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Comparison of rice production in an integrated rice-fish system using tilapia (*Oreochromis niloticus*) and common carp (*Cyprinus carpio*)

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Abstract

Rice and fish are globally essential staple foods. Given the common challenge of land scarcity faced by both fish farming and agriculture, integrating these practices can provide a viable solution. This study evaluated the integration of rice (*Oryza sativa* AT362) with tilapia (*Oreochromis niloticus*, T) and common carp (*Cyprinus carpio*, C) through four treatments: T, C, T+C (1:1 ratio) and a control (no fish), each treatment with three replicates. The stocking density was 3.75 individuals m^{-2}. Tilapia integration significantly increased the number of leaves, panicles and tillers, resulting in a high yield of 6.7 t ha^{-1} (approximately 1.6 times higher than that of control). In contrast, carp integration showed no significant improvements in these parameters. Rice growth was positively correlated with root area diameter, primarily influenced by tilapia activity. Tilapia demonstrated better growth performance compared to carp, with average survival rates of 74 and 64%, respectively. These findings highlight the potential of rice-fish integration in Sri Lanka, particularly the effectiveness of combining *O. sativa* (AT362) with *O. niloticus*.

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Introduction

There is a growing challenge to global food security in parallel with population increase. This challenge is further exacerbated by a combination of factors, including soil system degradation, climate change, industrial expansions and dietary shifts (Godfray *et al.*, 2010; Pretty *et al.*, 2010; Mishra *et al.*, 2013, 2021). As a result, the intensification of the food production system is practiced despite its inherent environmental issues. Certain environmental issues have been addressed through the diversification of agricultural systems without compromising production (Bunting *et al.*, 2017; Tamburini *et al.*, 2020). Further, organic farming is promoted among the general public due to the related environmental and health concerns arising due to the extensive use of agrochemicals such as fertilisers and pesticides in agriculture practices (Hazra *et al.*, 2018). Moreover, organic raw materials promote better root growth and soil fertility, leading to better crop production under fewer inputs (Adhikari *et al.*, 2018). Therefore, environmentally sound crop production techniques have paramount validity at present.

The global demand for fish as an animal protein source is still increasing despite the limited natural supply. Aquaculture production has the potential to fill this demand gap (FAO, 2020). However, agriculture and land-based aquaculture practices face a critical challenge of limited availability of land resources due to rapid urbanisation. Thus, integrating conventional agriculture systems with aquaculture would maximise resource utilisation, ensuring food security during this global population increase (Ahmed *et al.*, 2022). Hence, one of the potential ways to address the issues of food productivity, environmental sustainability and socioeconomic benefits is to combine aquaculture (the Blue Revolution) with agriculture (the Green Revolution) (Ahmed and Turchini, 2021; Sathoria and Roy, 2022).

Rice and fish play essential role in the food security and livelihood of rural communities, particularly in the Asian region (Bharucha and Pretty, 2010; Weimin, 2010; Dey *et al.* 2019). Rice fields are rich in biodiversity and are biologically productive manmade aquatic ecosystems (Fernando, 1993; Bambaradeniya *et al.,* 2004). This makes rice fields one of the potential sites for inland aquaculture, a practice widely adopted in many Asian countries, including Vietnam, Thailand, Laos, Cambodia and the Philippines (Mak, 2001; Berg, 2002; Mohanty *et al.*, 2004; Frei and Becker, 2005; Bosma *et al.*, 2012). In Sri Lanka, inland aquaculture (culture-based fisheries) plays a vital role in maintaining the health and wealth of rural communities by providing cheap animal protein sources and income (MOF, 2020). Rice-fish integration is one of the oldest integration techniques that benefit the production of rice and fine-quality aquatic products conforming to food safety standards (Lu and Li, 2006; De Silva and Davy, 2010; Ahmed *et al.*, 2021, Yuan *et al.*, 2022).

Rice-fish integration is a synergistic system. For instance, fish secretion and metabolic ammonia are nutrients to paddy, while fish consume some aquatic invertebrates, such as worms and larval stages of insects, and act as biocontrol agents (Kathiresan, 2007; Yuan *et al.*, 2022). The additional fish yield allows farmers to earn extra income while fulfilling their animal protein requirement (Berg, 2002; Berg and Tam 2012). Although rice-fish integration is a common farming practice in many Asian countries (Frei and Becker, 2005), it is not practiced in Sri Lanka. Thus, information on its potential applicability in the Sri Lankan context is largely unknown. The present study was designed to fill this information gap by investigating the effects of paddy and fish integration on rice production and selecting the most suitable fish species for rice-fish integration using rice *O. sativa* (AT 362), tilapia (*O. niloticus)* and carp (*C. carpio)*.

