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The role of fish-poultry integration on fish growth performance, yields and economic benefits among smallholder farmers in sub-Saharan Africa, Tanzania

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Aquaculture practices from sub-Saharan Africa are characterised by low production, owing to improper technology. Production can be increased through integrating fish farming with other existing on-farm activities, particularly livestock husbandry. We assessed the role of fish-poultry integration on all male Nile tilapia, *Oreochromis niloticus* growth performance, yields and economic benefits among smallholder farmers in sub-Saharan Africa, Tanzania. The study also compared phytoplankton species composition, abundance and biomass between the fish-poultry integration and non-integrated system. After 180 days of the experiment, all male *O. niloticus* cultured under fish-poultry integration exhibited significantly higher growth rates than those in the non-integrated system ($p < 0.05$). Gross fish yield (GFY), net fish yield (NFY) and net annual yields (NAY) obtained from fish-poultry integration were significantly higher than those from non-integrated system ($p < 0.05$). Partial enterprise budget analysis revealed that fish-poultry integration was more profitable than the non-integrated system. Moreover, fish-poultry integrated system produced significantly higher phytoplankton abundance and biomass than those from the non-integrated system. Results demonstrate that rural smallholder farmers can achieve higher growth rate, farm net yields and income by integrating all male *O. niloticus* with other on-farm activities than practising a stand-alone fish culture system.

Keywords: aquaculture, income, integrated farming, Nile tilapia, yields

Introduction

The majority of smallholder farmers in sub-Saharan Africa depend on seasonal rain-fed cereal crops, such as maize, millet and sorghum for their livelihoods (Tittonell and Giller 2013; Shiferaw et al. 2014). Farmers use limited resources to manage multiple activities separately in crop and animal production to spread risk and sustain their households (Miller 2009). This type of farming is not sustainable, owing to unpredictable climate conditions. Some farmers from several sub-Saharan African countries also practise aquaculture, mainly for consumption and to a lesser extent income generation (Gordon et al. 2013). Sub-Saharan African countries contribute less than 20% of Africa's tilapia production, which is less than four percent of World production (FAO 2017). It is interesting to note that there are promising aquaculture development initiatives in Egypt, Ghana, Uganda, Nigeria and Kenya, which in total account for about 95% of aquaculture production in Africa (FAO 2017). Diverse aquaculture systems, such as cage culture in Ghana (Coulibaly et al. 2007; Ofori et al. 2010; Frimpong and Anane-Taabeah 2017), Côte d'Ivoire, Malawi, Uganda and Zimbabwe (Ofori et al. 2009), concrete tanks in Nigeria (Miller and Atanda 2011; Satia 2012) and recirculating aquaculture systems in South Africa (Gutierrez-Wing and Malone 2006) are used in raising fish. Earthen pond is the most commonly used aquaculture practice in many parts of sub-Saharan Africa.

However, the majority of fish farmers in most African areas particularly in Tanzania still culture fish exclusively in ponds as a stand-alone enterprise despite benefits of integrated systems using vegetables that have been reported in the country (Shoko et al. 2011; Limbu et al. 2016a). This makes fish farming a part-time undertaking, whereas more time is devoted to other crop farming activities, rendering less time for attending fish. Stand-alone fish farms can be financially risky undertakings, particularly in rural smallholder farmers where resources are limited (Shoko et al. 2011). Moreover, stand-alone ventures have made significant environmental problems because of pollution and economic disasters due to price volatility in other parts of the World, such as Asia (Brummett 2002), which further render them unsustainable means of production.

The culture of Nile tilapia, *Oreochromis niloticus* from sub-Saharan African countries, particularly Tanzania, has resulted into low production values (Shoko et al. 2011). The yields of *O. niloticus* have usually been poor, because most fish ponds are nutrient starved, leading to thousands

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of ponds being abandoned (Roger and Mark 1995; Wetengere 2010a, 2010b). The *O. niloticus* pond production in sub-Saharan Africa can be increased through integrated farming systems where fish are incorporated with other existing on-farm activities, particularly livestock husbandry (Brummett and Jamu 2011; Alfaro and Miller 2014). Integrated farming involves the concurrent or sequential linkage between two or more activities, of which at least one is aquaculture (Edwards 1997; Ahmed et al. 2014). Such activities might take place directly on site or indirectly through off-site requirements and opportunities, or both (Edwards 1997; Edwards 1998; Ahmed et al. 2014). These systems are less risky, because when managed efficiently, they benefit from synergies among enterprises, diversify produce and are environmentally friendly (Brummett 2002; Ahmed et al. 2014). In an integrated aquaculture-agriculture (IAA) system, production from agriculture can also be enhanced through increased water availability throughout the year (Ahmed et al. 2014).

