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Research Article

ASSESSMENT OF THE BENEFICIAL EFFECT OF USING FRESH *AZOLLA FILICULOIDES* IN THE PRODUCTIVITY OF THE INTEGRATED RICE-FISH SYSTEM AT BONOUFLA, CÔTE D'IVOIRE

[1*] GROGA Noël, [2] KOUADIO Atto Delphin, [3] ZIÉ Barthélemy, [1]SORO Donafologo Drissa and [1]SORO Dognimeton

[1]Amelioration Production and Agricultural Laboratory, Jean LOROUGNON GUEDE University, BP 150 Daloa, Côte d'Ivoire
[2]Tropical Biodiversity and Ecology Laboratory, Jean LOROUGNON GUEDE University, BP 150 Daloa, Côte d'Ivoire
[3]Environment and Aquatic Biology Laboratory, Nangui ABROGOUA University, Côte d'Ivoire.

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ABSTRACT

The objective of this study was to determine the effect of *Azolla filiculoides* on the growth parameters of rice Wita 9 and tilapia *Oreochromis niloticus* in integrated rice-fish culture. Fingerlings (6.11 ± 0.19 g; 12 fingerlings/m²) were placed in the ponds transplanted with 14-day-old rice seedlings. These seedlings were transplanted two by two in clusters with a spacing of 20 cm between them and 25 cm between rows. Two treatments of fresh *A. filiculoides* and rice bran were applied in these ponds to compare the changes in fish zootechnical and rice agronomic parameters with a control after 3 months of production. The data collected showed that the best rice seedling growth and fish performance were obtained with the addition of *A. filiculoides*. Yields were also higher with the same treatment (6.97 ± 0.08 T/ha for rice and 166.13 ± 26.94 Kg/ha for fish) compared to the control and rice bran treatments. The use of *Azolla* fern could thus constitute an alternative of choice in front of the costs of the conventional inputs used in fish farming and rice farming in Côte d'Ivoire.

Keywords: *Azolla filiculoides*, Fish, Yield, Rice-fish culture, Côte d'Ivoire.

INTRODUCTION

Rice and fish are the main food resources available to almost all the world's populations. Rice, produced in around 110 countries, is the staple food of almost 40 % of the world's population (Lacharme, 2001). In Côte d'Ivoire, this deficit of around 50% is made up by massive imports of milled rice from Asian countries (ONDR, 2020). As for fish, it increasingly plays an essential role in food security, nutrition and the well-being of populations in both developed and developing countries (Yao *et al*., 2016). In Côte d'Ivoire, it is the primary source of animal protein for the population. The average Ivorian consumption of fish is 286,000 tonnes (MIRAH, 2014). National production, estimated at 8467 tonnes/year in 2023 (MIRAH, 2024), remains insufficient and covers barely 23% of food requirements, which are offset by massive imports of frozen fish (Avit *et al*., 2012). In 2013, these imports amounted to 298,200 tonnes (INS, 2014).

In addition, Côte d'Ivoire, like many developing countries, is facing rapid population growth. This strong demographic trend is creating a high demand for food. As a result, increasing agricultural and aquacultural production to ensure food security is a major challenge. To meet this challenge, farmers resort to chemical inputs. These inputs are more expensive and their excessive use has certainly improved agricultural yields (N'dah, 2012), but their effects, previously neglected, have become a major source of pollution of water resources used in both agriculture and aquaculture (Groga, 2012). To alleviate these problems in rice farming, systems that can combine agriculture without chemical inputs with aquaculture, such as aquaponics and rizipisciculture, are conceivable. In fact, rice-fish farming

*Corresponding Author: GROGA Noël, Amelioration Production and Agricultural Laboratory, Jean LOROUGNON GUEDE University, BP 150 Daloa, Côte d'Ivoire Email: groga7@yahoo.fr.

makes it possible to benefit from the simultaneous production of two entities (cereals and animal protein) on the same plot (FAO, 2003). It is therefore an important alternative for reducing food insecurity in underdeveloped countries (Halwart & Dam, 2010).

