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Assessment of pond and integrated aquaculture (IAA) systems in six districts of Tanzania

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Abstract

Integrated agriculture and aquaculture systems (IAA) are well known for their ability to improve the overall farm productivity and profitability. This is through recycling of on-farm resources, such as nutrient rich fish pond water and agriculture remains that would otherwise be considered as wastes. The present study explores the existing and potential IAA systems in Tanzania. It also examines management strategies and their influence on fish yield and the economic returns between IAA and non-IAA fish farming. The study assesses farmer's socio-demographic characteristics and their perception towards fish farming. The study was conducted through an on-site survey of 129 fish ponds owned by 89 farmers in six districts in Tanzania, involving 65 and 64 IAA and non-IAA ponds respectively. Results indicate that tilapia-vegetables is the most common type of IAA practiced by fish famers. Despite higher fish feed use and stocking density in non-IAA ponds, IAA ponds had an average fish yield of 2.46 t ha^{-1}, which was significantly ($p < 0.05$) higher than the fish yield of 1.54 t ha^{-1} found for non-IAA ponds. IAA ponds had also 1.6 and 2.9 times higher ($p < 0.05$) revenue and net profit, respectively, than non-IAA ponds. Additionally, the net return from IAA ponds in an integrated system was significantly ($p < 0.05$) higher than when practiced as stand-alone activities. IAA famers were more positive towards fish farming compared to non-IAA farmers. Thus, IAA systems should be promoted among small-scale farmers to cover for an increased fish demand and to improve food security.

Keywords: integrated fish farming, farm management practices, farm productivity and profitability, constraints, famers' perception

1 Introduction

Integration of agriculture and aquaculture (IAA) has been practiced for a long time in South East Asia, especially in China and Vietnam (Huong *et al*., 2018). This food production system promotes a reuse of by-products produced on-farm for improved overall farm productivity. In IAA, crops provide food for human, livestock and fish; livestock provide manure and nutrients for the fish ponds and crops; and pond water and sediments, rich in nutrients, are returned to the crops as fertiliser (Prein, 2002). Furthermore, the improved use of resources, such as farm remains as fish feeds and pond water for irrigating crops during the dry season, suggests that a diversification through IAA may be a good approach for improving farm productivity and hence access to nutritional food throughout the year (Dey *et al*., 2010).

Lack of inputs such as water, feed, capital and space for further development of aquaculture are critical constraints for a majority of small-scale farmers to produce enough food for their families. Dey & Ahmed (2005) identified four approaches to improve small scale aquaculture: (1) improved efficient use of the available inputs and technologies; (2) development and transfer of new technologies for farmers; (3) increased input use; and (4) increased area devoted to fish farming. Considering the first approach, promotion of IAA system holds a potential for increasing nutrition security by

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improving the availability of macro and micro nutrient rich fish and vegetables for farmers and non-farming consumers (Fisher, 2017). It is further argued that, in order to address the capital limitation that face a majority of small-scale farmers, research and development should focus on improving the profitability of small-scale aquaculture systems by considering both social and environmental aspects of the proposed technologies (Dey & Ahmed, 2005).

Tanzania is largely an agrarian economy, characterised by small-scale rural farming (URT, 2019). As of 2019 the country had a total population of about 58 million people, it is projected that by 2030 the population will be at about 78 million people (World Bank, 2020). About 70 % of the population live in rural areas and agriculture is their major livelihood strategy. About 29 % of the country's GDP comes from agriculture, employing over 77 % of the total work force (URT, 2017). Nevertheless, the agricultural sector continues to be a subsistence activity with low productivity leading to extended poverty among farmers (URT, 2017).

Similar to agriculture, aquaculture in Tanzania is still a low intensive activity dominated by small-scale fish farming with low productivity of less than 2.5 t ha^{-1} (Shoko *et al.*, 2011). The sector is faced by a number of constraints particularly lack of quality fingerlings and fish feed, lack of technological know-how, and lack of investment capital among others (Van der Heijden & Shoko, 2018; Mmanda *et al.*, 2020; Mulokozi *et al.*, 2020a). Integration of agriculture and aquaculture presents an opportunity to improve farm productivity for small-scale farmers, who are normally located in rural areas that are poorly linked to input and output markets (Mwaijande & Lugendo, 2015). Although, the impact of IAA technology on farm productivity has been assessed in Malawi (Dey *et al.*, 2010), Congo (Kinkela *et al.*, 2017) and Cameroon (Ewoukem *et al.*, 2017), in Tanzania there is lack of data on IAA systems and their impacts on farm productivity and economic benefits. This information is important to be able to identify how aquaculture in Tanzania could be further developed to strengthen economic growth, social justices and environmental sustainability. This paper, through field surveys and interviews with farmers, provides insights on the current status of fish pond and IAA farming in terms of management practices and their influence on yield, production and economic performance in six districts in Tanzania.

Therefore, this study aimed to: (1) assess socio-economic characteristics of households involved in IAA and non-IAA farming, (2) identify and analyse IAA and non- IAA management practices and their influence on fish production, (3) determine and compare production cost, gross return and net farm income of IAA and non-IAA fish farmers, and (4) assess major constraints and opportunities to further promote fish farming in Tanzania and, farmers' future plans regarding fish farming.