Most IAA systems rely largely on on-farm residues as pond inputs, especially feeds and/or fertilisers, to increase fish production (Brummett and Jamu 2011; Ahmed et al. 2014). In such systems, a fish pond can have a pivotal role in supporting other activities. For example, nutrient-rich pond waters can be used for irrigating vegetables during the dry season, whereas pond mud can be used to fertilise nutrient-depleted fields, hence increasing production of existing crops (Ahmed et al. 2014; Limbu et al. 2017). In *O. niloticus*-livestock integration, such as *O. niloticus* poultry farming, chicken droppings rich in nitrogen, phosphorus and potassium function as fertilisers to stimulate production of natural fish food organisms (Little and Edwards 2003a). The natural food organisms for fish include phytoplankton, zooplankton and bacteria; but, in fish-livestock integration, *O. niloticus* might feed directly on chicken droppings. In this type of *O. niloticus* farming, no supplementary feeding is required (Mridha et al. 2017). The farming relies on synergistic effects whereby the output of one (sometimes byproducts or wastes) becomes an input to the other (Brummett and Jamu 2011). Such an integrated farming system results in higher growth of *O. niloticus*, which leads to increased production and income (Limbu et al., 2017). Furthermore, it provides employment from a wide range of products as a result of its interaction and/or synergy. Integrated farming also enhances ecological sustainability, because wastes are recycled, consequently, reducing their possibility of causing detrimental impacts on the environment, such as pollution (Jayanthi et al. 2003; Ahmed et al. 2014).

There have been several successful reports of integrated fish farming from other parts of the world (Brummett and Jamu 2011; Ahmed et al. 2014). For example, most of the freshwater fish produced in China that come from semi-intensive farming systems depend on organic fertilisation provided by farm animals, including poultry (Little and Edwards 2003a). In a similar way, IAA contributes to the economic growth of Bangladesh through high economic returns obtained through exports of prawns from rice fields (Ahmed et al. 2007; Ahmed et al. 2010; Ahmed and Flaherty 2013). However, the concept of integrated fish farming in Africa is relatively new, with limited knowledge on the technical aspects and associated benefits of the practice (Brummett and Jamu 2011). Reports of successful integrated fish farming in Africa include Malawi (Dey et al. 2006; Dey et al. 2010; Brummett and Jamu 2011), Ghana, Cameroon, Mozambique and Zambia (Brummett and Jamu 2011), Nigeria (Ugwumba et al. 2010), Burkina Faso, Madagascar and Mali (Satia 2012), Kenya (Wood et al. 2001, Brummett and Jamu 2011) and Tanzania (Shoko et al. 2011; Limbu et al. 2017). However, the proposed technological packages do not consider farmers' perspectives and their access to resources, which has led to the failure of IAA in sub-Saharan Africa (Wetengere 2010a, 2010b; Brummett and Jamu 2011; Slater et al. 2013).

The current study was designed to gain an insight into the role of fish-poultry integrated and non-integrated fish farming systems on growth performance, yields and economic benefits of all male *O. niloticus* among rural smallholder farmers in sub-Saharan Africa, Tanzania. The study also compared phytoplankton species composition, abundance and biomass in the two culture systems. It was hypothesised that, growth performance, yields, and economic benefits, as well as phytoplankton species composition, abundance and biomass, will be significantly higher in fish-poultry integration system than in non-integrated system.

Materials and Methods

Study site

The study was conducted at Lufulu village, in Kilombero District approximately 110 km from Ifakara town located at 8°31′0″ S, 35°56′0″ E in the Morogoro region, Tanzania (Figure 1). The site is characterised by a rainy season starting in November to May and a dry season from June to October (Balama et al. 2013). The site receives annual rainfall of between 1200 and 1800 mm and the temperature ranges from 25 °C to 32 °C (Sumaye et al. 2013). The main economic activities at the site include agriculture, capture fisheries, fish farming, forestry and livestock keeping.

Experimental design

A participatory on-farm study was conducted in six static earthen ponds belonging to three independent farmers at Lufulu village in Kilombero district of Morogoro region, Tanzania. Each farmer owned two fish ponds measuring 200 m^2 with a mean depth of 1.25 m each. Before the start of the trial, the ponds were modified to ensure similar dimensions. The site has a reliable source of water mainly from streams originating from the Udzungwa Mountains. Prior to the start of the study, fish farmers were trained in the basic principles of an IAA, with emphasis on fish-poultry integrated farming system. Before stocking, the ponds were limed at a rate of 0.25 kg m^{-2} in order to regulate pond water pH and water chemistry in general (Engle and Neira 2005). Fish ponds were stocked with all male *O. niloticus* at a stocking density of four fish per square metre with an initial mean weight (± standard error, SE) of 4.21 ± 0.20 g and 4.32 ± 0.16 g for integrated and non-integrated system, respectively.

Chicken huts (each measuring 3 m × 2 m × 1 m) were constructed directly on top of each of the three farmers' fish ponds at the periphery, hereinafter referred to as



Figure 1: Map of Kilombero district, Morogoro region, Tanzania showing the study site. *Source: University of Dar es Salaam Cartographic Unit*.

fish-poultry integrated system. The other three ponds, one from each farmer had no chicken huts hereinafter referred to as non-integrated system. Each farmer had two ponds, one of which was used as a control and the other for the trial. Feeding and fertilization was not given to fish in the non-integrated system to imitate the normal practice of fish farmers in the study area. The floor of each chicken house had wire mesh of 1.5 mm to allow chicken droppings to fall directly into the fish pond water to provide nutrients. Four-week-old indigenous chicken were purchased from nearby farmers and stocked in each hut at a stocking density of two chickens per square metre, making a total of 12 chickens per hut. Fish and chicken were randomly assigned to the ponds and huts, respectively. Each treatment was repeated in three replicates. Chickens were introduced to the huts about one month prior to stocking of fish to allow the pond water to have enough natural food organisms for the fish. The chickens were vaccinated by using the Lasota strain vaccine against Newcastle disease and left for two weeks before being introduced to the chicken huts to avoid contaminating the pond water.

