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Fish polyculture system integrated with vegetable farming improves yield and economic benefits of small-scale farmers

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Abstract

This study explored the yield and economic benefits of African sharptooth catfish, *Clarias gariepinus,* and Nile tilapia, *Oreochromis niloticus* polyculture, reared in earthen ponds for 270 days integrated with Chinese cabbage, *Brassica rapa chinensis,* farmed for 45 days to small-scale farmers in Tanzania. An integrated aquaculture–agriculture (IAA) system involving fishes and vegetables resulted in three and 2.5 times higher net yield than the culture of fishes alone and farming of non-integrated vegetables respectively. Vegetables irrigated with pond water resulted in 1.8 times higher net and annual yields than those irrigated with stream water. The practice of fish–vegetable integration and growing of vegetables irrigated with pond water produced 14 and 13 times higher net annual yield, respectively, than the culture of fishes alone. The integrated system produced 20 and 150 times more net returns compared with vegetables irrigated with pond and stream water respectively. Integrating fishes with vegetables resulted in significantly higher annual net cash flow than the farming of fishes and vegetables separately. The study revealed that integrating fishes with *B. rapa chinensis* increases yields, income and food production to small-scale farmers. Thus, small-scale farmers can adopt IAA technology to meet the increasing demand of fish and vegetables, stabilize their incomes and diversify food production, consequently improving food security. These benefits will be realized by providing proper training in IAA technology and management skills to small-scale farmers.

Keywords: yield, fish culture, vegetable farming, integrated aquaculture–agriculture, net return, annual net cash flow

Introduction

Poverty, hunger and malnutrition are among the most critical problems confronting many farmers in developing countries including Tanzania (Rasowo, Auma, Ssanyu & Ndunguru 2008; Bisht 2011; Behera, Panigrahi & Sarangi 2012; Ogello, Mlingi, Nyonje, Charo-Karisa & Munguti 2013). Farmers in these countries are struggling for their livelihood from small-scale extensive agricultural farms (Dey, Paraguas, Kambewa & Pemsl 2010). They work in an agricultural sector that is poorly developed hence hardly earning sufficient food and income to sustain their families (Sekhar, Rao & Rao 2014). Declining wild fish stocks as an inexpensive protein source for the rapidly growing population has created a wide gap between demand and supply of protein in developing

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countries (Boland, Rae, Vereijken, Meuwissen, Fischer, van Boekel, Rutherfurd, Gruppen, Moughan & Hendriks 2013). Consequently, aquaculture has increased in prevalence as a means to meet the public demand for fish protein (Roosta 2014). Thus, in many developing countries, a large majority of farmers participate solely in either agriculture or fish farming. However, such stand-alone ventures are risky and therefore not a sustainable means of production for small-scale farmers in developing countries (Prein 2002; Shoko, Getabu, Mwayuli & Mgaya 2011).

Integrated aquaculture–agriculture (IAA) technology offers an opportunity to increase farm productivity for small-scale farmers due to concurrent or sequential linkage between two or more activities (Zajdband 2011). IAA is deemed a practical solution to the continuous food insecurity, malnutrition and poverty for the small-scale farmers in developing countries (Rasowo *et al.* 2008; Debnath, Ananthan, Biradar & Datta 2009). One form of such integration is that involving African sharptooth catfish, *Clarias gariepinus* and Nile tilapia, *Oreochromis niloticus* polyculture integrated with Chinese cabbage *Brassica rapa chinensis*. This integration has the potential to improve production and economics for small-scale farmers because *B. rapa chinensis* is a common crop on rural farms in Tanzania (Baitilwake, De Bolle, Salomez, Mrema & De Neve 2012) and a preferred vegetable by producers and consumers because it is easy to cultivate, with a short growing period (Kalisz, Kostrzewa, Sękara, Grabowska & Cebula 2012), has a unique flavour, health benefits (Pant, Radovich, Hue & Miyasaka 2012), an attractive appearance (Thosaikham, Jitmanee, Sittipout, Maneetong, Chantiratikul & Chantiratikul 2014) and high market demand worldwide (Cartea, Francisco, Soengas & Velasco 2010). Furthermore, *B. rapa chinensis* responds well to moist fertile soil and can be produced annually in the tropics under full sun conditions and it is one of the most productive leaf vegetables grown with an average edible leaf yield of 3577 g m^{-2} (Idris, Ali, Gayah, Hassan & Abidin 2011; Kalisz 2011; Wong, Tseng, Hsu, Lur, Mo, Huang, Hsu, Lee & Liu 2014). On the other hand, *C. gariepinus* and *O. niloticus* which are commonly cultured fish species have higher market demand, produce high yields, require low input resources to culture (El-Naggar 2007) and are preferred as source of protein all over the world (Shoko, Limbu, Mrosso, Mkenda & Mgaya 2016). The polyculture of *C. gariepinus* and *O. niloticus* integrated with vegetables under IAA ensures increased production consequently offers higher profits to farmers. When cultured together, *C. gariepinus* preys on *O. niloticus* fingerlings resulting from the prolific breeding of tilapia and ultimately controls overpopulation and thus improving fish growth rates and yields (Limbu, Shoko, Lamtane, Shirima, Kishe-Machumu, Mgana & Mgaya 2015). The resulting higher growth rates and yields from fishes and the production of vegetables transform into economic terms after sales leading to improved profitability for fish farmers (Akpaniteaku, Weimin & Xinhua 2005).

