AGRONOMIC AND ECONOMIC PERFORMANCE OF THE INTEGRATED RICE-FISH SYSTEM

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1. Introduction

Rice is the staple food for nearly half of the world's population, estimated at 7.7 billion in 2019 (United Nations, 2019). It is grown in 114 countries on a total area of about 153 million hectares, or 11% of the world's arable land (FAOSTAT, 2011). Among the different rice-growing regions, Africa and Latin America account for 10% of global rice production and consumption (Lampayan et al., 2015). However, rice is growing in importance in Africa, with a significant increase in annual per capita consumption over the past two decades, from 16.7 kg in 1990 to 23.3 kg in 2011 (Yamano et al., 2016) with 50 million consumers in Africa according to Kouassi (2019). Sub-Saharan Africa's population is expected to more than double to 2 billion by 2050 from 800 million in 2010 (UNDP, 2012). At the same time, its food needs will increase fourfold. In the case of rice, and assuming a constant average per capita consumption, total consumption in sub-Saharan Africa is projected to increase from 20 to 48 million tonnes in 2050, and to 88 million tonnes under an assumption of 1.5% per year growth (Agrimonde, 2009). To achieve this objective, the option of irrigated rice cultivation is more promising (Dossou-Yovo et al., 2020) because it is more productive (on average 3.8 t/ha compared to 2.6 t/ha in rainfed lowlands and 1.7 t/ha in rainfed plateaus). However, poor land management practices subsequently lead to soil nutrient depletion (Henao and Baanante, 2006). Yet, the amounts of nutrients present in the soil during the crop cycle determine the quality of the plants' mineral nutrition and largely the crop yields (Bacyé, 1993). The soil nutrient balance in tropical regions is the lowest in the world due to high rainfall, high temperatures and low pH levels (Ngongo et al., 2009). Also, the use of synthetic fertilizers in these regions is limited by the exorbitant and increasing price on the market and (2) the acidification caused by their long-term applications (Hien, 1990). Faced with these socio-economic and environmental challenges, it is becoming imperative to look for other sources of nutrients that can enable sustainable rice cultivation and also improve farmers' incomes.

To this end, Côte d'Ivoire has adopted a strategy to increase rice production and achieve rice self sufficiency. In addition, one of the production systems that can make both fish and rice available to rural populations for their consumption is the integration of rice cultivation and fish farming in ponds or in rice traps set up in the lowlands. Indeed, the integration of fish farming into irrigated rice production systems is now emerging in the world as one of the alternative solutions for reducing food insecurity in rural areas; and this, through the more intensive exploitation of lowlands (Halwartet Dam 2010). The challenge is therefore to find a simple, inexpensive form of aquaculture practice, adapted to the local geographical and socio-economic context and likely to be quickly adopted by rural populations. So, what would be the best agronomic and economic performance of the integrated rice-fish system in the Bouaké region? The objective of our study was to evaluate the agronomic and economic performance of the integrated rice-fish system to farmers.

2. Material and methods

2.1.Study sites

The study took place at AfricaRice's research station in M'bé 1 (8°06N, 6°00W, 180 m) in the administrative region of GBEKE in the department of Bouaké, located in central Côte d'Ivoire. The study site is located in the Guinean savannah zone and is characterized by a bimodal rainfall regime (1200 mm/year) with an average annual temperature of 28°C.

2.2.Experimental design and treatments

The study was a block of 1200 m² subdivided into 6 sub-plots of 120 m² named T1, T2, T3, T4 and T6 (Figure 1). T1 consisted of a combination of rice cultivation and fish farming without the application of mineral fertilizer in order to determine the effect of fish on rice yield. T2 was a control plot where we had only rice cultivation without fertilizer application. In T3, we had grown rice in association with fish. In T4, we had grown rice only with the addition of mineral fertilizer (NPK and Urea). In T5, we had grown rice without fertilizer, but we used water from T6 to irrigated rice plants in T5. In T6, we had fish only.