As the rice plant is a grass that needs nitrogen, soils with good water retention capacity and rich in organic matter, associating the aquatic fern *Azolla filiculoides* with this system would seem to be even more beneficial. Indeed, through its symbiosis with the cyanobacteria (*Anabaena azollae*), *A. filiculoides* enables the fixation of atmospheric nitrogen for good plant growth (Bocchi & Malgioglio, 2010). *Azolla* can supply up to 50 % of mineral nitrogen to plants (CTA, 1992). It also has a high nutritional value, with a protein content close to that of soya (Alalade & Eustace, 2006). As a result, this fern is used in aquaculture and rice cultivation (CTA, 1992; Accodji *et al*., 2009). This study aims to assess the impact of using fresh *A. filiculoides* on the growth of Wita 9 rice and *Oreochromis niloticus* fish in an integrated rice-fish culture system.

MATERIALS AND METHODS

Presentation of the farm

The study was carried out at the Kouadiokro-Bonoufla fish farm (Figure 1). It is located in the Department of Vavoua at coordinates 7°11'40" N and 6°31'38,5" W, 12 km from the village of Bonoufla (Kouadio *et al.,* 2022). Located in the Haut-Sassandra Region, the Department of Vavoua enjoys a transitional humid tropical climate. The department's soils are ferralitic. The region's climate is characterized by a dry season from October to March and a rainy season with two maxima, one in June and the other in September (Ligban *et al*., 2009). The farm comprises nine ponds numbered E1 to E9. Pond E1 has a surface area of 675 m^2 and the other eight ponds have surface areas ranging from 200 to 360 m^2 (Kouadio *et al.,* 2022). These ponds are gravity-fed from a one-hectare dam. Mud and sand are the predominant substrates in these ponds (Kouadio *et al*., 2023).

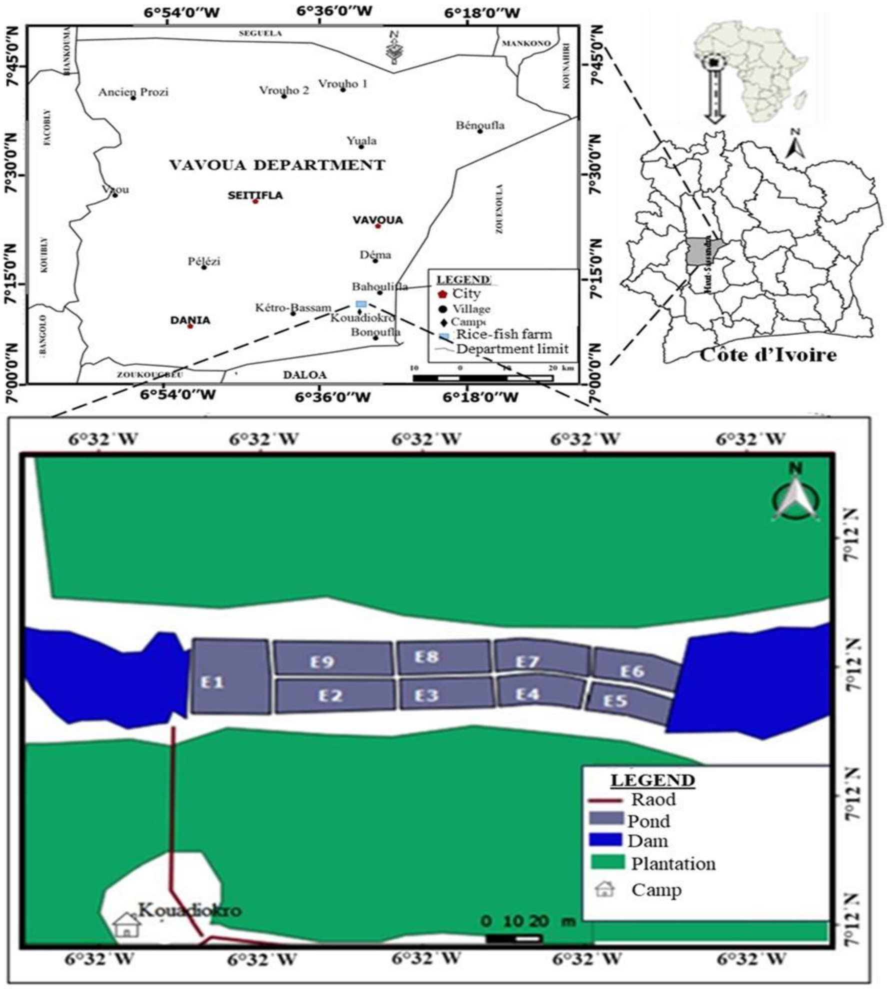

Figure 1. Geographical location of the Kouadiokro-Bonoufla rice-fish farm (Kouadio *et al.,* 2023).