Previous studies have demonstrated that IAA technology can lead to improved farm productivity, higher income, increased food production and better nutrition for small-scale farmers (Pant, Demaine & Edwards 2004; Murshed-E-Jahan & Pemsl 2011; Zajdband 2011; Mariscal-Lagarda, Páez-Osuna, Esquer-Méndez, Guerrero-Monroy, del Vivar & Félix-Gastelum 2012; Wang & Lu 2016). Despite this recognition, its adoption in African countries including Tanzania has been slow due to little rigorous empirical participatory research aimed at promoting IAA adoption in small-scale farmers' settings (Edwards 1998; Saiful Islam, Barman & Murshed-e-Jahan 2015). Poor publicity and high illiteracy among small-scale fish farmers have been revealed as major hindrance to the growth of integrated fish farming such as fish with *B. rapa chinensis* (Ogello *et al.* 2013). This is because IAA technology involves the provision of key management skills to farmers such that its successful application depends largely on the farmers' knowledge of the production systems involved at the farm (Murshed-E-Jahan & Pemsl 2011). Thus, technical knowledge is usually reckoned to be a crucial prerequisite in adopting IAA techniques (Karim, Little, Kabir, Verdegem, Telfer & Wahab 2011; Mirhaj, Boit, Razzak & Wahab 2013; Chau, Phuoc, Duc, Troell & Berg 2015).

Moreover, small-scale farmers' decisions to adopt production systems such as fish with *B. rapa chinensis* integration are largely influenced by economic factors and dietary preferences (Jian, Xue, Tang, Zhang, Luo & Xin 2011). Consequently, approaches used for promotion of IAA technology such as integrating fishes with *B. rapa chinensis* must involve small-scale farmers using participatory studies conducted on-farm (Karim *et al.*

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2011). These aspects are limited in many African and other developing countries particularly for the integration of *C. gariepinus* and *O. niloticus* polyculture with *B. rapa chinensis*. The majority of the studies on fish and *B. rapa chinensis* integration were conducted in aquaponics and glasshouse facilities (Palada, Cole, Crossman, Rakocy & Kowalski 1995; Idris *et al.* 2011; Mariscal-Lagarda *et al.* 2012). There is a paucity of information on the integration of fish culture and farming of *B. rapa chinensis* where effluent water is used as a fertilizer for the latter using participatory on-farm pond culture systems.

The objective of this study was to determine the yield and economic benefits of integrating *C. gariepinus* and *O. niloticus* polyculture with *B. rapa chinensis* into the existing farming practice of small-scale farmers in Tanzania. The study aimed at improving resource use efficiency to increase farm productivity in a sustainable manner through the diffusion of low-cost IAA farming technology. It was intentionally done on-farm in order to provide practical results based on farmers' conditions. The study hypothesized that integrating fishes with *B. rapa chinensis* could result in higher production and increased economic benefits.

Materials and methods

Study site

The study was conducted at Lufulu village in Kilombero District, about 110 km from Ifakara town located at 8° 31′ 0″ South, 35° 56′ 0″ East in Morogoro region, Tanzania (Fig. 1). The site is characterized by a rainy season from November to May and a dry season from June to October (Balama, Augustino, Eriksen, Makonda & Amanzi 2013). The site receives an annual rainfall of between 1200 and 1800 mm, and the temperature ranges from 25 to 32°C (Sumaye, Geubbels, Mbeyela & Berkvens 2013). The main economic activities at the site include agriculture, fishing, fish farming, forestry and livestock keeping.

Experimental design: fish

A participatory on-farm study was conducted in four static fish ponds each having an area of

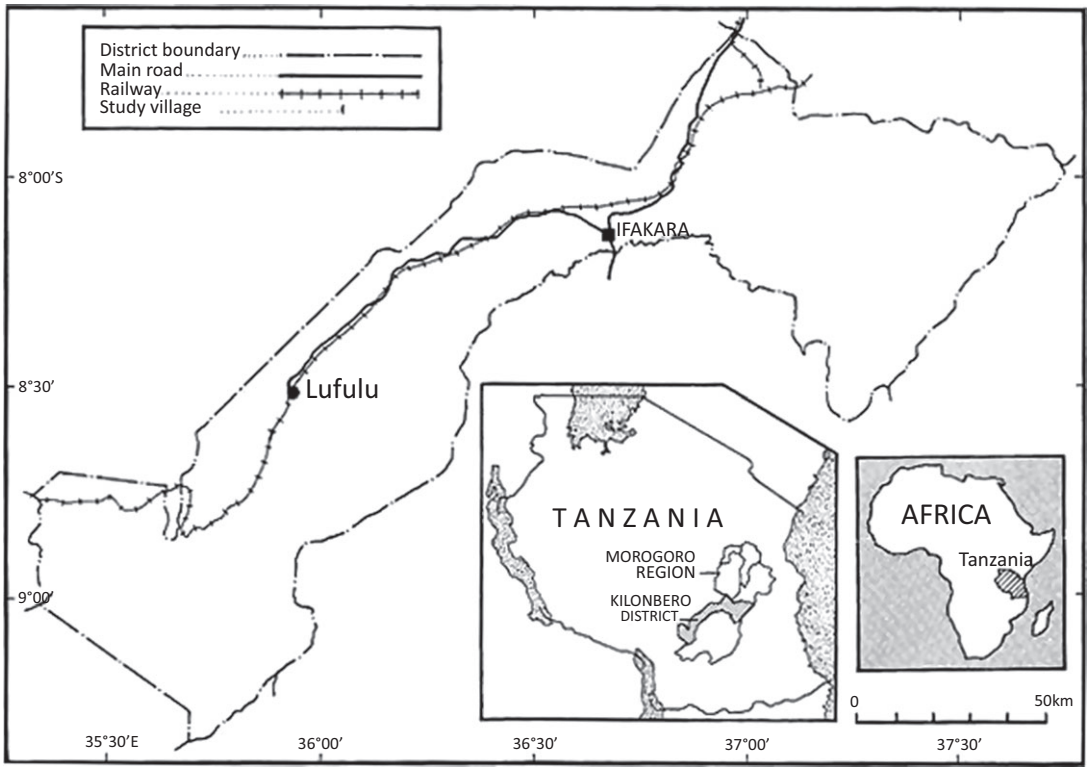


Figure 1 Map of Ifakara, Tanzania, showing study site (source: University of Dar es Salaam Cartographic Unit).