As far as inputs are concerned, we only used mineral fertilizers in T4. We applied NPK (15-18-18) as a basal fertilizer just before transplanting at an average rate of 200 kg/ha. We then had two top dressing of urea: the first between 20 and 30 days after transplanting (JAR) and the second at panicle initiation (45-60 JAR) at the rate of 100 kg/ha for each application. The fish feed was based on the industrial feed (Koudjis Tilapia) and the quantity distributed varied according to the average weight obtained in each control fishery. The experimental plots were 8 m x 15 m each. The plots are separated from each other by 1 m bunds. Three quantity of fingerlines in the ponds was: T1: 420 fish, T3: 420 fish and T6: 740 fish.

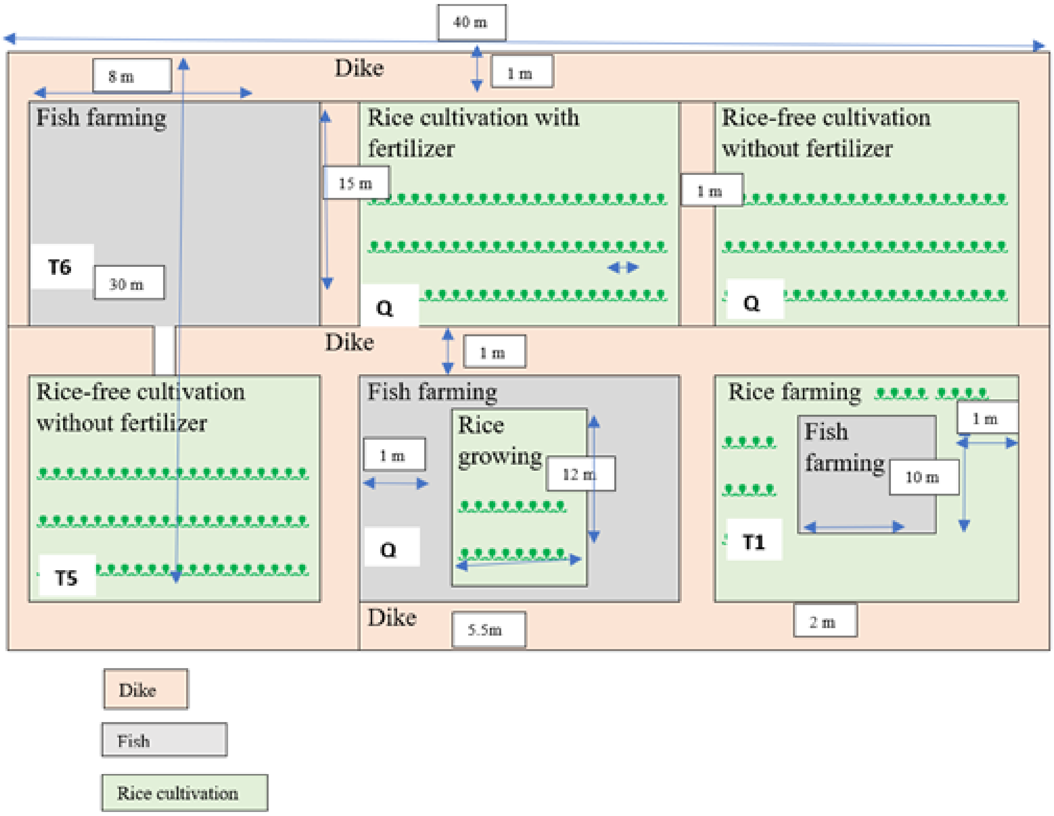

Figure 1. Layout of the experimental design

The plant material consisted of seed of PR107 rice varieties (Figure), while the fish species used was tilapia (Oreochromis niloticus). Oreochromis niloticus is a warm, thermophilic freshwater species that occurs in the wild between 14° and 35° C. Nile tilapia can withstand temperatures of 7° to 41° C and a salinity of 0.015 to 30 per thousand and a pH of 5 to 11. Coming from Africa, it has been acclimatized in Asia, America and Europe. It is is resilient, fertile and easy to grow.