Materials and methods

Experimental plants and fish

Oryza sativa (AT 362) was selected owing of its suitability in saline environments (Pradheeban *et al.*, 2014) as the study area has slightly saline soil. Both Nile tilapia and common carp are commonly cultured inland freshwater species in Sri Lankan reservoirs.

Experimental design

To select the best integration option for rice and fish species, four treatments *viz.,* (i). Paddy + Tilapia (T), (ii). Paddy + Carp (C), (iii). Paddy + [Carp and Tilapia, (C+P; 1:1 ratio)], and (iv). Control (only paddy) were tested. Each treatment with three replicates was randomly allocated into twelve (4×3) experimental plots (4×4 m^2) in a complete randomised design (Fig. 1).

A paddy nursery was separately prepared using parachute nursery trays, into which *O. sativa* (AT 362) was introduced. Germinated seeds were allowed to grow in nursery trays for ten days and ten-day-old rice seedlings were transplanted into the experimental blocks. In each plot, 144 (12×12) rice plants (one seedling per hill) were planted, keeping a 25 cm distance between plants.

Advanced fingerlings of tilapia (*O. niloticus*, initial weight, ~6 g) and common carp (*C. carpio*, initial weight ~4 g) were obtained from the fish breeding centre of the National Aquaculture Development Authority, Udawalawe, Sri Lanka. They were acclimatised for two weeks before introducing to the experimental plots using cement tanks located near the testing site. During this acclimatisation period, fish were fed three times per day using a commercial diet

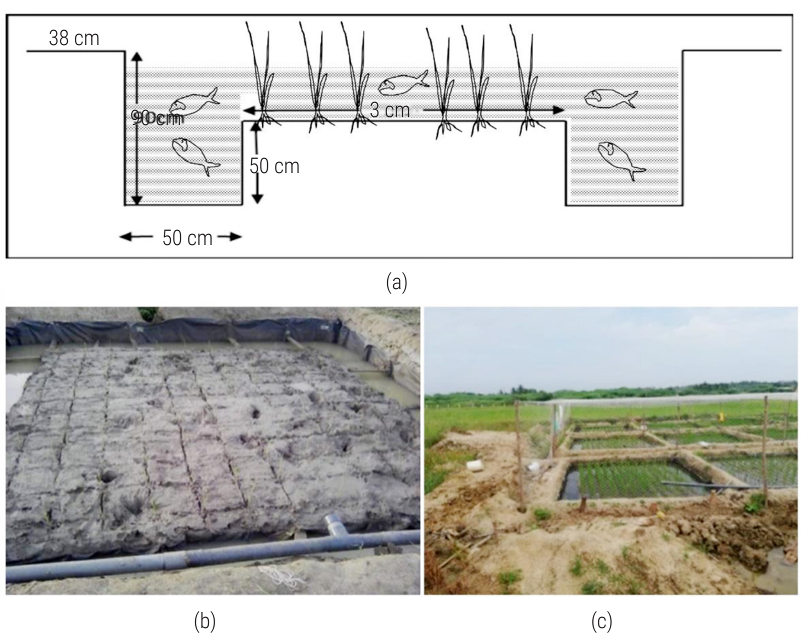


Fig. 1. Experimental research set-up. (a) Diagrammatic representation of the cross-section of a plot; (b) Experimental plot before planting paddy; (c) Completed experimental set-up after one week

to near satiety. After acclimatising, 60 advanced fingerlings were stocked per plot @ 3.75 m^{-2}). Thirty individuals of each species were added for the mixed culture treatment (T+C).

Initial bulk weights of fish (g) were measured for each fish species separately using a top-loading balance; thereafter the measurements were taken fortnightly by sampling ten fish randomly. Fish were fed two times every day using a commercial fish feed to near satiety. The water level was reduced at the end of the experiment, and all fish were caught. They were counted separately to estimate survival, and the individual weight was measured. The experimental duration was 84 days (until the paddy was ready for harvest).