2 Materials and methods

2.1 Study area

A survey was conducted from April to July 2017 in six districts of Tanzania to assess management practices, yield and economic profitability of IAA and non-IAA pond fish farming. The districts surveyed were Kilombero, Igunga, Mvomero, Songea rural, Songea urban and Mbarali (Fig. 1). The study sites were selected based on: (i) the relative high number of fish farmers recorded in these districts by the Ministry of Livestock and Fisheries, and (ii) previous reports on aquaculture technology transfer efforts such as IAA trainings, fish fingerlings and feed dissemination.

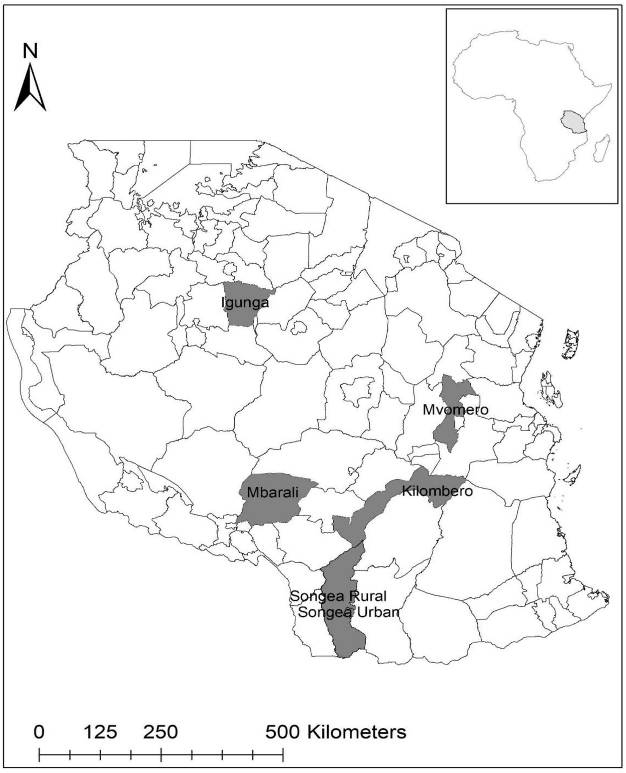

Fig. 1: *Map of Tanzania showing the sampled districts (Data source: Institute of Marine Sciences, UDSM GIS lab). The majority of the fish ponds are found in the Songea urban and Songea rural districts as fish farming was introduced to these districts a long time ago compared to the other districts.*

2.2 Research design and data collection

Fish pond farming was divided into two types; (i) ponds with adjacent cropping activities, mostly supplemented with agricultural remains and pond water used to irrigate the adjacent crops, herein after referred to as IAA ponds and, (ii) those without adjacent cropping activities, without or less frequently supplemented with agricultural by-products, herein after referred to as non-IAA ponds. Sampling was done based on a list of fish farmers obtained from district fisheries officers (DFOs) and field verification. Farmers with at least one fish pond in operation were selected depending on type of pond farming. Some farmers reported to have farm land away from the fish ponds where they normally cultivate cereal crops like maize, cassava and sorghum. These farms were not considered as part of IAA system because they were not in a direct interaction with the fish ponds. Few farmers integrated poultry and fish ponds, but due to difficulties in obtaining detailed information about the animals, which were kept in a free ranging mode, animal husbandry integrated with fish ponds was not included in the data analysis. In total, 129 fish ponds from 89 fish farmers were surveyed. The ponds included 65 IAA ponds and 64 non-IAA ponds.

The annual fish production was estimated through personal interviews. Farmers were asked about the production from their farms for the last one or two production cycles during 2014/2015 or 2015/2016 depending on the farmer's records and memory. Both the value of cash income obtained from fish sold and the portion consumed by the household were estimated and added to get the overall income from the fish pond. This information was then used in the fish pond financial performance analysis (Duc, 2009; Karim *et al.*, 2011). This was done through in-depth discussion with the head of the household in presence of other family members. Monetary values of the harvested fish and crops were estimated from the prevailing market prices in Tanzanian Shilling and converted to USD (USD 1 = TZS 2155.6).

The questionnaire consisted of six main sections: i. Fish farmer's demographics (age, gender, education level, and family size), ii. Fish pond characteristics and water use (pond size, pond depth, pond ownership, year of construction and water sources), iii. Fish pond management practices and production (species farmed, stocking density, feed types and feeding, pond fertilisation, integrated farming and yield), iv. Fish pond production costs and returns (pond construction, fingerling, water pumping, transport, feeds and fertiliser), v. adjacent cropping production costs and returns (equipment, fuel, seed costs, fertiliser manure, pesticides and harvest), and vi. Famers perception regarding major problems related to fish farming and their future plans on fish farming. Additional information was collected through key informant interviews and through field observation in order to cross-check and make triangulation of the information obtained through the questionnaires and interviews.

The profitability of IAA fish ponds, non-IAA fish ponds and integrated crops, were determined as follows:

$$NI = TR - TC$$

$$TR = PQ$$

$$BCR = TR/TC$$

Where:
NI = Net Income (USD); TR=Total Revenue (USD); TC= Total Cost (USD); P= Unit price of output (USD); Q= Total quantity of output (USD); BCR= Benefit Cost Ratio.