Experimental set-up

The experimental set-up used consisted of nine ponds ranging in size from 200 to 675 m^2. It was set up as a totally randomized Fisher block with three ponds per feeding treatment (Figure 2). The various treatments applied consisted of controls with no exogenous feed (SAE), rice bran (ASR) and fresh *Azolla filiculoides* (AAf). A refuge zone and a trench 60 cm and 30 cm deep respectively were created in each pond. The refuge zone created in each pond provides shelter for the fish during weeding. It also facilitates access to exogenous fish food, fish harvesting and pond stocking. Three yield area of 2.45 m^2 each were also defined in the ponds. They were marked out using wooden stakes and a roll of nylon thread. The ponds were equipped with an opposite water inlet and outlet in the rice-growing zone, and a water outlet in the refuge zone, in order to control the water level in the rice field for the fish. This piping system was fitted with a mosquito net to prevent the escape of reared fish.

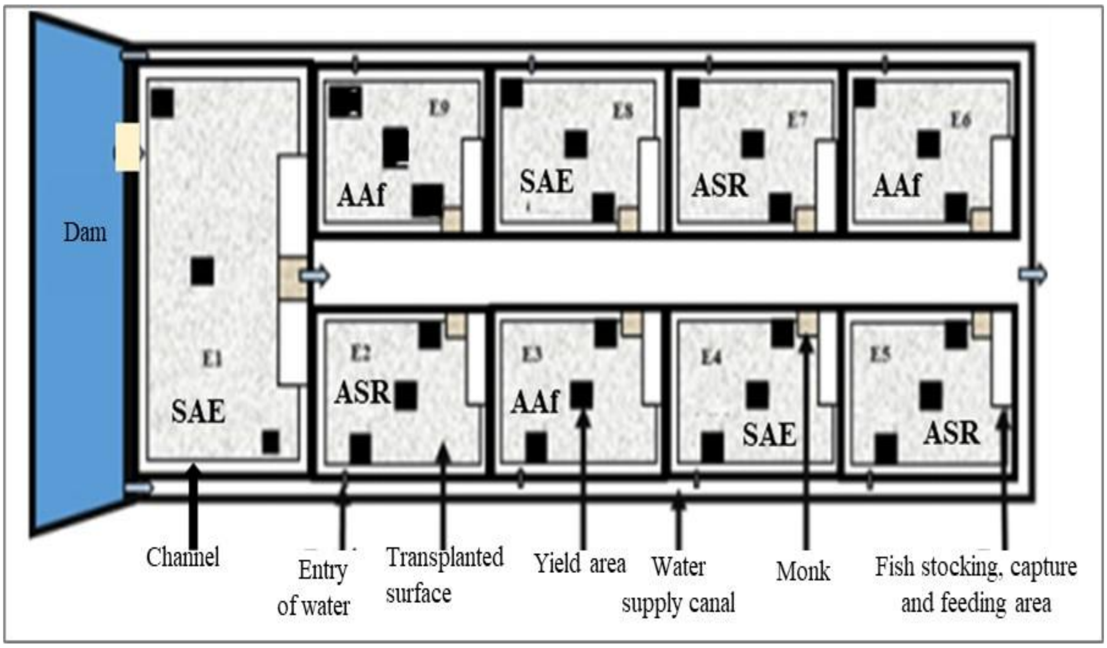

Figure 2. Experimental set-up.

SAE = No exogenous feed intake, ASR = Rice bran input, AAf = Fresh *Azolla filiculoides* input.