The 1 000-dose vaccine was dissolved in 10 l of clean water and administered by drinking. Chicken diet was purchased from an animal feed store at Ifakara town in the Kilombero district, Tanzania. The ingredients of the chicken diet included maize bran, fishmeal, sunflower seed cake, lime, bone meal, salt and vitamins. The percentage composition of the ingredients was not disclosed by the dealer. The proximate analysis of the diet used for feeding the chickens is given in Table 1. The chickens were fed on one ration throughout the trial at a rate of 980 g chicken^{-1}. The feeding regime was two times per day at 08:00, and 16:00. Supplementary feed was not given to the fish, in order to avoid masking the effect of the chicken excreta, as

Table 1: Proximate composition analysis of the chicken diet

Parameter	Composition (g kg^{-1}) dry feed
Moisture	60.50
Crude protein	170.30
Crude fibre	50.00
Ash	161.60
Crude lipid	57.60
Carbohydrate	500.00

adopted by Njoku and Ejiogu (1999). The experiment lasted for 180 days.

Data collection

Data collection of all measured parameters was done by scientists in collaboration with the farmers. Before stocking the pond, 30 individuals of all male *O. niloticus* were sampled randomly and weighed for their individual initial weights (g) and total lengths (cm) recorded to the nearest 0.01 g and 0.1 cm using a sensitive weighing balance (Boeco BBL, model 43, Hamburg, Germany) and a ruler, respectively, as we reported earlier (Shoko et al. 2016a). After weighing, the all male *O. niloticus* were immediately returned to the water of the same pond. Thereafter, subsequent sampling of 30 individuals of all male *O. niloticus* was conducted every 30 days by using a seine net (12.7 mm mesh size) and their weights and total lengths determined as described above.

After 180 days of culture, ponds were drained and all fish were harvested, counted for percentage survival determination and batch weighed for determination of gross yield (GFY, kg ha^{-1}) by using a spring scale (maximum 15 kg, graduation 50 g). Finally, a sample of 30 individuals of all male *O. niloticus* was drawn randomly from each pond, weighed individually to determine final mean body weight (FMW). The data obtained were used to calculate growth parameters (mean weight gain (g), daily weight gain (g day^{-1}), specific growth rate (% day^{-1}), condition factor (K) and percentage survival) and yield indices (net fish yield (kg ha^{-1}), gross annual yield and net annualised yield (kg ha^{-1} y^{-1}) using the formulae adopted from Limbu et al. (2015) and Shoko et al. (2016b):

$$\text{Mean weight gain (MWG, g)} = Wf - Wi \quad (1)$$

where, Wf and Wi are previous sampling mean weight and the current measured mean weight, respectively.

$$\text{Daily weight gain } (\text{DWG, g day}^{-1}) = \left(\frac{Wf - Wi}{\text{Time (days)}}\right) \quad (2)$$

$$\text{Specific growth rate } (\text{SGR, \% day}^{-1}) = \left(\frac{\ell nWf - \ell nWi}{\text{Time (days)}}\right) \times 100 \quad (3)$$

$$\text{The condition factor (K)} = \left(\frac{W}{L^3}\right) \times 100 \quad (4)$$

where, W and L are individual weight (g) and length (cm) of all male *O. niloticus,* respectively.

$$\text{Percentage survival } (\text{SR, \%}) = \left(\frac{Fh}{Fi}\right) \times 100 \quad (5)$$

where, Fh and Fi refer to final fish harvested and initial

stocked number of all male *O. niloticus,* respectively.

$$\text{Net fish yield } (\text{NFY, kg ha}^{-1}) = \frac{W_h - W_s}{A} \quad (6)$$

where, W_h = total weight of fish harvested (kg), W_s = total weight of fish stocked (kg), A = pond area (ha).

$$\text{Gross fish yield } (\text{GFY, kg ha}^{-1}) = \frac{Wh \times Ws}{A} \quad (7)$$

$$\text{Gross annual yield } (\text{GAY, kg ha}^{-1}\text{year}^{-1}) = \frac{\text{GFY} \times 365}{\text{Time (days)}} \quad (8)$$

$$\text{Net annual yield } (\text{NAY, kg ha}^{-1}\text{year}^{-1}) = \frac{\text{NFY} \times 365}{\text{Time (days)}} \quad (9)$$

Chickens and eggs were sold per piece and individual weights were recorded for economic analysis by using a spring balance. A sample of four chickens was randomly collected from each hut and weighed individually by suspending on a spring weighing balance by using an enclosure made of fishing net. The mean weight of the four chickens from each hut was used as the weight of chickens from the respective house and treatment. The mean weight of chickens was used to determine the total weight and income generated from each hut as follows:

$$\text{Income (Tshs)} = \text{Average weight (kg)} \times \text{total number of chickens x price per chicken (Tshs)} \quad (10)$$

Chicken eggs were collected on a daily basis and their number recorded. The weight (g) of eggs was determined by using a spring balance. Several eggs were weighed to determine the number of eggs that make one kg. Thereafter, the total number of eggs making one kg was multiplied by the price of each egg to get the price of eggs per kg. The total number of eggs collected in each system was used to determine the amount of income generated from eggs per kg. The price of chickens and eggs recorded was used in the economic analysis for determination of total income generated.