2.3 Data analysis

One-way analysis of variance (ANOVA) was used to compare the productivity and profitability between IAA and non-IAA farms. ANOVA was also used to compare the financial performance of fish and crop when grown separately and in integration. Correlation analysis was done to assess the influence of pond size, cultivation cycle, manure and feed quantity and stocking density on the fish pond productivity. Pond yield, costs and revenue data were transformed to log base ten, before the statistical analysis, as they did not follow normal distribution. Net income and the correlation was analysed using the Kruskal-Wallis test and the Spearman correlation respectively, as data did not comply with parametric assumption even after the transformation. Statistical analysis was performed using SPSS statistical software (Version 20). Results are presented as mean ± standard error (SE).

3 Results

3.1 Socio-demographic profile of fish farmers

About 93 % of fish farmers were males with only 7 % being females (Table 1). The majority (43 %) fell within the age group of 26–45 years. About 57 % of the fish farmers had only attended primary school education with an overall average of 9.4 years of schooling. About 66 % had a family size of equal or less than six (6) family members, while 27 % fell in a range of 7–9 members. About 65 % of the IAA farmers had attended some form of training regarding fish farming as opposed to only 38 % of the non-IAA farmers. Approximately half of the farmers had more than 5 years of fish farming experience and IAA farmers had longer experience (16 years) than non-IAA farmers (7 years). The reasons (Fig. 2) for not practicing IAA fish farming were mainly due to lack of knowledge and physical factors, such as unsuitable soils and weak pond dykes.

Table 1: *Distribution of gender, age, household size, education level and fish farming experience between IAA (N=43), non-IAA (N=37) and fish farmers having both systems (combined; N=9).*

Characteristic	*Description*	*IAA* %	*non-IAA* %	*Combined* %	*Overall* %
Gender	Male	95	97	100	93
	Female	5	3	0	7
Age (year)	<36	21	11	34	18
	36-45	16	35	22	25
	46-55	21	16	22	19
	56-65	26	22	0	21
	>65	16	16	22	17
House hold size	<7	70	71	34	67
	7-9	28	24	33	27
	10-12	2	0	22	3
	>12	0	5	11	3
Level of education (year spent in school)	0 year (never went to school)	2	5	0	3
	7 years (primary school)	51	57	89	57
	11years (OSE)	21	5)	0	12
	13 years (ASE)	0	5.	0	2
	12 years (basic certificate)	7	5	0	6
	14 years (ODE)	7	8	0	7
	16 years (bachelor degree)	9	8	0	8
	18 years (master's degree)	2	5	11	4
Fish farming experience	<5 years	26	74	22	45
	5-10 years	16	5	56	16
	11-15 years	12	5	22	10
	16-25 years	23	11	0	16
	> 26 years	23	5	0	13

OSE: Ordinary secondary education; ASE: Advanced secondary education; ODE: Ordinary diploma education. IAA: Integrated agriculture and aquaculture systems.

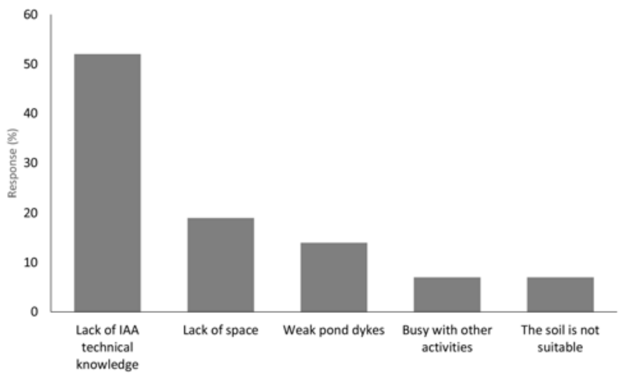

Fig. 2: *Farmers' reasons for not integrating fish pond with agricultural activities.*

3.2 Fishpond characteristics and water sources

The majority (40 %) of the fish ponds were constructed after 2010, and 25 % were constructed between 1985 to 1995, with non- IAA ponds being constructed more recently compared to IAA ponds (Table 2). The average pond size and depth were 388 m2 and 1.76 m, respectively, with no statistical difference ($p < 0.05$) between the farming systems. Almost all of the ponds (93 %) were under individual ownership. The main water sources were rivers (42 %), springs (34 %) and irrigation canals (16 %) (Fig. 3). Almost all (95 %) fish farms consisted of earthen ponds. About 54 % and 65 % of IAA and non-IAA ponds respectively were reported to suffer from some extent of water seepage (Table 2). There was no reported use of chemicals such as antibiotics, chemical fertiliser and hormones in the fish ponds.

3.3 Pond management practices and fish production

The majority of the ponds were stocked with fish sourced from local hatcheries, neighbours and restarting (Table 3). In restarting, the fish farming cycle started by removing all big fish from previous cycle and leave the small ones to grow to maturity. Almost all ponds (96 %) were fertilised once or several times in the cycle, with cow-dung being the most common type of manure used (Table 3). The most com-

Table 2: *Characteristics (size, depth, ownership, age and water seepage) of IAA and non-IAA fish ponds in the surveyed districts.*

Characteristic	*Description*	*IAA N=65*	*non-IAA N=64*	*Overall N=129*
Average Pond size (m^2)		398.5 ± 51.6	377.4 ± 73.4	388.0 ± 44.6
Average pond depth (m)		1.74 ± 0.1	1.78 ± 0.1	1.76 ± 0.1
Ownership*	Individual	91	94	92
	Multiple	9	5	7
	Leased	0	2	1
Pond type*	Earthen	97	94	95
	Concrete	3	6	5
Year of fish pond construction*	<1985	6	3	5
	1985-1995	20	11	16
	1996-2005	40	9	25
	2006-2010	9	20	15
	>2010	25	56	40
Pond water seepage*	Yes	54	65	60
	No	46	35	40

* Figures are percentages. IAA: Integrated agriculture and aquaculture systems.