200 m^2 and a mean depth of 1.25 m. The ponds are owned and managed by four independent fish farmers within Lufulu village. They were rehabilitated to ensure similar dimensions before the start of the experiment. The main source of water to the ponds was streams originating from the Udzungwa Mountains. Prior to the start of the study, the fish farmers were trained in the basics of integrated aquaculture–agriculture with particular emphasis on integrated fish farming. Fish ponds were stocked with *O. niloticus* and *C. gariepinus* with an initial mean weight (± standard error, SE) of 14.62 ± 0.61 g and 20.34 ± 1.44 g, respectively, at a stocking ratio of 1:3 for *C. gariepinus* and *O. niloticus*. The stocking of *C. gariepinus* was intentionally delayed for 30 days to allow *O. niloticus* to attain 29.02 ± 2.50 g so that the former would be unable to prey on them. They were stocked at a density of three fish m^{-2} and reared for 270 days. The fishes were fed on a diet containing 184.74 g kg^{-1} crude protein dry feed consisting of locally available sunflower seed cake (760.00 g kg^{-1}) and rice bran (240.00 g kg^{-1}; Table 1) ingredients.

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% of the average body weight of *O. niloticus* and *C. gariepinus* at the beginning of the study. The feeding rate was reduced to 4% and 3% when the average weight of the fishes reached >50 and >100 g respectively. The ration was divided into two portions and fed to the fish by hand, by broadcasting at the periphery of each pond, twice per day in the morning and evening between 0900 and 1000 h and 1500 and 1600 h respectively. In order to ascertain proper feeding regimes and sampling frequencies, scientists collaborated closely with farmers. Supervision was important so as to avoid variation caused by daily management regimes in different farmers' ponds. A proximate analysis of the feed used was conducted according to the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC 1990).

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

Ingredients	Composition (g kg^{-1}) dry feed
Sunflower seed cake	760.00
Rice bran	240.00
Total	1000.00
Proximate composition of feed	
Dry matter	917.02
Crude protein	184.74
Crude fibre	188.09
Crude fat	102.95
Ash	67.28
Carbohydrate	373.96

In addition to feeding, the fish ponds were fertilized using cattle manure at a rate of 280 kg ha^{-1} $week^{-1}$ (Garg & Bhatnagar 1999). The manure was applied using a bamboo wooden crib constructed near the water inlet in each pond. The chemical composition of the dry cattle manure (g kg^{-1}) was moisture (755.00), organic matter (222.00), total nitrogen (N; 9.20), total phosphorus (P_2O_5; 4.30), potassium (4.00) and calcium (5.50).

Experimental design: vegetables

Six vegetable plots measuring 1.5 × 5.0 m each were prepared after 6 months post stocking of fishes during the dry season at the periphery of each pond making a total 24 vegetable plots for the four ponds. *B. rapa chinensis* was planted in the plots at a spacing of 30 × 30 cm. The period of 6 months was deemed appropriate to create enough nutrients for growth of the vegetables. Of the six vegetable plots in each pond, three plots were irrigated with pond water hereinafter referred to as integrated vegetables whereas the other three plots were irrigated with water from streams hereinafter referred to as non-integrated vegetables. The vegetable plots were irrigated with 20 L of water twice daily in the morning between 0900 and 1000 h and evening between 1500 and 1600 h. The irrigation of vegetable plots lasted for 45 days. The pond water used for irrigation in the plots was replaced daily by an equal amount of water obtained from the streams to ensure similar water levels in ponds throughout the study. Water from the fish ponds was used as a source of nutrients resulting from uneaten feed and excrement dissolved in it. The fish pond water and soil from vegetable plots were analysed for nutrients levels. Weeding of growing plants in the vegetable plots was performed regularly whenever observed to reduce competition for nutrients and space.

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Yield estimation of the fishes and *Brassica rapa chinensis* and their integration

Data collection was performed at the end of the experiment by completely draining out all the water from the ponds and harvesting both fish species. The fish species obtained in each pond were weighed for determination of yield using a weighing scale and converted into tonnes. Net yield (NY) and net annual yield (NAY) were calculated using the following formulae adopted from Limbu *et al.* (2015) and Shoko *et al.* (2016):

$$\mathrm{NY(tonnes\ ha^{-1})} = \frac{W_h \times W_s}{P} \qquad (1)$$

where W_h = Total weight harvested (tonnes), W_s = Total weight stocked/sowed (tonnes), P = Pond area (ha).

$$\mathrm{NAY(tonnes\ ha^{-1}year^{-1})} = \frac{\mathrm{NY} \times 365}{t} \qquad (2)$$

where t = Growth period (days).

Harvesting of *B. rapa chinensis* was performed regularly during the study period by chopping mature leaves and measuring them using an electronic precision balance. Only one total harvest of vegetables was performed because the study intended to avoid influence of rain water. Total harvest was performed after 45 days by weighing all harvested mature leaves using a weighing scale. Mature leaves with no physical damage were included among marketable yield. All the leaves obtained in each of the three plots were pooled together to obtain the gross yield (GY). The net annual yield (NY) of *B. rapa chinensis* was calculated using equation (1) with the weight of seeds forming the total weight sowed. NAY for *B. rapa chinensis* was calculated using equation (2). The integration yield was obtained by summing the fishes and *B. rapa chinensis* yields for each parameter.

Economic benefit analysis of the fish species and *Brassica rapa chinensis* and their integration

Partial enterprise budgets were used to compare the relative profitability of the fishes, *B. rapa chinensis* reared by irrigating with pond and stream water and the integration of fishes and vegetables. Costs involved in production process represented the inputs required and were categorized into variable and fixed costs. Variable costs for fish production included fingerlings, feeds, seine nets, fish containers, weighing scale, casual labour, transport and interest on operating costs whereas fixed costs included fish pond construction and family labour. Vegetable variable costs included seeds, casual labour and interest on operating costs whereas fixed costs included plot construction and family labour.