Partial enterprise budget analysis was used to compare the relative profitability of the fish-poultry integrated and non-integrated system. Costs were defined in terms of inputs categorised 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, chicks, chicken feed, lime, casual labour, interest on operating costs and transport costs whereas fixed costs included fish pond and chicken huts construction, and family labour costs. Fish were sold at a local market price of US$ 2.73 kg^{-1}, whereas chicken and chicken eggs were sold at US$ 5.0 kg^{-1} and US$ 2.4 kg^{-1}, respectively. The actual values of revenue generated by farmers after selling their fish, chickens and eggs were used in the enterprise budget 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 converted to US$ (US$ 1 = TZS 2000 during the study period). An interest rate of 20% per annum was adopted from the local branch of National Microfinance Bank (NMB) for the economic analysis. Benefit-cost ratio (BCR) was calculated for each fish farming system to determine the most worth investment based on the formula given by Ndanga et al. (2013) as follows:

$$\text{BCR} = \frac{\text{Total income obtained}}{\text{Total cost incurred}} \quad (11)$$

Phytoplankton species composition, numerical abundance and biomass

Sampling for phytoplankton species composition, numerical abundance and biomass was conducted every month for five months. In each pond, 2 L of water samples were taken at a depth of 30 to 100 cm, using a van Dorn sampler and filtered through a phytoplankton net (30 µm mesh size) for qualitative analyses of phytoplankton. For quantitative analysis of phytoplankton, 20 ml aliquots were collected separately in glass bottles and fixed with Lugol's solution and 2.5% formaldehyde prior to laboratory analysis (Wetzel and Likens 2000). The samples were then transported in a cool box to the laboratory for analysis.

In the laboratory, phytoplankton species identification was done by using an inverted microscope (Leitz-Labovert FS, type 090-127-017, Germany) at 400 × magnification using available freshwater phytoplankton keys (Utermohl 1958; John et al. 2002). All specimens were distributed over at least two transects from the sedimentation chamber and counted. Different phytoplankton groups were counted as numbers of filaments (e.g. *Planktolyngbya* sp.), colonies (e.g. *Aphanocapsa* sp.) and single cells (e.g. *Scenedesmus* sp., *Nitzschia* sp.) depending on the nature of the group. In general, different species were combined to meaningful subgroups, e.g. *Planktolyngbya* sp. were combined and not distinguished further. Phytoplankton species identified in a given sample was used to estimate its composition. The phytoplankton numerical abundance was calculated according to Greenberg et al. (1992) using the formula:

$$\text{Abundance} = \frac{C \times At \times v}{Af \times F \times V \times Vi} \quad (12)$$

where, C = number of organisms counted, At = the total bottom area of the settling chamber (mm^2), Af = area of field (mm^2), F = number of fields counted, Vi = volume of the sedimented sample, V = volume of the sample observed (2 ml), v = volume of concentrated sample (20 ml).

Phytoplankton biomass was estimated indirectly using a chlorophyll *a* analysis (Vörös and Padisák 1991). Water samples were filtered through a 0.45 µm Millipore membrane filters and extracted in 90 % acetone overnight at 4 °C. The chlorophyll *a* concentration was measured using a Shimadzu 1201 Spectrophotometer according to Parsons et al. (1984).

Water quality

Water quality parameters were monitored to gain an insight into the prevailing environmental conditions in the fish ponds. During the experimental period, water temperature, pH and dissolved oxygen (DO; mg l^{-1}) were taken on daily basis in the morning (08:30 to 09:00) by using a multiprobe kit (model KTO, HQ, 40D PHC 101-LD 101-01 by Hach Company Ltd, USA). Water transparency was measured by using a 20 cm diameter Secchi disc.

Statistical analyses

Results are presented as mean ± standard error (SE). All measured parameters were analysed by using an independent *t*-test. The Pearson correlation (*r*) was used to determine the relationship between measured variables. All statistical analyses were performed using SPSS Statistics version 20 for windows (IBM SPSS, Inc, Armonk, NY: IBM Corp., USA). Results with $p \leq 0.05$ were considered statistically significant for all statistical tests.

Results

Growth performance, condition factor and percentage survival

The growth increments of all male *O. niloticus* raised under fish-poultry integration and non-integrated systems during the study are shown in Figure 2. Results showed that all male *O. niloticus* cultured under the integrated system exhibited much higher growth rates than those in non-integrated system. Clear separation of growth between integrated and non-integrated systems became apparent during the first month of culture (Figure 2).

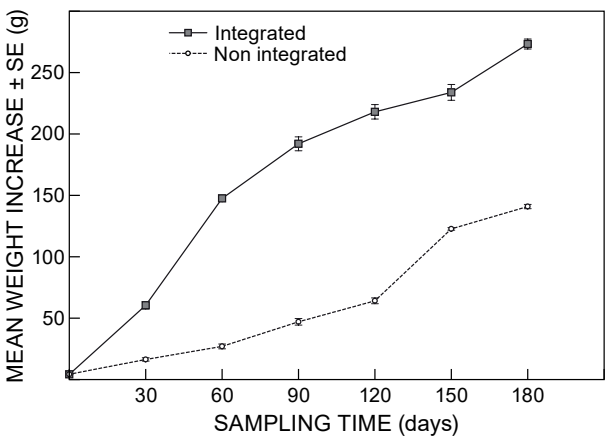


Figure 2: Mean weight increments (g ± s.e) of Nile tilapia *O. niloticus* reared under integrated and non-integrated systems.