***Azolla filiculoides* production**

The experiment was carried out between March and July 2018. Rectangular basins measuring 3m^2 and 30 cm deep were dug using picks and hoes. Black and blue bags were arranged to cover the soil perfectly to prevent water leakage. Each basin was filled 2/3 with water and 5 liters of liquid chicken droppings were added. The solid chicken droppings had previously been left in water-filled buckets for 24 hours. After adding water and liquid chicken droppings, the media were homogenized and 125g of fresh *A. filiculoides* (Figure 3A) were inoculated into each tank. These basins were covered with mosquito netting to prevent colonization by frogs and other macrophytes (Figure 3B). Harvesting was carried out weekly for three months.

Creation of the rice nursery

Orza sativa paddy rice grains of the WITA 9 variety were used in this study. This variety was chosen because of its short crop cycle (105 days) covering almost the duration of the pre-pregnancy phase of *O. niloticus* and also its high yield (9 t/ha) (Bouet *et al*., 2013). The rice grains were tested for sterility before being placed in the nursery. It consisted in pouring paddy rice into buckets containing water (10 L) for a stay of 24 hours. Floating grains corresponding to sterile grains were eliminated. Only the seeds at the bottom of the buckets were considered fertile and selected for the nursery. Fertile seeds were broadcast over the entire surface of the beds. They were then covered with palm leaves to protect the young shoots from granivorous birds. These palm leaves were removed one week after the rice grains had germinated. The nursery lasted 14 days, with regular daily watering.

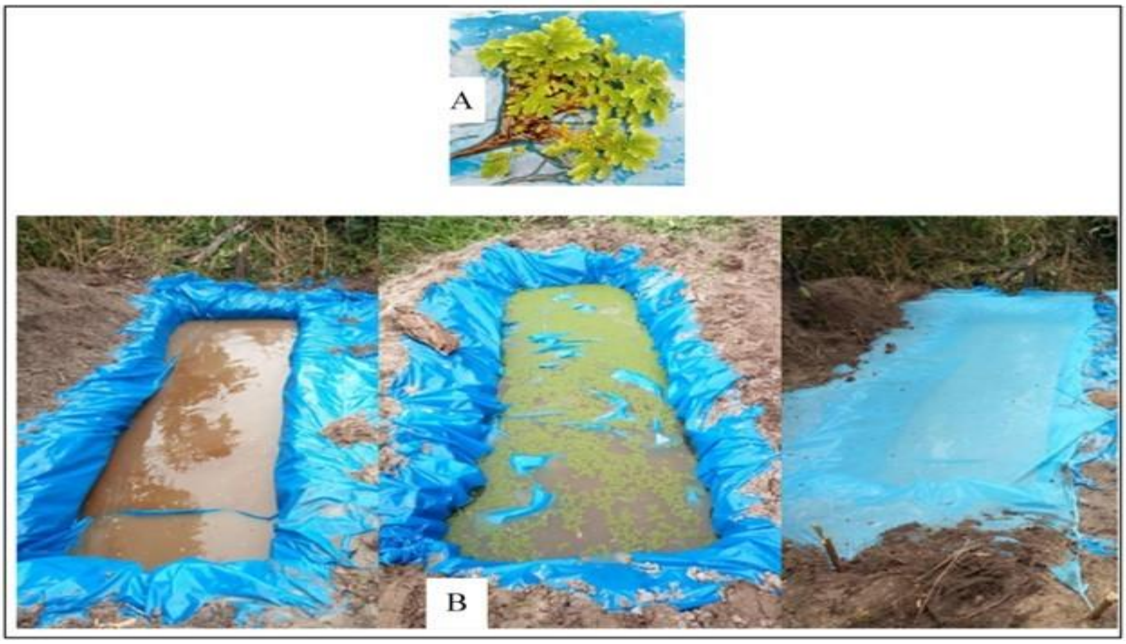

Figure 3. *Azolla* production.

A= Frond of *A. filiculoides*, B = Cultivation basins.