Total income was calculated for the culture of fishes alone, integrated and non-integrated vegetable farming. The calculation was based on local market price of 3.62 and 0.55 USD $\mathrm{kg^{-1}}$ for the fishes and *B. rapa chinensis* respectively. Total cost was calculated as fixed cost plus variable cost. Net return was computed as total income less the total cost incurred during production for a particular system. The actual values of revenue generated by farmers after selling their fishes and *B. rapa chinensis* were used in the analysis. The analysis was based on local market retail prices converted in USD (USD 1 = TZS 1658.00) using prevailing rates 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.

The annual net cash flow (ANCF) was estimated according to Rupasinghe and Kennedy (2010) to describe the most cash-generating farming system using the equation:

$$\begin{aligned}\mathrm{ANCF} = {} & (\mathrm{Price} \times \mathrm{annual\ quantity\ produced}) - \\ & \mathrm{annual\ variable\ cost} - \\ & \mathrm{annual\ fixed\ cost}\end{aligned} \qquad (3)$$

To measure the profitability of the farming systems, gross profit margin (GPM) was calculated using the formula:

$$\mathrm{GPM\ (\%)} = \frac{\mathrm{Gross\ profit}}{\mathrm{Net\ sales}} \times 100 \qquad (4)$$

Nutrients analysis

Water samples for nutrients analysis were collected from each pond and stream once a month for 5 months. These water samples for nutrient analysis in the ponds and streams were collected from triplicate points at about 10–35 cm below water surface using a 250-mL wide-mouthed plastic bottle. Samples for analysis of dissolved nutrient species were immediately filtered through a 0.45-

μm Millipore membrane filters and stored in a cool box with ice. Those for total nitrogen (TN) and total phosphorus (TP) were left unfiltered but stored separately in the same cool box. Similar to water samples, triplicate soil samples from each vegetable plot were collected at a depth of 10–30 cm using a soil corer, stored in plastic bags and kept in a different cool box with ice for nutrient analysis. The water and soil samples collected were transported in cold environment to Tanzania Fisheries Research Institute (TAFIRI) and Sokoine University of Agriculture laboratories in Kigoma and Morogoro, respectively, for further analysis of nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), phosphorus (PO_4^{3-}), total nitrogen (TN) and total phosphorus (TP) using standard methods (Boyd & Tucker 1998; APHA 2005).

Water quality analysis

Water temperature, pH and dissolved oxygen (DO) measurements were taken twice daily in the morning between 0830 and 0900 h and in the afternoon between 1630 and 1700 h using a multiprobe kit (model KTO, HQ, 40D PHC 101-LD 101-01 by Hach Company, USA). Water temperature was 28.56 ± 0.68°C, dissolved oxygen (DO) was 5.16 ± 0.51 mg L^{-1}, and water pH was 6.34 ± 0.07 throughout the study period.

Statistical analyses

Results are presented as means ± SE of means and the data were tested for homogeneity of variance using Levene's test. After confirming homogeneity of variances, one-way analysis of variance (ANOVA) was used to test for significant differences in the yield parameters, economic benefit variables and nutrients among farming systems. When significant differences were detected, the Tukey *post hoc* test was performed to determine specific significant differences among treatments. Percentage data were arcsine-transformed prior to ANOVA and reversed afterwards for reporting purposes. The percentage contributions to the integration yield for integrated vegetable farming and fish culture were assessed using independent-samples *t*-test. Pearson correlation was used to establish the relationship between net return and farming system, and net return and yield. All statistical analyses were performed using SPSS version 20 (IBM, Armonk, NY, USA) for Windows. Significant differences were judged at a probability level of $P \leq 0.05$ for ANOVA, Tukey *post hoc* test and *t*-test, whereas $P \leq 0.01$ was used for Pearson correlation.

Results

Yields of the fishes and *Brassica rapa chinensis* and their integration

The mean percentage survival of *O. niloticus* was 82.60 ± 4.53% whereas that of *C. gariepinus* was 87.83 ± 1.65%. The fishes attained a final mean weight of 155.95 ± 22.62 g and 222.22 ± 27.78 g for *O. niloticus* and *C. gariepinus* respectively. The net yields were 5.18 ± 2.43 tonnes ha^{-1} for non-integrated vegetables, 9.13 ± 1.34 tonnes ha^{-1} for integrated vegetables and 13.33 ± 1.33 tonnes ha^{-1} for fish–vegetable integration. The yield of fishes alone was 4.20 ± 0.41 tonnes ha^{-1} contributed by 2.20 ± 0.19 and 2.00 ± 0.56 tonnes ha^{-1} of *O. niloticus* and *C. gariepinus* respectively.

The farming system affected significantly the net yield of vegetables, fishes and their integration ($F = 17.393$, $P < 0.001$). Integrating fishes with vegetables resulted in three and 2.5 times higher net yield than the culture of fishes alone ($P < 0.001$) and farming of non-integrated vegetables ($P < 0.001$) respectively. Vegetables irrigated with pond water had 1.8 times higher net yield than those irrigated with stream water ($P = 0.037$). The culture of fishes alone and non-integrated vegetables had statistically comparable yields ($P = 0.896$). The contributions of integrated vegetables and fishes to the integration net yield were 66.39 ± 6.54% and 33.61 ± 6.54% respectively. Integrated vegetable farming contributed twice to the net integration yield compared with the culture of fishes alone ($t = 3.546$, $P = 0.012$).

The net annual yield was 74.05 ± 16.55 tonnes ha^{-1} $year^{-1}$, 79.73 ± 16.43 tonnes ha^{-1} $year^{-1}$ and 42.08 ± 19.73 tonnes ha^{-1} $year^{-1}$ for integrated vegetables, fish–vegetable integration and non-integrated vegetables respectively. The yield of fishes was 5.68 ± 0.85 tonnes ha^{-1} $year^{-1}$ contributed by 2.98 ± 0.26 and 2.70 ± 0.76 tonnes ha^{-1} $year^{-1}$ from *O. niloticus* and *C. gariepinus* respectively.