Table 3: *Fish species farmed, pond fertilisation and fish feeding among IAA and non-IAA pond farming in surveyed districts.*

Characteristic	*Description*	*IAA N=65*	*non-IAA N=64*	*Overall N=129*
Species farmed	Tilapia	72	83	78
	Catfish	19	14	16
	Tilapia-catfish combination	9	3	6
Fish seed sources	Hatchery	43	40	42
	Wild	8	13	10
	Neighbours	32	30	31
	Restarting/ Regeneration	17	17	17
Common manure type	Goat manure	5	0	3
	Cow dung manure	71	80	76
	Pig manure	2	0	0
	Chicken manure	11	3	7
	Duck manure	5	3	4
	Combination of manure	6	8	7
	No-fertilisation	2	6	3
Common fish feed types	Brans only	17	27	22
	Brans+vegetables	45	25	35
	Brans+kitchen leftovers	2	16	9
	Vegetable+kitchen leftovers	9	0	5
	Bran+cow/goat skin	2	6	4
	Brans+kitchen leftovers+vegetable	17	2	9
	Homemade formulated diet	9	25	17
Feeding frequency	Once a day	25	9	17
	3 to 4 times per week	37	14	26
	Once a week	15	31	23
	Biweekly	12	13	12
	Once per month	8	10	9
	Occasionally	3	23	13

Figures are percentages. IAA: Integrated agriculture and aquaculture systems.

Table 4: *Fish species farmed, pond fertilisation and fish feeding among IAA and non-IAA pond farming in surveyed districts.*

Description	*IAA N=65*	*non-IAA N=64*	*Overall N=129*
Cultivation cycle (months)	9.12 ± 0.43	8.76 ± 0.30	8.88 ± 0.27
Stocking density (fish m^{-2})	3.9 ± 2.4	4.7 ± 1.4	4.3 ± 2.2
Farmers who could estimate (%)	74	78	76
Farmers who could not estimate (%)	26	22	24
Average feed (t ha^{-1} yr^{-1})	7.6 ± 1.1	9.0 ± 1.5	8.3 ± 0.9
Manure (t ha^{-1} yr^{-1})	2.1 ± 0.2	2.2 ± 0.3	2.2 ± 0.2
Farmers who could estimate (%)	86	94	90
Farmers who could not estimate (%)	24	6	10
Fish weight at harvest (g)	158.6 ± 3.6^{a}	112.1 ± 2.2^{b}	135.1 ± 3.0^{a}
Yield			
t $pond^{-1}$	0.098 ± 0.02^{a}	0.058 ± 0.01^{b}	0.078 ± 0.01^{ab}
t ha^{-1}	2.46 ± 0.29^{a}	1.54 ± 0.19^{b}	2.01 ± 0.18^{ab}
t ha^{-1} yr^{-1}	3.24 ± 0.34^{a}	2.11 ± 0.32^{b}	2.72 ± 0.24^{ab}

Numbers in the same rows with different superscript letters are significantly different ($p < 0.05$). IAA: Integrated agriculture and aquaculture systems.

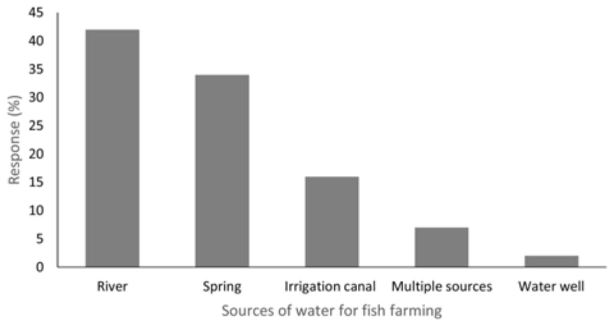

Fig. 3: *Sources of water for pond fish farming in the surveyed districts.*

Table 5: *The results from Spearman correlation analysis between different factors and fish yield (kg pond^{-1}) in IAA and non-AA pond farming.*

	ponds		
Parameter	*IAA*	*non-IAA*	*Overall*
Cycle length	0.16	0.25	0.15
(months)	($p = 0.20$)	($p = 0.28$)	($p = 0.03$)
pond size	0.57	0.79	0.62
(m^2)	($p < 0.01$)	($p < 0.01$)	($p < 0.01$)
Manure	0.32	0.04	0.28
(kg $pond^{-1}$)	($p < 0.01$)	($p = 0.66$)	($p < 0.01$)
Feed	0.11	0.18	0.13
(kg $pond^{-1}$)	($p = 0.40$)	($p = 0.17$)	($p < 0.01$)
Stocking density	-0.29	-0.36	-0.41
(fish ha^{-1})	($p = 0.055$)	($p = 0.01$)	($p = 0.01$)

The number represent the Spearman's correlation coefficient. $p < 0.05$ indicate a statistically significant correlation. IAA: Integrated agriculture and aquaculture systems

mon fish feeds used by all farmers included a combination of brans (both maize and rice) and vegetable scraps followed by brans alone (Table 3). On an average, farmers stocked their fish at a rate of 4.3 fish m^{-2}. A stocking density of 4.7 fish m^{-2} in the non-IAA ponds was 20 % higher than that of 3.9 fish m^{-2} in the IAA ponds (Table 4).