After 180 days of the experiment, the final mean weight was significantly higher for all male *O. niloticus* reared under integrated than those reared in non-integrated systems ($t = 7.354$, df = 4, $p = 0.002$, Table 2). Fish reared under fish-poultry integrated system attained significantly higher mean weight gain ($t = 6.833$, df = 4, $p = 0.002$), mean daily weight gain ($t = 7.410$, df = 4, $p = 0.002$), mean specific growth rates ($t = 4.045$, df = 4, $p = 0.016$) and mean total weight gain ($t = 7.34$, df = 4, $p = 0.002$) than those reared in non-integrated system (Table 2). Likewise, fish reared under the fish-poultry integration had better condition factor (K) than those reared under the non-integrated system ($t = 7.060$, df = 4, $p = 0.002$, Table 2).

The percentage survival was statistically comparable between all male *O. niloticus* reared under the two culture systems ($t = 1.76$, df = 4, $p = 0.154$; Table 2). Pearson correlations (*r*) showed a significant positive relationship between specific growth rate and percentage survival ($r = 0.693$, df = 4, $p = 0.05$).

Yields of O. niloticus

The yield results showed significantly higher gross fish yield (GFY, $t = 7.307$, df = 4, $p = 0.002$) and net fish yield (NFY, $t = 7.307$, df = 4, $p = 0.018$) of all male *O. niloticus* from a fish-poultry integration system than those from a non-integrated system (Table 2). Similarly, fish reared in integrated system attained twice as higher NAY and GAY than those raised in non-integrated system ($t = 7.31$, df = 4, $p = 0.002$; Table 2). Specific growth rate correlated positively and significantly with all yield parameters ($r = 0.986$, df = 4, $p = 0.001$).

Economic benefit analysis

Results of partial enterprise budget analysis showed that fish-poultry integration is a more profitable system in terms of income above variable cost and net returns than non-integrated system (Figure 3; Table 3). Income above variable cost obtained from the fish-poultry integrated system was significantly higher than those from the non-integrated system ($t = 10.858$, df = 4, $p = 0.001$; Table 3). Similarly, the net return from the fish-poultry integrated

Table 2: Mean growth performance and yield parameters of Nile tilapia *Oreochromis niloticus* reared under integrated and non-integrated systems during the study

Growth parameters	Integrated	Non-integrated
Initial weight (g)	4.21 ± 0.20[a]	4.32 ± 0.16[a]
Final weight (g)	273.28 ± 17.99[a]	140.92 ± 0.61[b]
Daily weight gain (g)	1.49 ± 0.10[a]	0.75 ± 0.01[b]
Total weight gain (g)	269.06 ± 17.94[a]	136.60 ± 0.69[b]
Percentage survival	97.58 ± 0.70[a]	95.58 ± 0.91[a]
Weight gain (g)	44.94 ± 2.94[a]	22.64 ± 2.48[b]
Specific growth rate (% day^{-1})	2.36 ± 0.75[a]	1.85 ± 0.12[b]
Condition factor (K)	2.34 ± 0.07[a]	1.84 ± 0.01[b]
Yield parameters		
GFY (kg^{-1})	10668.79 ± 722.06[a]	5387.46 ± 33.21[b]
NFY (kg ha^{-1})	10468.79 ± 722.06[a]	5187.46 ± 33.21[b]
GAY (kg^{-1} ha^{-1} y^{-1})	21633.94 ± 1464.18[a]	10924.57 ± 1464.18[b]
NAY (kg^{-1} ha^{-1} y^{-1})	21228.38 ± 1464.18[a]	10519.02 ± 67.34[b]

Different superscripts in each row indicate significant differences between culture systems ($p < 0.05$).

system was significantly higher than those obtained from the non-integrated system (t = 10.417, df = 4, p = 0.001, Table, 3; Figure 3). The results of break-even analysis showed that lower break-even prices in terms of variable and total costs were attained from the fish-poultry integration than the non-integrated system. A break-even price in terms of variable cost obtained from the fish-poultry integration was significantly lower than those attained from the non-integrated system (t = −5.591, df = 4, p = 0.005; Table 3).

Likewise, a break-even price in terms of total cost attained from the fish-poultry integration was significantly lower than that obtained from the non-integrated system (t = −5.789, df = 4, p = 0.004; Table 3). Further analysis showed that a benefit-cost ratio (BCR) of greater than one was attained in both culture systems. The BCR attained from the fish-poultry integrated system was significantly higher than that obtained from the non-integrated system (t = 7.565, df = 4, p = 0.002; Table 3). A strong positive relationship was revealed between yields and gross revenue (r = 0.960, df = 4, p = 0.001), total variable costs (r = 0.995, df = 4, p = 0.001), income above variable costs (r = 0.736, df = 4, p = 0. 05) and net returns (r = 0.699, df = 4, p = 0.05).

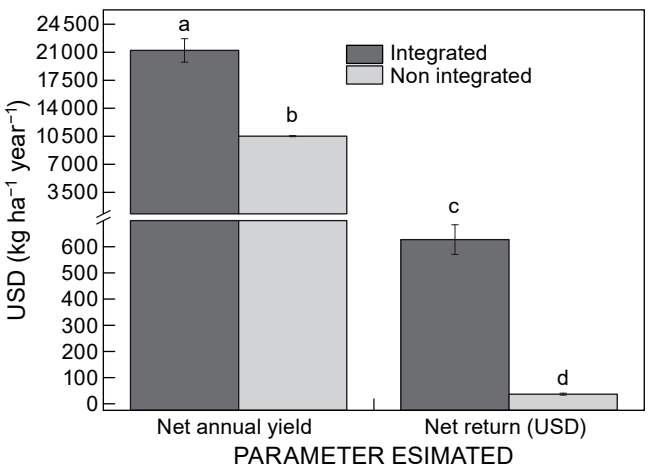


Figure 3: Net annual yields (kg ha^{-1} yr^{-1}) and Net returns (USD) obtained from integrated and non-integrated system. Different letters above bar in each parameter indicate significant differences between culture systems (p < 0.05). Vertical bars indicate SE.