The net annual yield of the vegetables, fishes and their integration was different among farming systems ($F = 18.264$, $P < 0.001$). The integration

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of fishes and vegetables produced 14 times higher net annual yield than the culture of fishes alone ($P = 0.009$). In the same vein, the farming of integrated vegetables resulted in 13 times higher gross annual yield than the culture of fishes alone ($P = 0.015$). For the farming of vegetables, the net annual yield of the integration system was approximately 1.8 times higher than that of non-integrated vegetables ($P = 0.009$). On the other hand, the net annual yield of integrated vegetables was twice as much compared to that of fishes alone ($P < 0.001$). Integrated vegetable farming contributed 91.73 ± 2.17% to the integration yield compared with only 8.27 ± 2.17% rendered by the culture of fishes alone. This represents a 10 times higher contribution of vegetables to the integrated yield than the culture of fishes alone ($t = 27.144$, $P = 0.001$).

Economic benefits of the fish species, *Brassica rapa chinensis*, and their integration

The results of income above variable cost for the non-integrated vegetables, integrated vegetables and integration of fishes and vegetables are shown in Fig. 2. The culture system used affected significantly the income above variable cost ($F = 21.543$, $P < 0.001$). Farming of integrated and non-integrated vegetables resulted in significantly lower incomes above variable costs than the culture of fishes alone ($P = 0.001$) and the integration of fishes with vegetables ($P < 0.001$) respectively. A statistically comparable income above variable cost was obtained between the farming of integrated and non-integrated vegetables ($P = 0.998$) as well as between the culture of fishes alone and fish–vegetable integration ($P = 0.986$). The incomes above variable costs of fishes alone (USD 123.96 ± 20.78) and fish–vegetable integration (USD 131.18 ± 21.96) were approximately 16 and 35 times higher than the farming of integrated (USD 7.50 ± 2.01) and non-integrated vegetables (USD 3.61 ± 2.40) respectively. The income above variable cost from integrated vegetables was twice as high as the farming of non-integrated vegetables.

The results showed positive net returns from all the four farming systems used with significant differences among them ($F = 14.288$, $P < 0.001$; Fig. 3). The net return for non-integrated vegetables was significantly lower than the culture of fishes alone ($P = 0.003$) and the fish–vegetable integration system ($P = 0.002$). Similarly, the net return of integrated vegetables farming was significantly lower than the culture of fishes alone ($P = 0.004$) and the fish–vegetable integration system ($P = 0.003$). The net returns obtained from the culture of fishes alone (USD 99.83 ± 20.78) and their integration with vegetables (USD 107.06 ± 21.96) represent 20 and 170 times more returns compared with the farming of integrated (USD 4.48 ± 2.01) and non-integrated vegetables (USD 0.59 ± 2.40) respectively. Statistically comparable net returns were obtained from raising fishes alone and fish–vegetable integration ($P = 0.987$) as well as the farming of integrated and non-integrated vegetables ($P = 0.998$). The net return was significantly and positively

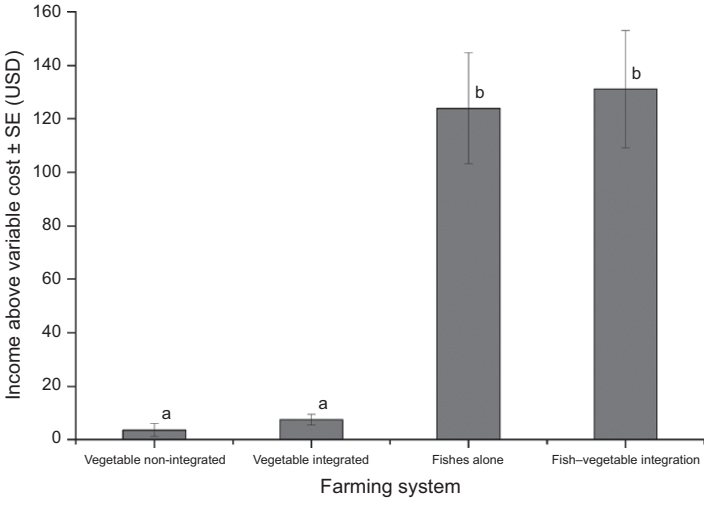


Figure 2 The income above variable cost ± SE (USD) of vegetable integrated, fish and vegetable integration and vegetable non-integrated obtained during the study period. Different letters (a and b) above the bars indicate significant difference ($P < 0.05$).

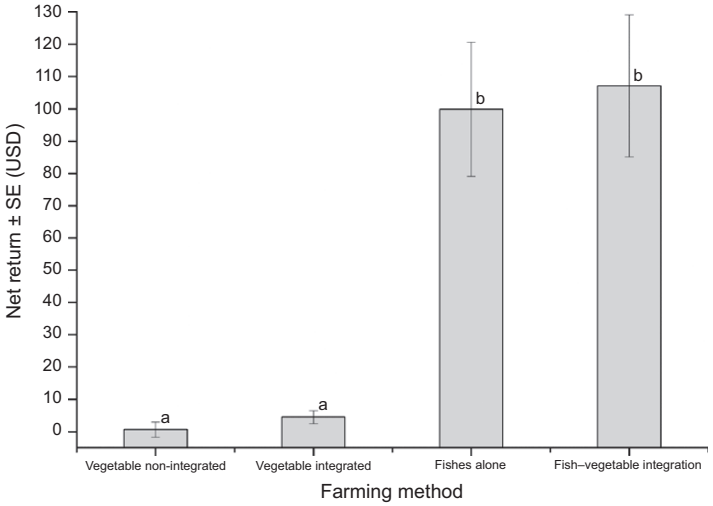


Figure 3 The net return ± SE (USD) of vegetable integrated, fish and vegetable integration and vegetable non-integrated obtained during the study period. Different letters (a and b) above the bars indicate significant difference ($P < 0.05$).

correlated with the farming system used ($r^2 = 0.738$, $P = 0.006$). The net return increased sharply from non-integrated and integrated vegetables farming systems to fish farming and fish–vegetable integration systems (Fig. 3).