The feeding frequency ranged from once per day to once per week (Table 4). The majority (45 %) of the IAA ponds were fed with a combination of brans and vegetables scraps, which was only done in a minority (25 %) of the non-IAA ponds. The estimated feed quantity that was used included only the amount of dry feeds (maize or rice bran). This was because it was difficulty for farmers to estimate the quantity of vegetable scraps and kitchen wastes that was supplemented to the fish ponds. On an average (Table 5), the total amount of feed provided to the ponds was about 8.3 t ha^{-1} yr^{-1} and the amount of feed for the non-IAA ponds was about 20 % higher ($p > 0.05$) than that provided to the IAA ponds with no statistical differences. No farmer reported to use commercial feeds.

The fish yield from the IAA ponds was 2.46 t ha^{-1}, which was significantly ($p < 0.05$) higher than the yield of 1.54 t ha^{-1} from the non-IAA ponds. There was a positive, statistically significant correlation between fish yield with pond size, farming length, pond fertilisation and feed quantity (Table 5). There was a negative correlation between fish yield and fish stocking density.

Table 6: *Partial budget analysis per pond for IAA (N=65), non-IAA (N=64) and overall (N=129).*

	IAA ponds		*non-IAA ponds*		*Overall ponds*	
Expenditures	*USD*	*% TC*	*USD*	*% TC*	*USD*	*% TC*
Fixed costs	*17.1 ± 3.2*	*14*	*14.1 ± 2.4*	*12*	*15.6 ± 1.9*	*13*
Pond construction	13.5 ± 2.1	11	11.4 ± 1.3	9	12.4 ± 1.3	10
Equipment	3.6 ± 1.4	3	2.7 ± 1.5	2	3.1 ± 1.2	3
Variable costs	*111.5 ± 23.6*	*87*	*108.0 ± 18*	*88*	*109.8 ± 14.8*	*87*
Water pumping	1.9 ± 0.9	2	1.2 ± 0.5	1	1.6 ± 0.5	1
Transport	3.5 ± 0.7	3	2.9 ± 0.8	2	3.2 ± 0.5	2.6
Fish fingerlings	15.7 ± 2.8	13	18.3 ± 4.1	15	17.0 ± 3.2	14
Pond fertilisation	1.8 ± 0.3	1	2.4 ± 0.4	2	2.1 ± 0.3	2
Fish feed	70.4 ± 17.0	58	73.2 ± 14.2	60	71.6 ± 11.3	59
Labour*	18.6 ± 4.6	15	10.1 ± 2.2	8	14.4 ± 1.7	12
Total costs	*128.8 ± 26.1*		*122.1 ± 19.3*		*125.4 ± 16.2*	
Total revenue (USD)	*258.6 ± 37.5*^{a}		*166.9 ± 19.8*^{b}		*222.1 ± 21.6*^{ab}	
Harvest (kg pond^{-1})	98.3 ± 14.6^{a}		58.1 ± 8.2^{b}		78.4 ± 8.6^{ab}	
Price (USD kg^{-1})	2.63 ± 0.1		2.87 ± 0.1		2.83 ± 0.1	
Net income (USD)	*130.5 ± 44.1*^{a}		*44.8 ± 21.2*^{b}		*97.1 ± 24.98*^{ab}	
Benefit Cost Ratio	1.99 ± 0.23^{a}		1.37 ± 0.16^{b}		1.68 ± 0.31^{ab}	

Numbers in the same rows with different superscript letters are statistically significant different ($p < 0.05$);
IAA: Integrated agriculture and aquaculture systems; TC: total costs.
* Labour was valued based on prevailing wage rates. Farmers were asked to estimate how much they would charge for the same labour if they were hired in piecework (Dey *et al.*, 2010).

3.4 *Financial performance of IAA and non-IAA fish farming practices*

Costs, income and financial performance of the two fish farming systems are presented in Table 6. Among input variables, feed accounted for over 59 % of the total production costs followed by fish fingerlings (14 %) and labour (12 %). IAA ponds had 1.54 ($p = 0.03$) and 3.0 ($p = 0.04$) times higher total revenue and net income respectively than non-IAA ponds. Cost benefit analysis indicated that, IAA ponds had a significantly ($p = 0.01$) higher BCR than non-IAA ponds. About 27 % of the ponds were noted to generate a negative net income, where 19 % and 36 % of the IAA and non-IAA ponds had a negative net income, respectively.

3.5 *Crops integrated with fish pond farming*

The most common type of integrated agriculture and aquaculture was fish and vegetables, especially tilapia-Chinese cabbage integration. Second to this was tilapia-with a combination of different vegetables. Examples of IAA systems identified during the survey and are shown in Fig. 4.