The specific growth rate (SGR) of fish was calculated using the equation:

$$\%SGR = \frac{(\ln W_{t2} - \ln W_{t1})}{(t_2 - t_1)} \times 100$$

where W_{t2} is the final weight of fish, W_{t1} is the initial weight of fish, $(t_2 - t_1)$ is the time gap.

During the experimental period, parameters such as plant height, scrub collar width, number of leaves and number of tillers were measured in the paddy plants, while the number of panicles and total rice yield were measured at the end of the experiment following standard sampling techniques (Gomez, 1972; Mirhaj *et al.*, 2013).

Water quality parameters, including nutrients (NO_3^- and PO_4^{3-}), pH and electrical conductivity (EC) were measured at two-week intervals. Nitrate levels were detected using a water quality meter (HI9829-Hanna Instruments, Romania), while the PO_4^{3-} content was detected following the standard ammonium molybdate method (APHA, 1999). EC and pH were detected using a pH meter (EUTEC/Cyberscan PC300).

Statistical analysis

Data were tested for normality before beginning statistical analysis. Data was presented as mean±SEM, while results were statistically compared using a one-way analysis of variance (One-way ANOVA) followed by Duncan's *post-hoc* test to evaluate the mean difference at the significance level of $p \leq 0.05$.. Pearson's correlation analysis was employed to detect the relationship between growth performances. Percentage survival data were arcsine transformed and all statistical analyses were conducted using IBMSPSS (version 25), while graphical illustrations were prepared using MS Excel.

Results

Plant growth and rice production

At the end of the experiment, rice plants exhibited a sigmoid growth pattern in all treatments. The average height of rice plants at the end of the experiment was approximately one meter. There was no significant difference ($F=1.485$, $p>0.05$) in plant height among the different treatments (Fig. 2a). The number of leaves per plant was significantly higher in paddy cultivated with *O. niloticus* than that of the other three treatments ($F=4.56$, $p<0.05$) (Fig. 2b). Plant growth as indicated by the increased number of tillers was augmented by the integration of *O. niloticus* than *C. carpio*.

No significant variation could be detected in the number of tillers until 42 days (Fig. 2c). This number exhibited a slight variation after 42 days. Plants grown with *O. niloticus* produced the highest number of tillers, followed by (T+C), carp (C) and control treatment, respectively ($F= 4.76$, $p<0.05$), allowing fish to move freely throughout the experimental plots. There was no significant difference in the collar width of plants ($F=0.74$, $p>0.05$) (Fig. 2d).

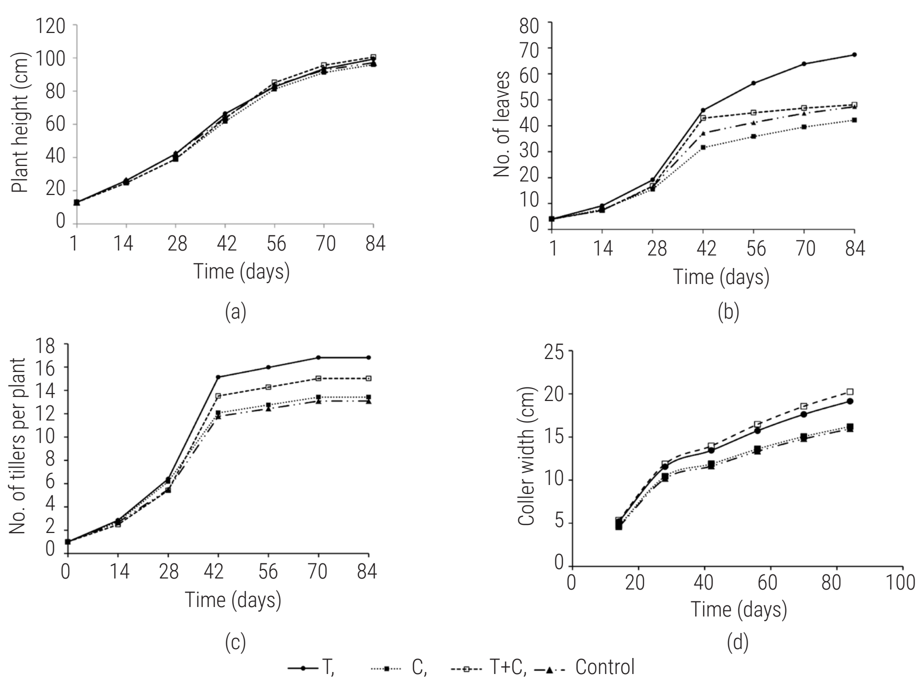


Fig. 2. Growth performance of paddy plants (a) Plant height; (b) Number of leaves; (c) Number of tillers; (d) Collar width