The annual net cash flow (ANCF) was USD 26.25 ± 12.75 for non-integrated vegetable, USD 57.80 ± 8.53 for integrated vegetable, USD 143.45 ± 14.67 for fishes alone and USD 200.88 ± 20.65 for fish–vegetable integration (Fig. 4). Farming using the four methods resulted in significantly different ANCF ($F = 31.119$, $P < 0.001$). Integrating fishes and vegetable resulted in significantly higher ANCF than the farming of non-integrated vegetables ($P < 0.001$), integrated vegetables ($P < 0.001$) and culture of fishes alone ($P = 0.033$). Moreover, the culture of fishes alone resulted in significantly higher ANCF than the farming of integrated ($P = 0.001$) and non-integrated vegetables ($P < 0.001$). However, the farming of integrated and non-integrated vegetables resulted in comparatively similar ANCF ($P = 0.411$).

The results on gross profit margins (GPM) indicated negative profits for farming of non-integrated vegetables (-4.53 ± 4.45%). The other three farming systems indicated positive profits (GPM) for integrated vegetable (4.93 ± 1.92%), culture of fishes alone (20.11 ± 2.40%) and integrated fish–vegetable system (20.57 ± 2.42%; Fig. 5). The gross profit margins from the four farming systems used differed significantly ($F = 17.104$,

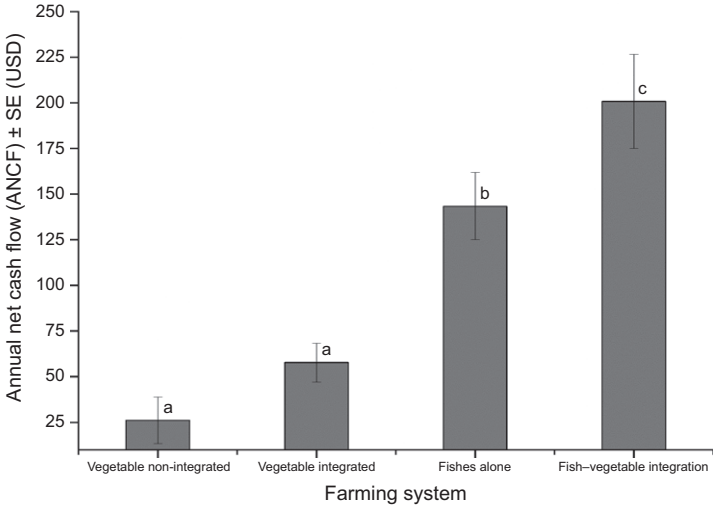


Figure 4 The annual net cash flow (ANCF) ± SE of vegetable integrated, fish and vegetable and vegetable non-integrated obtained during the study period. Different letters (a, b and c) above the bars indicate significant difference ($P < 0.05$).

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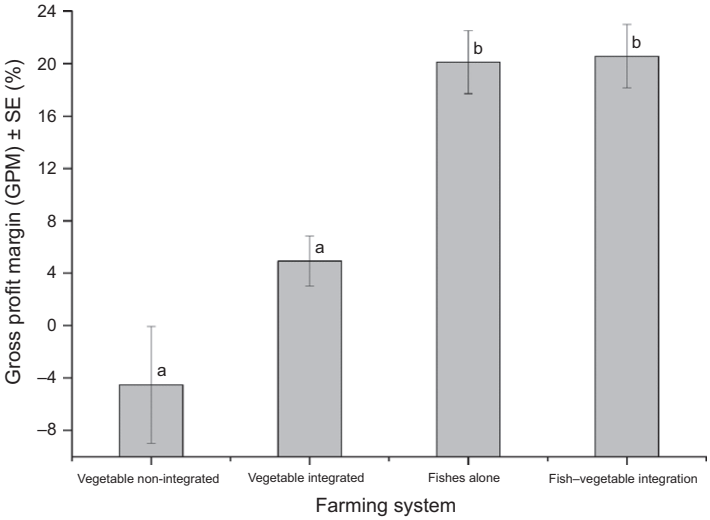


Figure 5 The gross profit margin (GPM) ± SE (%) of vegetable integrated, fish and vegetable integration and vegetable non-integrated obtained during the study period. Different letters (a and b) above the bars indicate significant difference ($P < 0.05$).

$P < 0.001$). The gross profit margin obtained from non-integrated vegetable farming was significantly lower than the culture of fishes alone ($P < 0.001$) and their integration with vegetables ($P < 0.001$). Similarly, integrated vegetable farming had significantly lower GPM than the culture of fishes alone ($P = 0.016$) and their integration with vegetables ($P = 0.013$). The culture of fishes alone and integrating them with vegetables produced a comparable gross profit margin ($P = 1.000$) as well as the farming of integrated and non-integrated vegetables ($P = 0.163$).

Nutrients levels

The nutrients levels in the fish pond water, vegetable plot soil and stream water obtained during the study are shown in Table 2. The concentration of NO_3^- was significantly different among fish pond water, vegetable plot soil and stream water ($F = 12.234$, $P < 0.001$). The pond water had a significantly higher concentration of NO_3^- than vegetable plot soil ($P = 0.001$) and stream water ($P < 0.001$). However, vegetable plot soil and stream water had statistically comparable concentration of NO_3^- ($P = 0.581$). The concentration of NH_4^+ was significantly different among the three environments ($F = 14.564$, $P < 0.001$). The pond water had a significantly higher NH_4^+ concentration than vegetable plot soil ($P = 0.016$) and stream water ($P < 0.001$). Similarly, vegetable plot soil had a higher concentration of NH_4^+ than stream water ($P = 0.037$). The concentration of PO_4^{3-} was significantly different in fish pond water, vegetable plot soil and stream water ($F = 7.642$, $P = 0.001$). The pond water had a significantly higher concentration PO_4^{3-} than vegetable plot soil ($P = 0.021$) and stream water ($P = 0.001$). However, vegetable plot soil and stream water had a statistically comparable concentration of PO_4^{3-} ($P = 0.565$). The concentration of total nitrogen (TN) was significantly different among the three environments ($F = 5.261$, $P = 0.008$). The pond water had a significantly higher TN concentration than vegetable plot soil ($P = 0.039$) and stream water ($P = 0.010$). Vegetable plot soil and stream water had a statistically similar TN concentration ($P = 0.861$). The concentration of total

