C. gariepinus will attain higher growth, yield and economic benefits than *O. niloticus* cultured under monoculture system.

The highest mean weight gain, SGR and large mean final weight of *O. niloticus* at harvest were attained from a polyculture of the two species reared at LSD of 30 000 fish ha^{-1}. The present results are corroborated by those from *O. niloticus* reared in polyculture with *C. gariepinus* at a stocking density of 30 000 fish ha^{-1} (Rurangwa 1997; Uddin *et al.* 2007). The results further indicated that *O. niloticus* polycultured with *C. gariepinus* attained highest growth performance than those cultured under monoculture. Comparable results were also reported by other workers (de Graaf *et al.* 1996; Isyagi 2005).

Higher growth of cultured organisms such as fish can be attained at an optimum stocking density. Suresh and Bhujel (2012) suggested that tilapias in polyculture with *C. gariepinus* should be stocked at stocking densities between 5000 and 10 000 fish ha^{-1}. Unfortunately, the suggestion is not tilapia species specific, since different tilapias may behave dissimilarly under varying stocking densities (Fryer & Iles 1972). The results suggest that farmers can achieve larger mean final weight of *O. niloticus* when reared in polyculture with *C. gariepinus* at an optimum stocking density of 30 000 fish ha^{-1}.

Interestingly, the present study reported higher mean weight gain, SGR and larger mean final weight at harvest from *O. niloticus* reared under monoculture system at a stocking density of 60 000 fish ha^{-1}. These findings are contrary to those from polyculture system where higher performance was attained from a stocking density of 30 000 fish ha^{-1}. Tilapias have been reported to perform better when cultured at low stocking densities (30 000–40 000 fish ha^{-1}) in monoculture conditions (Ammar 2009; Suresh & Bhujel 2012). Conversely, the present study reported higher growth performance of *O. niloticus* reared from relatively higher stocking densities (60 000–90 000 fish ha^{-1}) in monoculture conditions.

In a similar study by Diana *et al.* (1996), high growth performance were reported from *O. niloticus* reared at MSD (6 fish m^{-2}) whereas a low performance was shown from the same fish species reared at HSD (9 fish m^{-2}). The reduction in growth performance at HSD was associated with low water quality parameters especially DO (Diana *et al.* 1996). The reported higher growth performance from MSD to HSD in the present study could be explained by the good water quality. For example, DO levels recorded in MSD and HSD were 8.34 ± 0.54 and 6.20 ± 0.76 mg L^{-1} respectively as compared to the levels of 1.31 and 1.08 mg L^{-1} from mid to high density reported by Diana *et al.* (1996). The present results suggest that, under monoculture conditions farmers can achieve large mean final weight of fish through culturing *O. niloticus* at a stocking density of 60 000 fish ha^{-1}.

The results showed higher yield performance from polyculture than monoculture. It is evident from the economic benefit analysis that, polyculture is more profitable than monoculture. Income above variable cost and net returns were significantly higher from polyculture than monoculture system. Although operational cost was not significantly different between the two culture systems, break-even yield and prices were significantly lower in polyculture than in monoculture. These findings suggest that farmers can start making profit at an earlier stage in the production process from polyculture than monoculture system, which is of great advantage. The present findings are in agreement with those reported by Rurangwa (1997) and Isyagi (2005).

Higher yield and economic benefits from polyculture can be attributed to niche partitioning, which allows for coexistence of the two species and hence increase in the pond carrying capacity. In addition, growth of *O. niloticus* is improved because of the predation by catfish on fingerlings of *O. niloticus* that would otherwise compete with their adults for food (de Graaf *et al.* 1996; Isyagi 2005). Tilapia fingerlings consumed by catfish increase the biomass of the latter, which contribute into the combined yield of *O. niloticus* and *C. gariepinus*. It has been suggested that the lost *O. niloticus* fingerling biomass is replaced by more or equal biomass of *C. gariepinus* (de Graaf *et al.* 1996). The fact that polyculture performs better than monoculture is further supported by the negative net return from the latter which explains low fish pond performance of fish farms in Tanzania (Shoko *et al.* 2011b).

The highest NFYs and economic returns were obtained from MSD (60 000 fish ha^{-1}) and HSD (90 000 fish ha^{-1}) in both monoculture and polyculture. Whereas there was no profit made from monoculture, polyculture was more profitable at HSD and MSD than LSD. Unfortunately, most fish farmers in Tanzania practice monoculture and to a lesser extent polyculture at a stocking density of 1–3 fish m^{-2} which is equivalent to 10 000–30 000 fish ha^{-1} (Mwangulumba 1997; Shoko 2002; Shoko *et al.* 2003, 2005, 2011a). Results of this study suggest that, farmers can maximize profit from fish farming operations through practising polyculture at higher (HSD and MSD) than lower stocking densities.