Visual observations revealed that *O. niloticus* was actively moving throughout the experimental plot, which was rarely observed in *C. carpio*. Most of the time, *C. carpio* stayed inside the canal. The integration of *O. niloticus* benefited plant growth (Fig. 3).

The number of panicles per plant differed significantly among treatments ($F=5.198$, $p<0.05$). Significantly ($p<0.05$) higher number of panicles per plant occurred in *O. niloticus* treatment followed by mix (T+C), carp (C) and control, respectively, where the latter two were statistically similar (Fig. 4a).

The trend observed for the panicle number was further supported by the total yield, where the rice production of *O. niloticus* treatment was approximately 1.6 times higher than that of the control (Fig. 4b).

The root area diameter of the plants in rice-fish integration is significantly higher ($F=116.5$, $p<0.001$) than that of the control group. The highest diameter was observed in plots integrated with either tilapia alone or mixed with carp, followed by carp alone (Fig. 4c). The root area diameter significantly impacts the growth and yield of *O. sativa* (AT 362) since all tested correlations were statistically significant (Table 1).

Fish growth and survival

Both *O. niloticus* and *C. carpio* were still in their exponential stage of the growth cycle (Fig. 5a). However, at the end of the experiment,

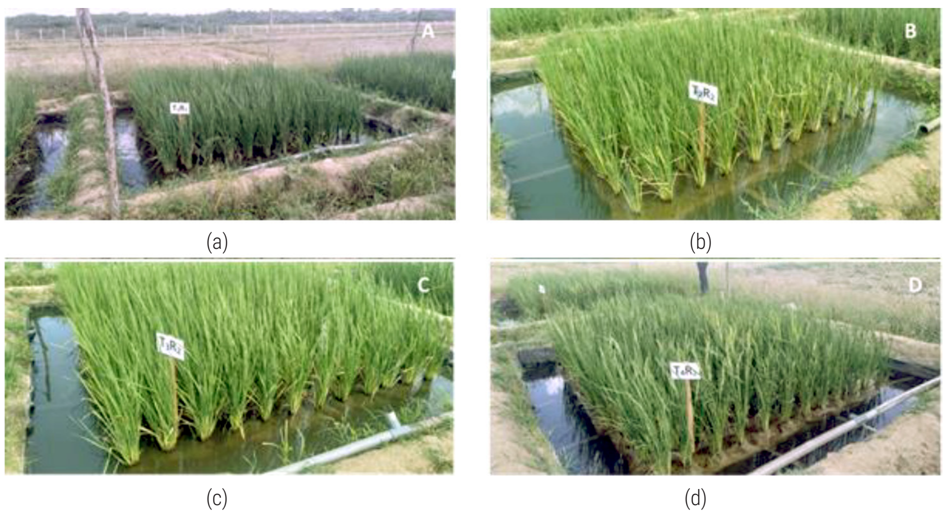


Fig. 3. Experimental plots. (a) Tilapia; (b) Carp; (c) Tilapia + Carp; (d) Control