Table 2 Nutrients levels in fish pond water, vegetable plot soil and stream water during the study period

Nutrient (mg L^{-1})	Fish pond water	Vegetable plot soil	Stream water
Nitrate (NO_3)	1.79 ± 031[a]	0.75 ± 0.11[b]	0.47 ± 0.11[b]
Ammonium (NH_4)	1.13 ± 0.14[a]	0.66 ± 0.13[b]	0.25 ± 0.81[c]
Nitrite (NO_2)	0.02 ± 0.00[a]	0.01 ± 0.00[a]	0.01 ± 0.00[a]
Phosphate (PO_4)	0.17 ± 0.01[a]	0.12 ± 0.02[b]	0.10 ± 0.01[b]
Total nitrogen (TN)	2.50 ± 0.39[a]	1.50 ± 0.14[b]	1.24 ± 0.23[b]
Total phosphorus (TP)	1.39 ± 0.41[a]	0.49 ± 0.06[b]	0.14 ± 0.13[b]

a,b,c: Means within each row sharing the same superscript are not significantly different among fish pond water, vegetable soil plots and stream water ($P < 0.05$).

phosphorus (TP) was significantly different among the three environments ($F = 4.477$, $P = 0.016$). The pond water had a significantly higher TP concentration than vegetable plot soil ($P = 0.036$) and stream water ($P = 0.029$). Vegetable plot soil and stream water had a statistically comparable TN concentration ($P = 0.996$). The concentration of NO_2^- was comparable among the fish pond water, vegetable plot soil and stream water ($F = 1.022$, $P = 0.366$).

Discussion

The present study aimed to explore the yield and economic benefits of integrating *C. gariepinus* and *O. niloticus* polyculture with *B. rapa chinensis* into the existing farming practice of small-scale farmers. The results showed that integrating fishes with vegetables led to significantly higher yields compared with culture of fishes alone and farming of non-integrated vegetables. The net annual yield of 5.68 ± 0.85 tonnes ha^{-1} year^{-1} for fishes alone obtained in the present study is lower than the yield of 8.02 ± 0.64 tonnes ha^{-1} year^{-1} reported by Shoko *et al.* (2016) for polyculture of *O. niloticus* and *C. gariepinus* stocked at 3 fish m^{-2} in earthen ponds. The differences are attributed to lack of water exchange in the present study as opposed to 30% renewal of water per week that was performed by Shoko *et al.* (2016).

The net annual yield of 42.08 ± 19.73 tonnes ha^{-1} year^{-1} and 74.05 ± 16.55 tonnes ha^{-1} year^{-1} obtained from cultivating non-integrated and integrated *B. rapa chinensis,* respectively, are more or less within the ranges reported from previous studies by Krezel and Kolota (2003), Kalisz and Siwek (2006), Kalisz *et al.* (2012) and Kalisz, Sękara, Joanna, Grabowska and Cebula (2013). The discrepancies in *B. rapa chinensis* yield observed in the present study and previous studies are related to culture systems used and variations in climatic conditions. Most of the previous studies used glasshouse and aquaponics systems in which conditions can be easily manipulated contrary to the present study where *B. rapa chinensis* was sown into the soil. In aquaponics and glasshouse systems, nutrients are usually maintained in liquid state enabling easy absorption by the roots of the farmed *B. rapa chinensis* resulting in faster growth and higher yields (Alamsjah 2014). Nutrients available in soils are in most cases inaccessible by the roots of *B. rapa chinensis* causing slower growth and lower yields as obtained in the present study.

Moreover, Chinese cabbage is affected by the variations in climatic conditions such as temperature (Kalisz & Cebula 2006). Higher yields of 99.32 tonnes ha^{-1} were produced from Chinese cabbage exposed to a lower temperature range of 11.60–12.90°C compared with 72.87 tonnes ha^{-1} produced at a relatively higher temperature range of 18.60–19.80°C (Kalisz & Siwek 2006). The present study was conducted in a tropical country where the temperature at the study site ranged between 25 and 32°C. These temperatures are higher than the optimum temperatures of 10–25°C given by McCormack (2005) for higher production of a cool season *B. rapa chinensis* (van Rensburg, Van Averbeke, Slabbert, Faber, Van Jaarsveld, Van Heerden, Wenhold & Oelofse 2007). The optimum temperature for maximal growth and development of *B. rapa chinensis* is just over 20°C and it is best grown between 12°C and well below 30°C (Thomas 2003; DAFF 2013). High temperatures above 27°C slow *B. rapa chinensis* development, increase the period of maturity and lower its yield (Thomas 2003).

The higher yields from fish–vegetable integration system obtained in the present study are corroborated by results reported by Shoko *et al.* (2011). Higher yields in integration system are due to the additive effect of the yields obtained from the various components of the integrated system. In the present study, the farming of integrated vegetables produced a gross annual yield 74.05 ± 16.55 tonnes ha^{-1} year^{-1} while fish culture produced 5.68 ± 0.85 tonnes ha^{-1} year^{-1}. Cumulatively, the two systems produced 79.73 ± 16.43 tonnes ha^{-1} year^{-1} greater than the culture of fishes alone and non-integrated vegetables.