Phytoplankton species composition, numerical abundance and biomass

In terms of phytoplankton species composition, with minor differences, Bacillariophyta dominated in the integrated system, whereas Cyanophyta prevailed over other taxa in the non-integrated system (Figure 4). Total number of phytoplankton species recorded in the integrated and non-integrated pond systems varied considerably (Figure 5). Irrespective of species, the fish-poultry integrated pond had significantly higher mean numerical

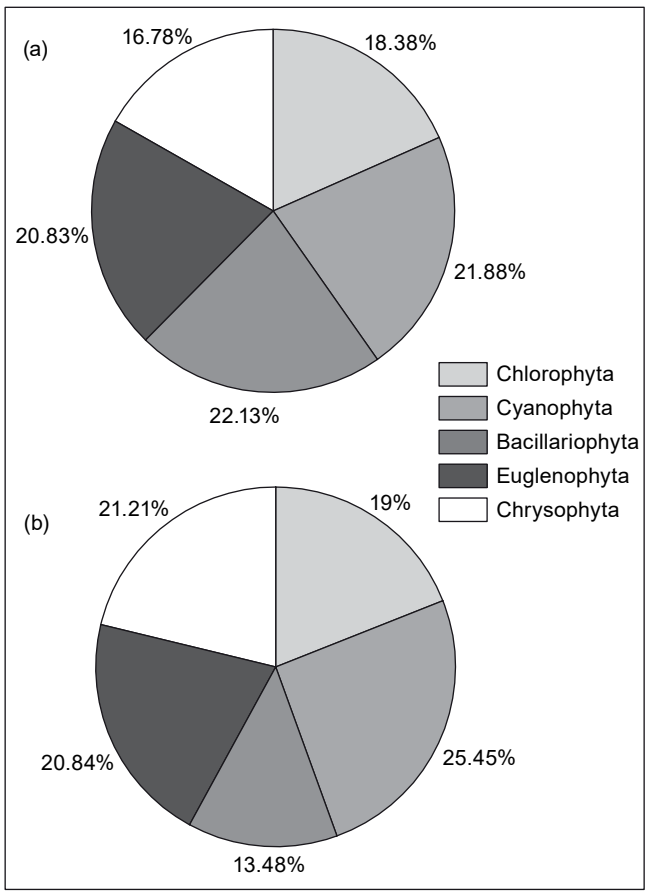


Figure 4: Percentage composition of phytoplankton community in integrated (a) and non-integrated (b) ponds.

Table 3: Mean overall economic comparison between an integrated and a non-integrated system

Parameter	Unit	Integrated	Non-integrated
Gross revenue	US$	1 458.98 ± 54.23^{a}	323.25 ± 2.00^{b}
Total variable costs	US$	791.48 ± 2.80^{a}	271.43 ± 4.00^{b}
Income above variable cost	US$	667.50 ± 56.59^{a}	51.82 ± 3.58^{b}
Total costs	US$	831.48 ± 2.80^{a}	286.43 ± 4.00^{b}
Net return	US$	627.50 ± 56.59^{a}	36.82 ± 3.57^{b}
Break-even yields	kg	239.85 ± 0.81^{a}	93.81 ± 3.00^{b}
Break-even price (variable cost)	US$	2.06 ± 0.07^{a}	2.52 ± 0.03^{b}
Break-even price (total cost)	US$	2.17 ± 0.08^{a}	2.66 ± 0.03^{b}
Benefit-cost ratio (BCR)		1.44 ± 0.04^{a}	1.13 ± 0.01^{b}

1 US$ = TZS 2 000. Different superscripts in each row indicate significant differences between culture systems (p < 0.05).

abundance of phytoplankton taxa (37.87 × 10^6) than those from the non-integrated pond system (23.38 × 10^6, t = 2.516, df = 4, p = 0.015). Chlorophyta (t = 9.125, df = 4. p = 0.001), Cyanophyta (t = 5.393, df = 4, p = 0.006), Bacillariophyta (t = 5.556, df = 4, p = 0.005), Euglenophyta (t = 7.099, df = 4, p = 0.002) and Chrysophyta (t = 6.982, df = 4, p = 0.002) were significantly higher in the integrated than non-integrated ponds (Figure 5).

The results of the phytoplankton biomass (chlorophyll *a*) analysis showed that the fish-poultry integrated system had significantly higher productivity than the non-integrated system (t = 2.55, df = 14, p = 0.023, Figure 6).