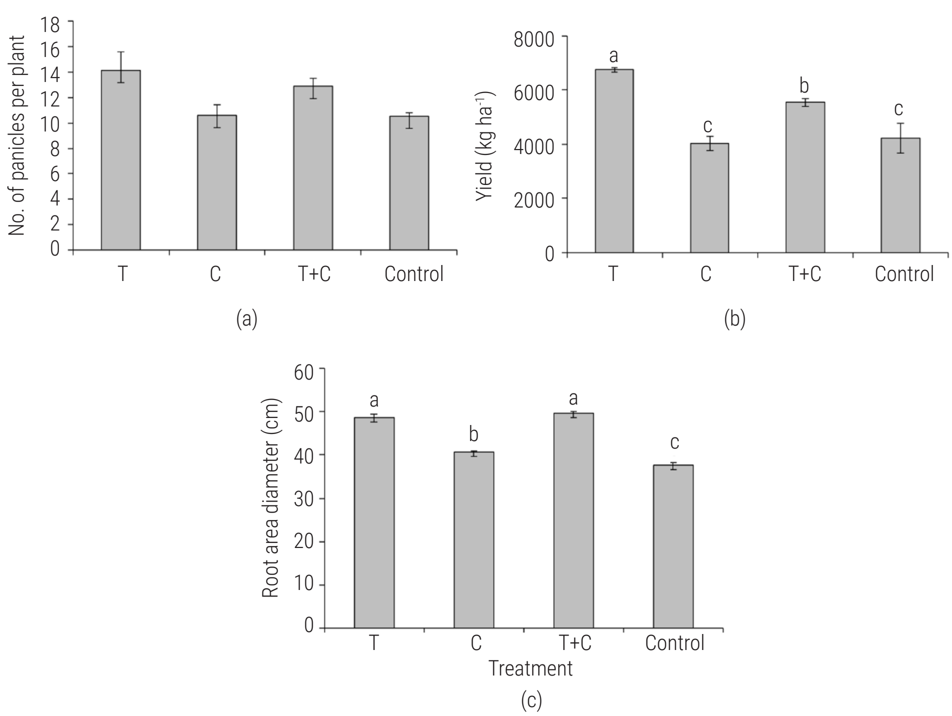


Fig. 4. Number of panicles (a), yield (b), and root area diameter (c). Different letters above the columns indicate a significant difference at p≤0.05

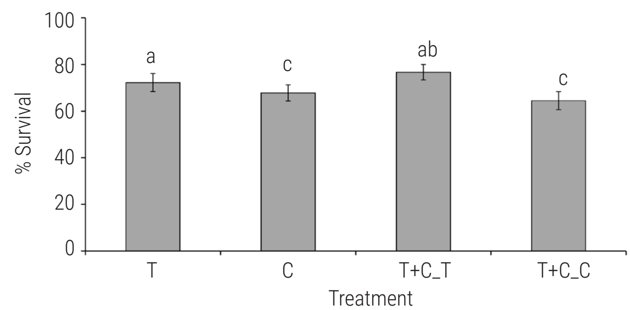
Table 1. Correlation matrix for root area diameter, growth and growth performances of rice

		Root Area diameter	No. of tillers	No. of panicles	Yield	Total biomass
Root area diameter	r	1	.618*	.693*	.778**	.756**
	p		.032	.012	.003	.004
Number of tillers	r		1	.639*	.766**	.815**
	p			.025	.004	.001
Number of panicles	r			1	.708*	.741**
	p				.010	.006
Yield	r				1	.929**
	p					.000
Total biomass	r					1

r = Pearson correlation* and ** indicate the correlation is significant at $p\leq0.05$ and $p\leq0.01$ respectively (2-tailed)

the weight of *O. niloticus* was significantly higher than that of *C. carpio* (F= 895.7, p<0.05). The average final weights of *O. niloticus* grown in T and T+C treatments were 111.3±3.8 g and 109.6±3.1 g, respectively, while the average final weights of *C. carpio* in C and T+C treatments were 33.9±2.2 g and 24.4±0.80 g, respectively. The lowest weight was detected in carp cultured in the mixed treatment of T+C (Fig. 5a).

The lowest specific growth rate occurred in *C. carpio* reared in the mixed treatment (T+C), where the %SGR values of the other three treatments were statistically higher (F=11.75, p<0.05) (Fig. 5B). The highest fish survival rate was noted in *O. niloticus* and the survival rates of the Nile tilapia reared in mix treatment (T+C) and tilapia treatment (T) had a similar survival rate. *C. carpio* presented a significantly lower survival rate than *O. niloticus* (Fig. 6).



T: Tilapia, C: Carp, T+C_T: Tilapia in the mix treatment, T+C_C: Carp in the mix treatment

Fig. 6. Survival rate of fish. Different letters above the columns indicate significant difference at p≤0.05

Water quality

The water quality parameters were suitable for fish growth, where the nitrate and phosphate concentrations were not toxic for fish, while the pH was in the range of 7.54 - 8.05 (Table 2).