The culture of fish–vegetables integration and the farming of integrated vegetables produced 14 and 13 times higher net annual yield, respectively, than the culture of fishes alone. Similar results were obtained by Dey *et al.* (2010) in Malawi where the yields from IAA farmers were more than 11% higher than non-IAA farmers. Logically, the integration system plays a central role in diversification of the outputs from an existing farming system resulting in overall higher farm yields (Pant *et al.* 2004). This is one of the major reasons for advocating IAA system.

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The present study further showed higher yields of integrated *B. rapa chinensis* compared with fish culture alone. The contributions of *B. rapa chinensis* farming to the integration yield ranged from 2–10 times more than the culture of fishes alone. The higher yields of integrated vegetables compared with fishes alone are due to the shorter production period of vegetables compared with fish culture (Idris *et al.* 2011). *B. rapa chinensis* has a high growth rate and it matures in a short period of time, specifically within 30–45 days after planting depending on environmental conditions (Palada & Crossman 1999). In the present study, *B. rapa chinensis* was grown only for 45 days compared with 270 days for the fishes. Thus, given the continuous supply of nutrients contained in pond water, when estimated on annual basis, there will be at least more than eight harvests of *B. rapa chinensis* in a year (365 days) compared with approximately one harvest of fishes based on the present study harvesting strategy. The higher yield of *B. rapa chinensis* suggests that it plays a significant role in contributing to the final yield in fish–vegetable integration as discussed above. Thus, small-scale farmers with access to the fishes and *B. rapa chinensis* can strategically improve significantly their farm yields by practising the IAA system.

Vegetables irrigated with pond water (integrated) resulted in 1.8 times higher net and annual yields than those irrigated with stream water (non-integrated). The growth rate of integrated vegetables was accelerated by nutrients levels obtained from the fish pond water as a result of uneaten feed, manure and fish through decomposition, fertilization and excrement respectively. Nutrient concentrations were generally higher in pond water than in stream water. Moreover, the higher levels of nutrients in fish ponds than vegetable plot soil obtained in the present study suggest the assimilation of nutrients contained in water from the ponds by the vegetables to increase their growth rate and subsequent higher net annual yields.

The present study revealed that the incomes above variable costs of fishes alone and integrated fish–vegetable were approximately 16 and 35 times more than farming of integrated and non-integrated *B. rapa chinensis* respectively. Furthermore, the culture of fishes alone and their integration with *B. rapa chinensis* represented an increase of more than 20 and 170 times net returns compared with the farming of integrated and non-integrated *B. rapa chinensis* respectively. A similar trend has been reported by Rupasinghe and Kennedy (2010) and Abdul-Rahman, Saoud, Owaied, Holail, Farajalla, Haidar and Ghanawi (2011). The higher economic benefits obtained in an integrated system are attributed to positive correlation between net return and culture system, higher annual net cash flow and gross profit margin. The net return in the present study increased from non-integrated and integrated vegetables farming towards integrated system. The increase in net return is related to its positive correlation with net yield.

Moreover, integrated system had the highest annual net cash flow of all the farming systems. In other words, integrated farming produced more money after paying all costs involved in production than the stand-alone farming of non-integrated vegetables, integrated vegetables and culture of fishes alone. Integrated system offers an attractive means to generate more money to small-scale farmers as opposed to stand-alone farming of vegetables and culture of fishes. The additional income generated can be used to sustain small-scale farmers' daily needs such as shelter, food clothing, medical care and pay for their children's school fees which could significantly reduce poverty.

Furthermore, the higher economic benefits of an integrated system are due to the higher gross profit margin it generated. The present study showed a higher gross profit margin for integrated and culture fishes alone than the farming of vegetables alone. Higher economic benefits have also been reported by Saiful Islam *et al.* (2015) in integrated rice–fish farming system. Gross profit margin indicates how much money a production system is making relative to its costs. It essentially measures the amount of each dollar of sales that a production has left over after it pays all the expenses involved. Based on the results, the 20% gross profit margin obtained for integrated system means that for every dollar of sales, integrated system produces 20 cents of profit. Accordingly, integrating fish with vegetables such as *B. rapa chinensis* produces better economic benefits than either of the farming systems practised independently.

The present study further showed that a much lower income was generated from the non-integrated and integrated farming of *B. rapa chinensis*. The lower economic contribution obtained for

B. rapa chinensis in the present study is due to lower market price compared with fish price. The price of *B. rapa chinensis* during the present study was USD 0.55 kg^{-1} compared with USD 3.62 kg^{-1} for fishes. The price of fishes was 6.5 times higher than that of *B. rapa chinensis*. Thus, although the yield of fishes was lower, it had a significantly higher economic contribution due to a difference in price. This concurred with the observation made by Karim *et al.* (2011) who noted that the economic contributions from vegetables is generally small. Despite its low economic contribution, the *B. rapa chinensis* component is nevertheless important when considering other performance aspects such as small-scale farmers' food. Thus, regardless of the lower contribution to the economic gain, the contribution of *B. rapa chinensis* to small-scale farmers' nutritional benefits is still important. Therefore, farmers should integrate their fishes with vegetables such as *B. rapa chinensis* to achieve food security and economic benefits.

Conclusion

The findings from this study indicate that the integration of fishes and *B. rapa chinensis* increases yield, net returns and annual net cash flows compared with stand-alone fish culture and *B. rapa chinensis* farming systems commonly practised by small-scale farmers. Consequently, the integration of fishes and *B. rapa chinensis* increases yields, provides additional income and food and generates employment for small-scale farmers. Thus, small-scale farmers should integrate fishes with *B. rapa chinensis* as a practical solution to meet the increasing demand for both fish and vegetables, stabilize their income and diversify food production, consequently improving their food security. Moreover, the integration of fish with other farming activities helps farmers to provide proper pond management for increased production. However, improper management skills still constrain its production in many developing countries including the current study area. Hence, the profitability of IAA must be geared towards providing sufficient management skills to small-scale farmers by providing knowledge through training as it was done in the present study.

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