Water quality parameters

With the exception of temperature, which was statistically comparable (t = −0.593, df = 4, p = 0.585), dissolved oxygen (DO) and pH differed significantly between the two culture systems (Table 4). Pond water in the non-integrated system was slightly alkaline with a mean pH of 7.82 ± 0.06, whereas pond water in the fish-poultry culture system was slightly acidic with a mean pH of 6.40 ± 0.14 (t = −9.719, df = 4, p = 0.001). Similarly, DO was significantly lower in the fish-poultry integrated pond system (4.79 ± 0.32 mg l^{-1}) than in the non-integrated pond system (7.17 ± 0.33 mg l^{-1}; t = −5.241, df = 4, p = 0.006). The water transparency was also lower in fish-poultry integrated pond system than in the non-integrated pond system (t = −2.735, df = 4, p = 0.052).

Discussion

The current study investigated the role of fish-poultry integrated and non-integrated systems on growth performance, yields and economic benefits of all male *O. niloticus* for rural smallholder farmers. The results from the current study support the hypothesis that *O. niloticus* reared in a fish-poultry integrated system exhibit higher growth performance, yields and economic benefits, as well as phytoplankton species composition, abundance and biomass than those reared in a non-integrated system. These results are corroborated by the findings obtained by Njoku and Ejiogu (1999) who reported higher growth rates from *O. niloticus* reared in fish-poultry integration systems. Higher growth rates in terms of daily, final and total weight gains attained in *O. niloticus* fish cultured under fish-poultry integration in the present study are attributed to the poultry droppings for pond fertilization and food for fish in the respective pond (Njoku and Ejiogu 1999).

Chicken droppings provide nutrients, such as nitrogen, phosphorous and potassium, which function as fertilisers to stimulate production of natural food organisms, such as phytoplankton for fish feeding (Little and Edwards 2003b). Poultry droppings are more efficient in enhancing fish growth rate than pigeon or goat droppings (Jayanthi et al. 2003). In the current study, the chicken droppings improved growth of phytoplankton in fish-chicken integration. Total phytoplankton community in terms of numerical abundance for all the species, biomass and productivity (chlorophyll *a*) were higher in the fish-poultry integrated ponds than non-integrated ponds. Phytoplankton form an important component in a fish-poultry integrated farming system by acting as a major source of natural food, as well as

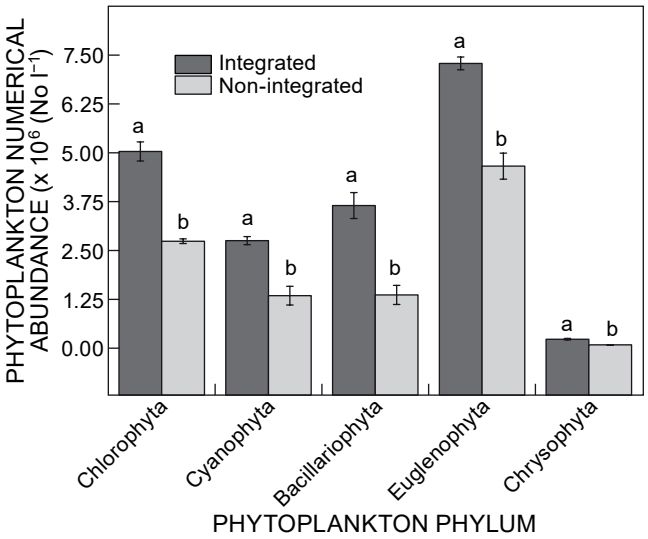


Figure 5: Numerical abundance of phytoplankton phyla from fish-poultry integrated and non-integrated ponds. Different letters above bar in each parameter indicate significant differences between culture systems (p < 0.05). Vertical bars indicate ±SE.

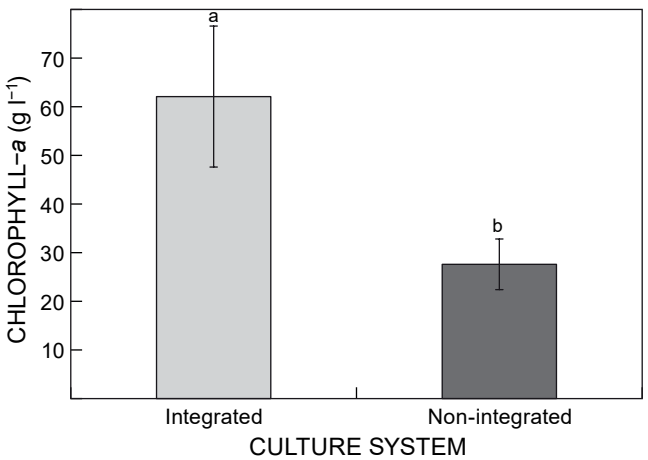


Figure 6: Phytoplankton biomass (chlorophyll-a) from fish-poultry integrated and non-integrated ponds. Different letters above bar in each taxa indicate significant differences between culture systems (p < 0.05). Vertical bars indicate ±SE.

Table 4: Mean water quality parameters obtained during the study period

Water quality parameter	Integrated	Non-integrated
Temperature (°C)	27.07 ± 0.75[a]	27.54 ± 0.29[a]
Dissolved oxygen (mg l^{-1})	4.79 ± 0.32[a]	7.17 ± 0.33[b]
pH	6.40 ± 0.14[a]	7.82 ± 0.06[b]
Water transparency (cm)	40.63 ± 1.07[a]	50.43 ± 3.44[b]

Different superscripts in each row for individual parameters indicate significant differences between culture systems (p < 0.05).

converting the polluting organic manure into useful biomass resulting in adequate dissolved oxygen and acceptable water quality for fish culture (Moi 1992). In addition to natural food organisms available in the fish-poultry integrated system, some groups of fish, such as tilapia, might feed directly on chicken droppings (Petersen et al. 2002). This might be one of the main factors contributing to the higher all male *O. niloticus* growth rate in the fish-poultry integrated system. These results suggest that smallholder farmers can adopt integrated farming technology to improve the growth rate of all male *O. niloticus* for food security and provision of protein.