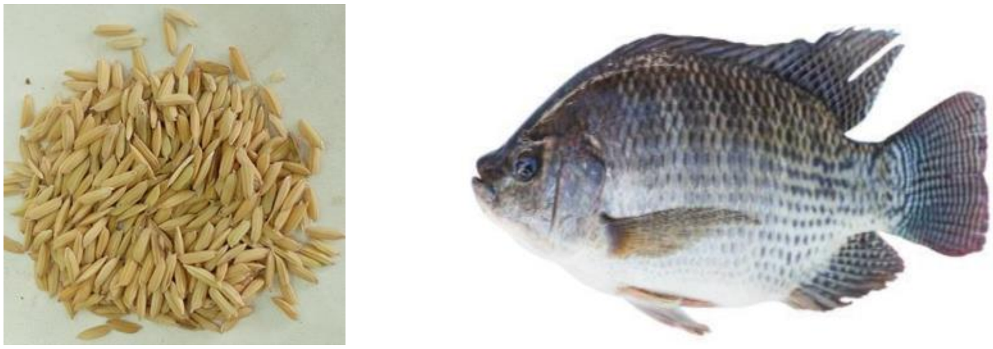

Figure 2: PR107 rice varieties (a) and tilapia Oreochromis niloticus (b)

The technical equipment used to set up the experimental design, apply treatments and collect data was composed of:

- A 3-metre tape for measuring the heights of tillers
- A 50 meter tape measure
- A scale for weighing samples
- Signs for the identification of plots
- A fishing net for control fishing
- Sickle for rice harvesting

2.3.Data collection and analysis

At maturity, grain yield (GDR) was determined from two areas of 2m*2m in the centre of each plot and adjusted to 14% grain moisture:

RDG (t/ha) = (dry weight in grain (kg)/ 4m2) × (10000/1000) × ((100-H) /86) [1]

H is the humidity level measured by the moisture meter.

The system's rice equivalent yield (SREY) was calculated using Equation 2.

$$SREY(kgha^{-1}) = Rendement\ en\ grains\ cumulé\ du\ riz\ (USD^{-1}) + \frac{Rendement\ cumulé\ en\ grains\ de\ haricot\ mungo(kgha^{-1}) \times Prix\ du\ haricot\ mungo\ (USDkg^{-1})}{Prix\ du\ riz\ (USDkg^{-1})}$$

The System Production Efficiency (SPE) was calculated using Equation 3.

$$SPE(kgha^{-1}journée^{-1}) = \frac{Rendement\ équivalent\ riz\ du\ système(kgha^{-1})}{Durée\ totale\ du\ système\ de\ culture\ (jours)}$$

At the tillering stage, the number of tillers per plant was counted for each treatment. Panicles numbers were counted at flowering at each observation square. The heights of all plants in the observation square were measured (from crown to last ligule) using a tape measure at kernel maturity.

In order to determine the most profitable rice farming technique for the producer, production costs were and profits have been calculated.

The data were entered with Microsoft Excel version 2016 which was used to construct the graphs and calculate the averages. The analysis of variance (ANOVA) was performed using R 4.1.2

software. The Shapiro-Wilk test was used for the normality test and the Levens test was used to check for homogeneity of variances. When the normality and homogeneity of variance tests were verified, the ANOVA test was performed afterwards. If a significant difference was indicated by the ANOVA test. In case the conditions of normality and/or homogeneity of variances were violated, the various analyses were carried out at the significance threshold of 5%.

3. Results

3.1.Agronomic performance of the integrated rice-fish system

The agronomic performance of the integrated rice-fish system was evaluated using the rice yield, growing cycle duration, number of tillers, plant height, harvest index, percentage of fertile tillers, straw weight, weed biomass (Table 1). The results of these agronomic performances show that the treatments had no significant effect on agronomic parameters except for the rice yields and weed biomass. T4 resulted in the highest rice yield of 9.86 t/ha, while the lowest rice yield was recorded in T2. Interesting, there was no difference in rice yield between T1, T4 and T5. Weed biomass was the highest in T4, and was the lowest in T3. Overall, the weed biomass was lower in integrated rice-fish plots compared to plots where rice was cultivated with the recommended level of fertilizer application.