Transplanting and stocking ponds

The transplanted areas of ponds E3, E6 and E9 (Treatment AAf) were amended a priori with 500 g of fresh *A. filiculoides*. The 14-day-old rice seedlings were hand-pulled and only the most vigorous were used. These vigorous seedlings were then transplanted two by two in clusters with a spacing of 20 cm between clusters in the same row and 25 cm between different rows (Figure 4). In this way, the areas remaining after development, ranging from 189 m^2 to 657.4 m^2, were transplanted on the same day, i.e. 3.720 to 12.568 seedlings transplanted per pond. The transplanted ponds were gradually supplied with water by gravity according to the size of the rice seedling, at a flow rate of 15 L/min. The water level was maintained at 1/5th the height of the rice stem during the study. This water level is suitable for both fish and rice. The water level in the refuge areas was set at 60 cm. The ponds were stocked 30 days after rice transplanting, at a stocking density of 12 fry/m². The average weight of these fry was 6.11 ± 0.19 g. Ponds were stocked with quantities ranging from 2,400 to 8,100 fry, depending on their surface area.

Figure 4. Transplanting rice plants.

Fish feeding

Fingerlings were fed morning (9h) and evening (15H) for 90 days with a rationing rate of 5 % of total live weight was applied in accordance with Bamba *et al*. (2014). Two feeds consisting of fresh *A. filiculoides* and rice bran (ASR) were fed to fish from ponds E3, E6 and E9 (AAf), and E2, E5 and E7 (ASR) respectively. Fish from other ponds (E1, E4 and E8) receiving no exogenous feed were used as a control (SAE).

Measurement of physical and chemical water parameters

The main physical and chemical water parameters (pH, temperature, conductivity, dissolved oxygen and transparency) were measured monthly in situ. Transparency was measured at noon using a Secchi disk. Other parameters were measured with HANNA multiparameter probes (model Hi 9828) between 7 and 8:30 a.m. in the morning and between 4 and 5:30 p.m. in the evening.

Measurement of rice and fish growth parameters

Rice growth parameters were measured weekly from day 14 to day 70 after emergence. They involved measuring the length of rice tillers and leaves using a decameter (Figure 5). The number of tillers and leaves was counted. These parameters were taken from the plants of 10 rice bunches selected at random from the yield square, i.e. a total of 30 rice bunches per pond. The yield square was determined by counting eight rice plantlets along its length and width respectively, giving a surface area of 2.45 m² (1.75 m x 1.40 m), taking into account the equidistances between plants. Fish zootechnical data were taken from samples of 30 fish per feeding treatment. These fish were caught after 90 days of rearing using a landing net. They were weighed individually using a Terraillon portable electronic balance (0.01 g) to determine their average final weight.

Figure 5. Measuring the length of rice leaves (Co-author).

Determination of rice and fish yield

Rice and fish yields were measured at the end of rice production as a function of pond surface area. The yield (Y) is calculated by dividing the dry biomass produced by the ponds by the hectare. The calculation formula is as follows from Avit *et al*. (2012).

$$Y\ (\mathrm{T/ha}) = \frac{DP}{A}\ ,$$

Where: Y= Rice yield, DP = Dried production of paddy rice (Tons), A = Area (ha).

Fish yield was determined using the same formula as for rice.

Calculation of Body Mass Gain

Average weight gain (AWG) is used to assess fish weight growth over a given time and is calculated using the following formula from Sarr *et al*. (2015):

$$\mathrm{AWG\ (g) = FAW - IAW}$$

Where: FAW = Final average weight (g) and IAW= Initial average weight (g).

Determination of specific growth rate

The specific growth rate (SGR) was used to evaluate the weight gained by the fish each day as a percentage of its live weight. According to Sarr *et al*. (2015), this rate is obtained using the following formula:

$$\text{SGR } (\%\text{day}^{-1}) = \frac{\ln(\text{FAW}) - \ln(\text{IAW})}{d}\ 100$$

Where: FAW = Final average weight, IAW= Initial average weight, d= Rearing duration.

Calculation of survival rate and fish yield

The survival rate (SR) is used to determine the percentage of fish that survived from the start of the experiment to harvest. SR was calculated from the total number of fish at the end of the experiment and the number of fish at the start of rearing, according to the following relationship:

$$\text{SR } (\%) = \frac{\text{TnFF}}{\text{TnIF}}\ 100$$ Sarr *et al*. (2015).

Where: TnFF = Total number of final fish, TnIF = Total number of initial fish.