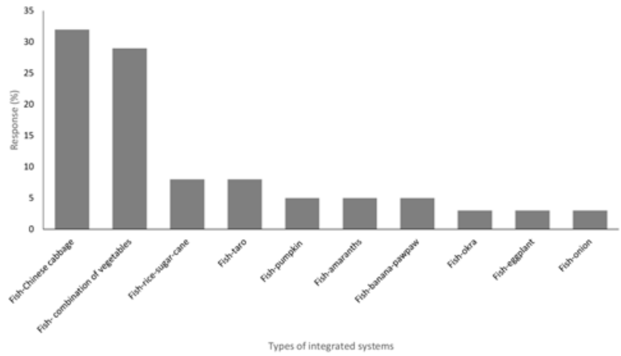

Fig. 4: *Common types of fish pond-crop integration in surveyed districts.*

3.6 *Farmers perception of problems and future plans in relation to fish farming*

Water related problems were perceived to be the biggest challenge by a majority of both IAA and non-IAA farmers (Table 7). However, the problem was less frequently mentioned by IAA farmers as compared with non-IAA farmers. Other fish farming challenges were perceived differently by the two types of farmers. Lack of capital and good quality fish fingerlings were the second and third most common challenges among IAA farmers as opposed to poaching and lack of good quality feeds among non-IAA farmers. A majority of both IAA and non-IAA farmers expressed their willingness to continue with fish farming, at least at the current scale (Figure 5). A higher percentage of IAA farmers considered to expand their fish farming production compared to non-IAA farmers. Only less than 10 % of the farmers wanted to quit, while less than 20 % had not decided whether to continue or not (Fig. 5).

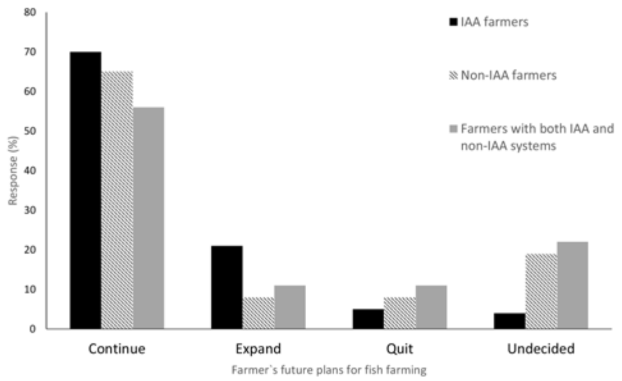

Fig. 5: *Future plan regarding fish farming by IAA farmers, non-IAA farmers and farmers practicing both IAA and non-IAA farming.*

Table 7: *The biggest problems in fish farming as perceived by IAA (N=43), non-IAA (N=37) and combined farmers (N=9).*

	fish farming system		
Problem	*IAA*	*non-IAA*	*combined*
Water related problems	23	35	22
Lack of capital	16	3	22
Lack of quality fish fingerlings	14	3	11
Stunted growth of fish	9	5	0
Weak pond wall and water seepage	9	8	0
Poaching	9	18	44
Lack of good quality fish feeds	5	14	0
Pests (monitor lizards and otter)	5	14	0
Lack of labour	5	0	0
Lack of space to add more ponds	5	0	0

4 Discussion

In this study, almost all (93 %) ponds were owned by men. This is in line with cultural settings in many aspects in Tanzania where traditionally assets are under men ownership. The few women owning fish ponds were mainly widows, divorced or unmarried. This corresponds well with findings by Mmanda *et al*. (2020) who reported that majority of ponds (83 %) in 8 regions of Tanzania were under men ownership. However, this does not mean that women do not contribute to fish farming in Tanzania. It was reported in the study area that women had great contribution to fish farming practices such as fish feed preparation and feeding, harvesting and selling to neighbours and local markets (Mulokozi *et al*., 2020a).

The majority (61 %) of the respondents were between 26 and 55 years old with a primary school education, which is in agreement by Mwaijanande & Lugendo (2015). This indicates that there is enough work force but with low formal education level. Furthermore, the majority (45 %) of the pond owners had less than 5 years of experience in fish farming, which can be a reason for the fairly low fish yield. However, this implies that there is an opportunity to improve aquaculture production as experience increases with time, considering that the majority of famers were within the working age class and also motivated to continue with fish farming (Mulokozi *et al*., 2020a). When farmers were split into farming types, IAA farmers had longer fish farming experience and the majority of them had been trained in fish farming. This could be an important factor for the adoption rate of IAA technology, which requires a relatively high knowledge to manage both fish and crops, reflecting reasons for not practicing IAA farming among non-IAA farmers.

The overall average pond size in this study (388 m^2) was within ranges reported of 150–300 m^2 by Kaliba *et al*. (2006) and of 200–400 m^2 as reported by Mwaijande & Luegndo (2015). A majority of the fish ponds (95 %) were earthen with limited water exchange. Water was only changed in ponds that did not experience water seepage. For those with water seepage, water was added regularly to maintain an appropriate water depth. A majority of the ponds were under individual ownership, a mode which is reported to work better than when ponds are under group ownership. In group fishpond ownership, a passive kind of management, misunderstandings between group members and consecutive pond abandonments have been reported in some areas (Wetengere & Kihongo, 2011).

Pond fertilisation using manure is highly recommended in subsistence and small-scale fish farming mainly due to lack of sufficient feeds (Green *et al*., 2002) . In the present study, 97 % of the surveyed ponds were once or several times fertilised, where cow dung manure was most commonly used. Similar findings were reported in the Mbarali district by Chenyambuga *et al*. (2014), who reported that 89 % of fish ponds were fertilised by cow dung manure. The predominance use of cow dong manure was due to the high availability in the community compared to other types of manure.