Table 1. Rice yield, growing cycle, number of tiller, plant height, harvest index, percentage of fertile tillers, straw weight and weed biomass in the experimental plots

	Yield Rice (t/ha)	Rice Cycle	Number of tillers	Plant height	Harvest Index	Percentage of fertile tillers	Straw weight t/ha	Biomass Adv T/ha
T1 RP around	8.96 a	211.33 a	21.88 a	192.88 a	2.68 a	179.97 a	3.99 a	0.47 ab
T2 R without F	6.55 b	211.33 a	18.45 a	189.63 a	2.97 a	184.61 a	3.95 a	0.42 ab
T3 RP in the middle	6.82 b	211.33 a	21.16 a	189.82 a	2.56 a	182.45 a	4.20 a	0.32 a
T4 RF	9.86 a	213.33 a	20.63 a	197.87 a	2.46 a	184.61 a	4.23 a	0.68 c
T5 R. Fert Water Fish	8.99 a	211.33 a	20.16 a	200.62 a	2.53 a	180.22 a	3.95 a	0.54 bc
P-Value	0.03	0.802	0.316	0.98	0.995	0.729	0.946	< 0.005 ***

3.2.Economic performance of the integrated rice-fish system

Overall, the treatments had a significant effect on the benefits. The highest benefit was achieved with T6. Among the integrated rice-fish system, T1 had a higher benefit, and this was higher than the benefit in T4. Similarly, the highest benefit cost ratio was recorded in T6, and the lowest in T4. T1 had also a higher benefit cost ratio compared to T4 and T3.

Table 2. Economic performance of the integrated rice-fish system

	Production cost (FCFA/ha)	Benefits (FCFA/ha)	Benefit cost ratio	SREY (Kg/ha)	System Production Efficiency (SPE)
T1 RP around	630837 b	2787808 ab	4.38 bc	2247020 a	10593 a
T2 R without F	671952 b	1613546 a	2.40 a	1637722 a	7671 a
T3 RP in the middle	530449 a	1860732 a	3.32 ab	1712340 a	8112 a
T4 RF	959168 c	2102348 a	2.19 a	2465561 a	11512 a
T5 R. Fert Water Fish	671952 b	2104388 a	3.13 ab	2248327 a	10569 a
T6 Fish	678443 b	4813159 b	6.62 c	3223236 a	15518 a
P-Value	<0.0005 ***	0.00875 **	0.000488 ***	0.0907	0.0667

SREY is system rice equivalent yield.

3.3.Water quality affected by integrated rice-fish system

Among the water quality indicators, phosphorus content was significantly affected by the treatments. The highest phosphorus content was recorded in T1, and this was significantly higher than the phosphorus content in T4.

Table 3. Water quality indicators of the experimental treatments

Treat	Ph	P (mg/L)	K (mg/L)	N (mg/L)	CEC ($cmol^{+}/L$)
T1 RP around	7.08 ± 0.037 a	0.048 ± 0.005 b	1.972 ± 0.24 a	1189.40 ± 600.91 a	0.00125 a
T2 R without F	7.08 ± 0.011 a	0.026 ± 0.023 ab	2.060 ± 0.20 a	1089.02 ± 518.24 a	0.00117 a
T3 RP in the middle	7.07 ± 0.11 a	0.013 ± 0.000 a	2.016 ± 0.28 a	951.28 ± 333.69 a	0.00113 a
T4 RF	7.06 ± 0.10 a	0.014 ± 0.001 a	2.265 ± 0.88 a	1075.01 ± 126.64 a	0.00107 a
T5 R. Fert Water Fish	7.06 ± 0.06 a	0.012 ± 0.001 a	1.636 ± 0.50 a	1065.67 ± 357.74 a	0.00107 a
T6 Fish	7.03 ± 0.04 a	0.015 a	2.726 ± 0.17 a	1072.67 ± 126.31 a	0.00103 a
P-Value	0.964	0.0053 **	0.169	0.987	0.0895

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