Statistical analysis of data

Shapiro-Wilk normality tests were applied to all variables. Then, tests to check the homogeneity of variances with Bartlet's test before carrying out all analyses. Analyses of variance (ANOVA) with one criterion or classification factor were applied to data following the normal distribution in order to compare the different means. These analyses were completed by Fisher's LSD (Least Significant Difference) tests when a difference was found. Differences were considered significant at the threshold of $\alpha = 0.05$ ($p < 0.05$). Non-parametric Kruskal-Wallis and Mann-Whitney tests were performed on data that did not follow the normal distribution at the same probability threshold. All these tests, carried out using Statistica 7.1 statistical software, enabled us to determine the effect of treatments on the various agronomic parameters.

RESULTS AND DISCUSSION

Table 1 shows the physicochemical characteristics of the water in the rearing structures. Maximum pH values were recorded in the ASR treatment with an average of 5.81 ± 0.44, while minimum values were observed in the AAf treatment with an average of 5.66 ± 0.45. These averages are statistically identical at the 5% threshold. These averages are statistically identical at the 5% threshold. Temperature averages ranged from 26.31 ± 1.92°C for ASR to 26.51 ± 2.04°C for AAf. The ANOVA test revealed no significant difference in water temperature between treatments (p = 0.722). Dissolved oxygen levels were highest in the SAE treatment, with an average of 4.16 ± 0.37 mg/L, and lowest in the ASR (2.66 ± 0.22 mg/L) and AAf (2.64 ± 0.25 mg/L) treatments. Statistically, dissolved oxygen concentrations in the water varied significantly between treatments and tests (ANOVA, p = 0.000). As for conductivity, the highest mean value was observed in ASR treatment water (243.67 ± 38.03 µS/cm), while the lowest was measured in SAE treatment water (200.7 ± 36.19 µS/cm). The differences in values recorded did not vary significantly between treatments (ANOVA, p = 0.003).

As for transparency, water from the SAE and AAf treatments, with averages of 22.46 ± 1.58 and 22.23 ± 1.73 cm respectively, was less transparent than that from the ASR treatment (25.61 ± 2.26 cm). Statistical analyses reveal a significant difference (p = 0.001) at the 5% threshold for all waters from all three treatments.

Table 1. Physicochemical parameters of treated pond water.

Parameters	Treatments			p-valu
	SAE	ASR	AAf	
pH	5.79 ± 0.39[a]	5.81 ± 0.44[a]	5.66 ± 0.45[a]	0.980
Temperature (°C)	26.44 ± 2.51[a]	26.31 ± 1.92[a]	26.51 ± 2.04[a]	0.722
Dissolved oxygen (mg/L)	4.16 ± 0.37[b]	2.66 ± 0.22[a]	2.64 ± 0.25[a]	0.000
Conductivity (µS/cm)	200.7 ± 36.19[a]	243.67 ± 38.03[b]	225.83 ± 21.52[ab]	0.003
Transparency (cm)	22.46 ± 1.58[a]	25.61 ± 2.26[b]	22.23 ± 1.73[a]	0.001

Means bearing the same letters (a, b) on the same line are statistically identical at the 5% threshold. SAE = No exogenous feed input; ASR = Rice bran input; AAf = Fresh Azolla filiculoides input.

With the exception of the 14th day of cultivation, the number of tillers of Wita 9 rice varied significantly (p > 0.05) from one treatment to another at each cultivation period (Table 2). Plants from the AAf treatment had better tillering, with the number of tillers rising from 5.75 ± 1.36 on day 14 to 32.08 ± 5.30 on day 70 after transplanting. This is equivalent to around 7 tillers per week. In the ASR treatment, the number of tillers increased from 6.25 ± 0.87 to 30.08 ± 1.00 during the cultivation period, i.e. 6 tillers of rice per week. As for the number of tillers of plants from the control treatment (SAE), it increased from 5.33 ± 0.98

to 25.41 ± 4.27 tillers between the 14th and 70th cultivation periods, i.e. 5 tillers per week.

Table 2. Evolution of the number of tillers on rice plants.