The higher fish yield observed in the IAA ponds can be linked to feeding regimes. The fish in the IAA ponds were fed with small quantities of feed but more frequently, as opposed to the non-IAA ponds, which received higher feed quantities but less frequently. This can be related to the fact that IAA farmers spend more time attending their fish than non-IAA farmers. The higher fish yield in IAA ponds concur with the results by Wu *et al.* (2015) who reported improved juvenile golden pompano growth and feed utilisation as feeding frequency increased.

The IAA ponds had higher fish yield than non-IAA pond farming despite the fact that fish in non-IAA were fed more feed than the IAA fish. IAA ponds were also stocked with lower number of fingerlings compared to the non-IAA ponds. This suggests that the difference in yield would have been even higher if the two farming systems would have been stocked with the same number of fish, unless the stocking rate itself had a negative effect on the yield, which was indicated by the correlation analysis.

The higher fish yield from IAA ponds could also be associated to the supplemental effect of adding vegetables remains to the ponds (Poot-López et *et al.*, 2009; Mulokozi *et al.*, 2020b). This is because fish in IAA ponds were mainly fed with a combination of maize bran and vegetable remains as opposed to dominance of only maize bran in the non-IAA ponds. Fish are being recognised to be highly efficient in converting organic matter to protein (Hall, 2011). On the other hand, vegetables are known to be rich in protein, vitamin and minerals (Butnariu & Butu, 2014). A combination of these factors could improve the fish growth and thus result in a higher fish yield in the IAA ponds than in the non-IAA ponds. These findings agree with those by Dey *et al.* (2010) in Malawi, who reported a 11 % higher fish yield from IAA farms than non-IAA farms. This improved fish yield is an important argument for supporting further development of IAA systems among farmers in Tanzania. Although the fish yield is still quite small, it can provide very important nutritional input to rural farmers and even if few fish is sold for cash, either due to lack of access to wealthier markets or out of a need to meet more local food security priorities, it generates a small, but important amount of cash for emergencies, school fees, etc. (Brummett *et al.*, 2008; Mulokozi *et al.*, 2020a).

The higher yield from the IAA ponds could also be due to the fact IAA ponds were observed to be managed more actively as opposite to a more passive management of non-IAA ponds. For example, it was noted during the field work that IAA ponds were visited more frequently than non-IAA ponds because when farmers attended the vegetables close to the ponds, they also attended the ponds (feeding, cleaning and security aspects). Thus, IAA ponds were often relatively well managed, with less weed infestation than non-IAA ponds. Furthermore, fish loss due to poaching by human and wild animals such as otters and monitor lizards, which were seen as one of the most critical problems, were more prevalent in non-IAA ponds than in IAA ponds, probably because they were attended less frequently.

Good technical skills and knowledge is an important factor for increased productivity and profitability in any food production system. The fact that IAA farmers had more experience in fish farming and the majority of them had attended fish farming trainings, could also be a reason for higher fish yield from IAA ponds compared to non-IAA ponds. Our observation indicates that, in addition to a more efficient recycling of organic matter and nutrients, all these factors are linked to IAA management practices and jointly contributed to an increased fish yield and improved income for the IAA farmers. To attain an average fish weight at harvest of 158 and 112 g for IAA and non-IAA farmers respectively, required a production cycle that ranged from 5 to 12 months with an average of 9 months per cycle. These weights are low when compared to those (> 200 g) recommended by extension officers for commercial purposes, but enough for household consumption, serving as a good source of protein, nutrient and vitamin. For example, Fiedler *et al.* (2016) reported that, despite a small size, fish had a potential to increase the average daily vitamin A intake by 7 µg retinol activity equivalent (RAE) and save 3000 lives of small-scale Bangladeshi farmers in 11 years' project duration. Thus, improved fish yields in IAA can contribute to a small but important increased food security among subsistence farmers.

Despite higher yield in the IAA ponds than non-IAA ponds, the overall yields of 2.0 t ha^{-1} in the present study was lower than that of 4.2 t ha^{-1} reported by Limbu *et al.* (2017) in a more controlled semi-intensive on-farm experiment in Tanzania. These differences could be related to the fact that a majority of the fish ponds in the present study were stocked with mixed sex tilapia as opposed to tilapia – catfish poly-culture used in the former study. In tilapia-catfish poly-culture, catfish prey on new-born tilapia which control pond overcrowding from tilapia prolific breeding and thus improve the fish growth and yield.

There was a statistically significant positive correlation between culture period, quantity of manure, feed quantity and the fish harvest, indicating that the longer the farming cycle the higher the yield, the more optimal the feeds and manure input the bigger the fish and subsequently a higher fish yield. Surprisingly, a negative correlation existed between fish yield and fish stocking density both for IAA and non-IAA ponds. This could be related to the relatively high stocking density of 3.9 and 4.7 fish m^2 observed in this study, as opposed to 2 to 3 fish m^2 for mixed sex tilapia pond culture recommended by the extension officers. Overcrowding of fish in a pond can lead to physiological stress which can lead to poor growth and yield. For example, Diana *et al.* (1996) reported a negative fish growth-stocking correlation when tilapia stocking increased from 3 fish m^2 to 6 fish m^2 and finally to 9 fish m^2.