Table 2. Minimum to maximum ranges of water quality parameters during the experimental period

Parameter	Treatment			
	T	C	T+C	Control
NO_3 (ppm)	1.10-1.50	1.40-1.70	1.20-1.60	1.30 -1.40
PO_4^{3-} (ppm)	0.04-0.07	0.01-0.03	0.02-0.05	0.01-0.02
pH	7.76-8.00	7.54-7.94	7.72-8.05	7.92-7.95
EC (µS)	1598-1723	1635-1718	1674-1719	1494-1670

Discussion

Paddy fields are considered wetlands due to the presence of hydric soil and are inundated for a certain period. As rice fields consist of waterlogged hydric soil, there is a high possibility of anaerobic

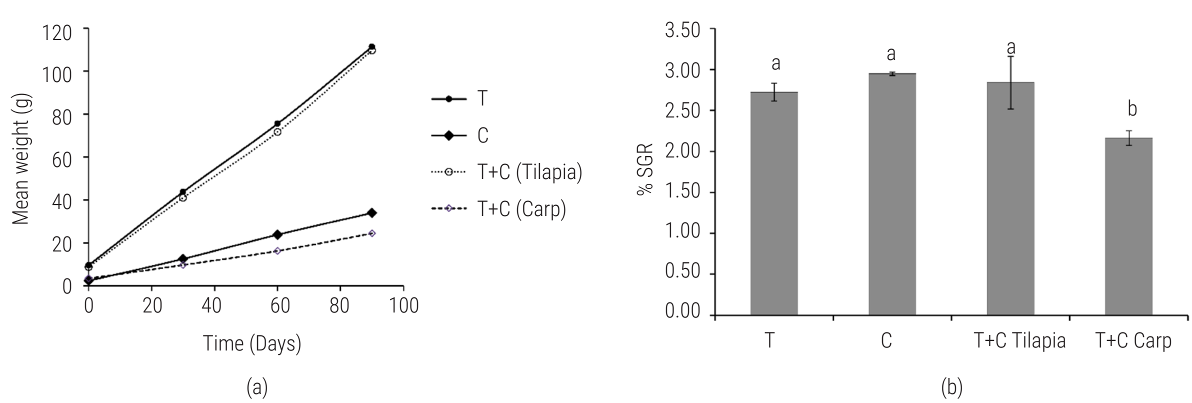


Fig. 5. Variation in fish growth in terms of (a) Mean weight of fish and (b) Specific growth rate. Different letters above the columns indicate significant differences at p≤0.05. T: Tilapia, C: Carp, T+C (Tilapia): Tilapia in the mixed treatment, T+C (Carp): Carps in the mixed treatment)

conditions being formed during the inundation period. However, fish integration disturbs the soil bottom during their reproductive and feeding behaviours, specifically by *O. niloticus*. Therefore, this integration improves nutrient availability not only by disturbing the soil bottom but also by adding their excretions, and consequently positively affects paddy growth (Fig. 7). Further, rice fish integration has been identified as an effective mechanism for enhancing soil microorganisms that increase soil fertility (Arunrat *et al.*, 2022).

Fish perturbation of the soil-water interface during their feeding helps remove trapped soil nutrients (Breukelaar *et al.*, 1994). *O. niloticus* is an omnivorous fish that searches for feed on the soil surface and consequently aerates the soil, releasing P from sediments (Fig. 7) and circulating nutrients in the entire aquatic system (Breukelaar *et al.*, 1994).

Rice agroecosystems support rich biodiversity; with 494 invertebrate species identified in Sri Lankan rice fields (Bambaradeniya *et al.*, 2004). Arthropods were the dominant group, including 55 pest insects. Since the larval stages of many of these insects develop in aquatic environments, rice-fish integration serves as an ecological method of pest control (Bambaradeniya *et al.*, 2004). This approach optimises ecological niches and consequently enhances farm sustainability (Nayak *et al.*, 2018).

Yang *et al.* (2012) reported that higher root biomass, root oxidation activity and cytokinin contents in roots are the key attributes influencing the growth performances of paddy. The present study supports this, as shoot growth during panicle formation, number of tillers, yield and biomass were found to be dependent on root development (Table 2), aligning with previous findings (Yang *et al*., 2012). The estimated rice production in the present study falls within the ranges reported in the literature (Frei and Becker, 2005). For instance, a maximum yield of 7.8 t ha^{-1} was reported from Indonesia (Purba, 1998). In the present study approximately 5.8 t ha^{-1} of rice was produced in an integrated system with tilapia and common carp without applying inorganic fertilisers or pesticides.