Duration of cultivation	Treatments			p-valu
	SAE	**ASR**	**AAf**	
14th	5.33 ± 0.98^a	6.25 ± 0.87^b	5.75 ± 1.36^{ab}	0.150
28 th	9.25 ± 1.60^a	12.42 ± 0.90^b	13.08 ± 2.50^b	0.000
42 nd	13.42 ± 2.07^a	16.83 ± 0.83^b	16.50 ± 2.71^b	0.001
46 th	20.16 ± 2.57^a	23.67 ± 1.56^b	27.17 ± 4.69^c	0.000
70 th	25.41 ± 4.27^a	30.08 ± 1.00^b	32.08 ± 5.30^b	0.000

For each mean, values bearing the same letters (a, b, c) on the same line are statistically identical at the 5% threshold.

The evolution of the length of rice leaves from the different treatments is presented in Table 3. This table shows that the length of rice leaves varies significantly from one treatment to another at each growth period ($p < 0.05$). In fact, the plants from the AAf treatments produced longer leaves with better evolution. The leaf length of rice plants from this treatment increased from 42.66 ± 3.83 cm on day 14 to 99.52 ± 7.57 cm on day 70 after transplanting. In contrast, the rice leaves of plants from the SAE treatment (control) were the shortest. The average increase was from 40.41 ± 1.98 to 90.08 ± 1.61 cm over the same period. As for the leaves of rice plants in the ASR treatment, their length increased from 40.11 ± 1.77 to 95.45 ± 3.88 cm during the cultivation period.

Table 4 shows the yield of Wita 9 rice from the different treatments. The table shows that yields varied significantly from one treatment to another ($p = 0.001$). The rice plants from the AAf and ASR treatments had the highest yields, with average yields of 6.97 ± 0.08 and 5.93 ± 0.38 T/ha respectively. These yields were statistically identical (Mann-Whitney test, $p > 0.05$). The average yield of rice plants in the control treatments (SAE) was 4.18 ± 0.25 T/ha. This yield is significantly lower than that of the other treatments (Mann-Whitney test, $p < 0.05$).

The zootechnical parameters of the fish are shown in Table 5. Fish survival rate (SR) was highest in the AAf treatment, with an average of 92.53 ± 1.64%. It was relatively lower in the ASR (76.80 ± 1.61%) and SAE (69.77 ± 0.50%) treatments. The specific growth rate (SGR) was 2.24 ± 0.01% day^{-1} with a mean weight gain (AWG) of 0.45 ± 0.07 g for fish in the AAf treatment. In the ASR treatment, the SGR was 1.61 ± 0.21% day^{-1} with a AWG of 0.32 ± 0.07 g, compared with 1.27 ± 0.22% day^{-1} and a AWG of 0.17 ± 0.05 g for the control treatment (SAE). Fish zootechnical parameters differed statistically between treatments (Mann-Whitney test, $\alpha = 0.05$).

Table 3. Evolution of the length of rice leaves (cm) after 70 days of cultivation.

Duration of cultivation	Treatments			p-valu
	SAE	**ASR**	**AAf**	
14th	40.41 ± 1.98^a	40.11 ± 1.77^a	42.66 ± 3.83^b	0.000
28 th	50.30 ± 2.79^a	50.56 ± 2.13^a	55.85 ± 4.40^b	0.000
42 nd	57.83 ± 2.55^a	57.48 ± 1.39^a	66.96 ± 4.13^b	0.000
46 th	80.24 ± 1.90^a	79.38 ± 1.85^a	85.67 ± 5.31^b	0.000
70 th	90.08 ± 1.61^{ab}	95.45 ± 3.88^a	99.52 ± 7.57^b	0.000

For each mean, values bearing the same letters (a, b, c, d) on the same line are statistically identical at the 5% threshold.

Table 4. Rice yield at the time of harvest.

	Treatments			p-valu
	SAE	**ASR**	**AAf**	
Yield (T/ha)	4.18 ± 0.25^a	5.93 ± 0.38^b	6.97 ± 0.08^b	0.001

Means bearing the same exponents (a, b) are not significantly different (Mann-Whitney test, $\alpha = 0.05$).

Table 5. Zootechnical parameters and fish performance.