Vegetables, especially Chinese cabbage (*Brassica* spp.) and amaranth (*Amaranth* spp.) were the main crops integrated with ponds. Similar findings were reported by Chenyambuga *et al.* (2014) in Tanzania, when evaluating the management and value chain of tilapia farming in ponds of small-scale farmers in the Morogoro region. This could be due to the fact that compared to other types of crops, vegetables require relatively short cultivation cycles and have high marketability (Schreinemachers *et al.*, 2018). In addition, cultivation of these vegetables is sustained by the fish pond water during water scarce periods, which ensures continued availability of immediate cash and vitamin for the household. This diversification of livelihoods is another important argument for IAA farming, where either crops or fish could provide food and cash even if one would fail. The fish pond water also secure nutrient rich water for crops over the year, and overall the combination of fish and crops in IAA can help to make farmers more resilient towards future environmental changes including climate change. Brummett & Chikafumbwa (1995) reported that IAA practices improved the ecological sustainability and economic durability of small farms in Malawi, and that this helped to sustain the farms during serious droughts. By retaining water on the land, ponds enabled farmers to continue to produce food and balance economic losses on seasonal cropland, and IAA farmers got 18 % higher net income than non-IAA farmers under a 60 % reduced precipitation.

It is revealed in the present study that IAA ponds had 50 % and 200 % higher revenue and net income respectively than non-IAA ponds. The higher economic befits from IAA ponds compared to non- IAA ponds is due to the reduced cost for feed, which is made possible through an increased recycling of vegetable by-products. This improves the fish yield without any additional costs, which in turn increases the pond revenue.

Fish feed is the largest portion (58 %) of the input costs. This could be associated to the competing demand for maize and rice brans (the main feed inputs found in this study) from sectors such as poultry and pig husbandry (Mbwambo *et al.*, 2016). Considering the risks for future competition for fish feeds, IAA practices provide an advantage compared to non-IAA practices as it not only reduces the costs for fish feed but also reduces the dependence on commercial fish feeds and thus the reliance on external markets. For example, it was reported by Limbu (2019) that the use of on-farm food resources reduced the feed costs by 36 % compared to using commercial feeds.

Overall, the integration of fish and crops resulted in a significantly higher net income than when not integrated. This is because the IAA system builds on a more efficient production through an increased recycling of nutrients and organic matter between fish and crops (irrigation of nutrient rich water from the fish pond to the vegetables and the use of vegetable waste to feed the fish). As indicated above this is further stimulated by an improved management as the fish and crops are located close to each other and are more easily attended. Overall this helps to decrease the production cost and improve the yields, which results in a higher net income. This is also reflected in the relatively lower number of the IAA ponds running with net negative income compared to non-IAA ponds.

Fish farming heavily depend on water availability, and water related problem was one the major concerns mentioned by farmers. In some areas of Mbarali, Igunga, and Songea urban districts, water was not enough to complete the whole farming cycle, especially during dry seasons. This was connected to; (i) anthropogenic activities such as destruction of water sources through deforestation and (ii) climate change impacts, such as uncertain rainfalls and increased temperatures, which negatively affect fish production in shallow water fish ponds. This forced some of the farmers to have shorter farming cycles, which were not enough to obtain sufficient sized fish thus negatively affecting the fish productivity and profitability.

Despite these challenges, fish famers had a positive attitude towards fish farming. The attitude was even more positive among IAA famers compared to non-IAA farmers. This was also reflected in the fact that over 38 % of IAA farmers wanted to expand their fish farming activities compared to only 8 % of non-IAA farmers. The stronger positive attitude among IAA farmers could be attributed to higher farm productivity and profitability due to integrating fish farming with agriculture as demonstrated in the present and previous studies. For example, Dey *et al.* (2010) in Malawi, found that IAA farmers obtained 11 % and 134 % higher farm productivity and farm income per hectare, respectively, than non-IAA farmers. Similar findings were reported in Tanzania by Limbu *et al.* (2017) and Shoko *et al.* (2019).

5 Conclusion

Aquaculture production in Tanzania has increased in recent years, corresponding to an increased demand for fish and stagnant catches from capture fisheries. Since the human population will keep increasing, the demand for fish is expected to increase further, and aquaculture could help to meet this demand, but it needs to be further promoted and developed. Considering that agriculture is already a popular practice, the integration of agriculture and aquaculture (IAA) could be a good entry point to increase adoption rates of aquaculture technology in Tanzania. In addition to increase the number of fish farmers, IAA technology can increase the production of both fish and crops due to increased resources use efficiency. The present study indicates how fish ponds are integrated with agricultural activities and the implication of such integration on farm productivity and economic benefits in selected districts of Tanzania. Although IAA systems have relatively lower productivity and profitability than more intensified commercial aquaculture systems, IAA systems have very low or even positive environmental impact and have often a positive social impact through enhanced food security, water availability and poverty alleviation. IAA provides small scale famers an opportunity for livelihood diversification and water security for irrigation, and can help farmers to become more resilient to environmental change, including climate change. The low scale of production and comparatively low production costs make these systems less dependent on well-established fish markets and infrastructure, and they provide a design that can operate in more remote areas. We therefore conclude that these systems should be strongly promoted and continue to be an important part of Tanzania's future aquaculture portfolio.

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Conflict of interest

The authors state they have no conflict of interest.

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