Similar to the present study, Frei *et al.* (2007) observed comparatively higher final weight in *O. niloticus* (83 g) compared to *C. carpio* (62 g). However, in this study the final weight of tilapia was slightly higher, while the carp weight was lower than previously reported (Fig. 5a). Except for *C. carpio* in the mixed treatment (T+C), the %SGR of fish was statistically similar in all other treatments. Interspecific competition for resources with *O. niloticus* may have contributed to the lower %SGR of carps in the mixed treatment. Most probably, *O. niloticus* outcompeted *C. carpio* leading to better growth and survival of tilapia. The presence or absence of *C. carpio* did not significantly affect the growth or survival of *O. niloticus*.

No mass fish mortality occurred during the experimental period except for a few instances of natural predations by herons and water snakes. Therefore, the observed mortality rates across all treatments were natural and the survival rates were comparable to those reported in previous studies (Frei *et al.*,2007; Mirhaj *et al.*, 2013). Water quality parameters, including phosphate levels and pH remained within suitable ranges, consistent with previous reports (Frei *et al.* 2007, Mirhaj *et al.*, 2013). The experimental site, an open plain area with relatively strong winds likely facilitated higher oxygen dissolution in the water. However, no fish kills or gasping in the early morning due to low oxygen levels were observed.

Integration of agriculture and aquaculture is a promising strategy for diversifying and optimising resource use, particularly in rural communities (Adhikari *et al.*,2018). The main objective of the current study was to identify the most suitable species based on their impacts on rice yield and hence, an economic analysis was not conducted. The findings indicate that integrating *O. sativa* (AT362) with Nile tilapia (*O. niloticus*) can enhance productivity of conventional paddy farming as well as aquaculture. However,

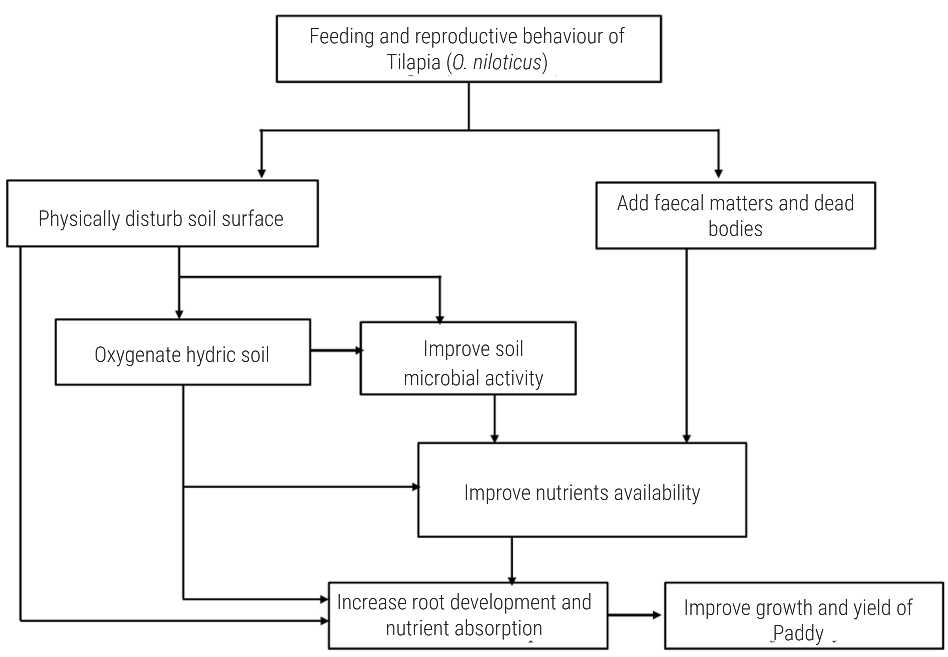


Fig. 7. Cause and effect of rice-fish integration

further studies are needed to determine optimal stocking densities, feeding regimes, together with economic analysis. The size of the fish harvested at the end of the experiment was smaller than marketable size, as the experiment was designed to end coinciding with paddy harvesting. Since these smaller fish yield limited economic benefits, the economic potential of larger fish in integrated systems requires further investigation. However, the economic return from fish production could be improved either by stocking larger fish at the start or extending the rearing period for another paddy cycle.

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