Pond fish yields in Tanzania are low (1800–4700 kg ha^{-1} year^{-1}) (Wetengere, Osewe & Herwaarden 1998; Shoko *et al.* 2005, 2011b; Kaliba *et al.* 2006) which discourage farmers from practising the activity as it is not worth the effort invested. It is worth noting that, fish farmers can achieve fish yields of about 15 600 and 22 200 kg ha^{-1} year^{-1} at stocking densities of 90 000 and 60 000 fish ha^{-1} respectively as reported in the present study for their food and income generation. Based on the present study it is suggested that farmers can attain higher fish yields by culturing fish at a stocking density of as high as 60 000 and 90 000 fish ha^{-1}. Since, there was no significant difference between MSD (60 000 fish ha^{-1}) and HSD (90 000 fish ha^{-1}) in both systems, for economic reasons fish farmers can adopt an optimum stocking density of 60 000 fish ha^{-1} for maximum profit. The differences in yields of *O. niloticus* between LSD and HSD in this study were due to reported higher growth rate at higher stocking densities. To achieve such higher yields, it is imperative that farmers should maintain proper pond management especially water quality as was done in the present study.

O. niloticus reared in MSD in the present study attained the highest mean weight gain over time under both systems. Thus, for farmers to achieve both maximum mean weight gain and yield they should culture their fish at a stocking density of 60 000 fish ha^{-1} (MSD). The highest mean weight gain reported for *O. niloticus* in polyculture system resulted from the predation of *C. gariepinus* on recruits. Under polyculture, large size adult *O. niloticus* are obtained as the growth rate of the stocked adults increases (de Graaf *et al.* 1996). This is because predation reduces competition for food caused by *O. niloticus* fingerlings derived from the initially stocked adults through reproduction.

The availability of food influences sexual maturation in *O. niloticus* because the energy that is normally used in reproduction is shunted into somatic growth (Turner & Robinson 2000; Rad, Bozaoglu, Gozukar, Karahan & Kurt 2006). Normally, increased densities of *O. niloticus* in ponds beyond optimum level due to recruitment result into sacrificing growth to maintain reproductive capacity as food supplies become insufficient (Coward & Bromage 1999).

Water quality within an aquaculture pond can change depending on certain conditions. A pond with good water quality will produce more and healthier fish than a pond with poor water quality. Monitoring of water quality parameters is an important management activity for attaining high fish growth and yields. The present study showed significant differences in DO, temperature and % UIA. However, despite the differences observed all water quality parameters measured from ponds were found to be within the optimal range for growth of *O. niloticus* and *C. gariepinus* (Boyd 1990).

The relatively high DO in the present study was due to the practice of regular exchange of water. However, the decrease in DO with increasing stocking density suggests that farmers should ensure proper fish pond management especially in high stocking densities. Adequate levels of DO are essential for maintaining optimal fish growth. Problems of low DO are particularly prevalent in fish ponds with high stocking densities (Chang & Ouyang 1988). High fish stocking density may also cause deterioration in water quality due to higher feed inputs, leading to stressful condition (Burton & Iwama 1991; Pankhurst & Van der Kraak 1997). Extreme water quality conditions in fish ponds such as low DO may cause death to fish and other benthic organisms (Chang 1986). Poor pond management contributes to low fish pond yield in the Lake Victoria basin, Tanzania (Shoko *et al.* 2011b).

It is a common practice for researchers to study aquaculture in ponds and other systems where ideal management protocols are strictly observed (e.g. on-stations) contrary to what is practised by majority of fish farmers. The present study was carried out in fish farmers' ponds, which were not strictly managed with a view to ensuring that the results depict the actual practice of fish farming in rural areas in Tanzania.

Conclusions

This is one of the few studies that have tested stocking densities higher than 30 000 fish ha^{-1}. Otherwise most studies put emphasis on fish stocking density of 10 000–30 000 fish ha^{-1} as indicated in the discussion of the present study. The present study has demonstrated that polyculture of *O. niloticus* and *C. gariepinus* performs better than monoculture of *O. niloticus*. It is therefore concluded that:

i. Higher growth rate was attained in polyculture of *O. niloticus* and *C. gariepinus* than in monoculture of *O. niloticus*.

ii. The largest mean final weight was attained at a stocking density of 30 000 and 60 000 fish ha^{-1} in polyculture and monoculture systems respectively.

iii. The highest fish yield and economic benefits were obtained from higher stocking densities of 60 000 fish ha^{-1} in both monoculture and polyculture systems.

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