Interestingly, the availability of natural food organisms in integrated ponds contributed to the higher growth rate, causing higher yields of male *O. niloticus* reared in the fish-poultry integrated system. Findings of the current study are in agreement with those reported by Jayanthi et al. (2003) and Brummett and Jamu (2011), who found that the highest yield of fish, including all male *O. niloticus* were obtained in fish cultured in a fish-poultry integrated system.

The yield of cultured fish is determined by growth rate, survival rate and water quality parameters (Ibrahim and Naggar 2010; Mridha et al. 2014; Limbu et al. 2016). In the current study, all male *O. niloticus* cultured in the integrated system had significantly higher growth rate than those cultured in the non-integrated system. The percentage survival was statistically comparable between the two culture systems. Although we obtained lower pH and dissolved oxygen in the integrated system, these water quality parameters were not stressful to all male *O. niloticus*, because the higher growth rate was obtained in the same system. The percentage survival was positively correlated with growth rate and the growth rate positively correlated with all yields. Hence, the higher yields of all male *O. niloticus* were directly influenced by the higher growth rate. These findings imply that smallholder farmers could improve yields of all male *O. niloticus* through adopting integrated farming technology.

Most importantly, it is evident from the economic benefit analysis that fish-poultry integration is a more profitable farming system than non-integrated system. It was apparent that income greater than the variable cost and net returns from the current study were significantly higher from fish-poultry integration than a non-integrated system. These findings are supported by Jayanthi et al. (2003) and Gangwar et al. (2013) who reported that the highest economic benefits can be accrued from fish farming when integrated with poultry. Furthermore, the break-even prices (price point at which a business will earn zero profits on a sale) were significantly lower in the fish-poultry integrated system than non-integrated system. This suggests that farmers can start making profit at an earlier stage in the production process from integrated rather than the non-integrated systems, which is of great advantage. The significantly higher BCR attained in fish-poultry integrated system shows that it is worth investing in an integrated than a stand-alone system. A benefit-cost ratio of 1:1.46 in fish-poultry integrated system implies that for every US$ 1 invested, a net income of US$ 0.46, which is greater than 46%, accrues to smallholder farmers. This is opposed to the investment of 1:1.13, where a net income of US$ 0.13 (about 13% only) is obtained for every dollar invested in stand-alone fish farming. Results from the current study accord with those reported by Njoku and Ejiogu (1999) and Gangwar et al. (2013) who reported a more or less similar BCR, which ranged from 1:1.26 to 1:1.35 from fish-reared in integration with indigenous chickens.

The higher economic benefits obtained in fish-poultry integrated system, such as net profit and higher economic returns are because of higher yields accruing from the same. Higher yield translates into higher income after selling the system's produce. In this study, yield was significantly positively correlated with economic benefits. Apparently, integrated fish-poultry systems rendered higher economic benefits than that of non-integrated systems. These results suggest that fish-poultry integrated farming is a more economically viable undertaking by smallholder farmers for their food security and poverty alleviation.

Successful aquaculture operations largely depend on the level of water quality in the culture system, such as a fish pond. Water quality in an aquaculture pond can change depending on certain circumstances such as time of the day and culture system (Shoko et al. 2014). In order to attain high fish growth and yields, water quality parameters should be monitored closely. In the current study, water from fish-poultry integrated ponds had lower pH, dissolved oxygen and water transparency than those from non-integrated pond. However, the growth performance, yields and profitability were higher for all male *O. niloticus* cultured in integrated than non-integrated system and the survival was statistically comparable between the culture systems. This indicated that, although pH, dissolved oxygen and water transparency were somewhat low, their levels were not stressful enough to affect growth and survival of all male *O. niloticus*. Low dissolved oxygen and water transparency in fish-poultry integration systems could be attributed to overstimulation of phytoplankton, because of continuous fertilization from chicken droppings. Therefore, if water quality parameters are not properly monitored in fish-poultry integration systems, it is likely that their levels could be lower than the recommended limits, thereby affecting fish growth and survival. Such unfavourable situations can be avoided by limiting the continuous flow of chicken droppings and further limiting the monthly water exchange to at least 30% to enhance availability of dissolved oxygen as adopted by Shoko et al. (2016a).

Findings from the current study suggest the importance of using local resources in designing appropriate and feasible technology for integrated semi-intensive aquaculture in sub-Saharan countries, such as Tanzania. Such technology should be easily adoptable and affordable as an intervention in an already existing practice, rather than providing complex and expensive systems, which only concentrates on high production, without considering the local conditions. Therefore, if adopted properly, an integrated aquaculture-agriculture system has an important positive impact on reducing poverty and improving income generation for many smallholder farmers.

Conclusions

The current study has demonstrated that fish-poultry integrated system attains higher growth rate of all male *O. niloticus*, yields and economic returns than non-integrated system. Accordingly, it is suggested that smallholder farmers could increase their incomes and food security, consequently

improving their livelihoods, through adopting an integrated farming system technology. These benefits can be attained through outreach on integrated aquaculture technology to smallholder farmers and the community at large.

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