Parameters	**Treatements**			p-valu
	SAE	**ASR**	**AAf**	
AWG (g)	0.17 ± 0.05^a	0.32 ± 0.07^b	0.45 ± 0.07^c	0.007
SGR (%day^{-1})	1.27 ± 0.22^a	1.61 ± 0.21^b	2.24 ± 0.01^b	0.000
SR (%)	69.77 ± 0.50a	76.80 ± 1.61b	92.53 ± 1.64c	0.000

Means with the same superscripts (a, b) are not significantly different (Mann-Whitney test, α= 0.05). AWG = Average weight gain; SGR = Specific growth rate; SR = Survival rate.

Table 6. Yield of *Oreochromis niloticus* at the end of rearing.

Parameters	Treatements			p-valu
	SAE	ASR	AAf	
Rendement (Kg/ha)	45.72 ± 0.95^a	78.65 ± 2.97^b	166.13 ± 26.94^c	0.000

Means with the same exponents (a, b) are not significantly different (Mann-Whitney test, α = 0.05).

Table 6 shows yield of *Oreochromis niloticus* for the different treatments. The highest yield was obtained in the AAf treatment with an average of 166.13 ± 26.94 Kg/ha. Fish yield averages for the ASR and SAE treatments were 78.65 ± 2.97 and 45.72 ± 0.95 Kg/ha respectively. According to the Mann-Whitney test, the different yields recorded are significantly different from one treatment to the other at the 5% threshold. The evolution of the different growth parameters (number of tillers and leaf length) of rice plants was significantly better with the AAf treatment during the growing period. This result is similar to that of Groga *et al*. (2018) and Kouadio (2015) who respectively observed better vegetative growth with tomato and rice plants treated with *Azolla* sp. This growth would be justified by the fertilizing properties of *Azolla*. Because according to Brasset & Couturier (2005), *Azolla filiculoides* provides the soil with a significant amount of nitrogen and phosphorus which are the main growth factors of plants. These minerals provided by *Azolla* would complement those provided by fish through their excreta. This assertion is supported by Hong (2007) who states that rice-fish systems improve soil fertilization via fish feces and that fish feed on certain predators harmful to rice, thus promoting its good development. Also, *A. filiculoides* covering the surface of rice-fish ponds helps reduce the proportion of volatilizable ammoniacal nitrogen, thus improving the efficiency of nitrogen use by rice (Hêdji *et al*., 2014).

The best paddy rice yields were obtained using the AAf (6.97 T/ha) and ASR (5.93 T/ha) treatments. These yields are significantly higher than those obtained with rice-fish culture by Avit *et al.* (2012), which is 3.68 T/ha without fertilisation in Bouaké (Côte d'Ivoire), and those of Zié *et al.* (2022), which are between 3.34 and 4.24 T/ha using agricultural by-products. The higher yield recorded with AAf treatment could be linked to the high fertilizing capacity of *A. filiculoides*. Indeed, according to Kouadio (2015), the use of the fern *A. filiculoides* as a fertilizer improves the chemical properties of soils due to its high concentration of phosphorus, manganese, iron and nitrogen. In addition, the symbiosis between *Anabaena azollae* and this fern promotes the fixation of atmospheric nitrogen for good plant growth (Bocchi & Malgioglio, 2010).

Regarding the zootechnical parameters of fish, the average weight gain was higher in rice-fish ponds where fish were fed with fresh biomass of *A. filiculoides* (AAf) compared to other ponds. This would be attributed, on the one hand, to the nutritional properties of *Azolla* and, on the other hand, to the diversity and availability of natural foods (plankton, periphyton and macro-invertebrates) established by the rice-fish system. Indeed, according to Saikia & Das, (2015), rice plants maximize the availability of natural resources easily accessible to fish. *Oreochromis niloticus* fry from ASR and AAf rice-fish ponds grew at higher specific growth rates (1.61 ± 0.21 and 2.24 ± 0.01 % day-1) than those from SAE ponds (1.27 ± 0.22 % day-1). This weight gain is thought to be due to the good quality of the exogenous food (rice bran and azolla) supplied daily to the fish. However, this growth is comparatively higher than that recorded in rice-fish culture by Avit *et al.* (2012) and Zié *et al.* (2022), who recorded 0.67% day-1 without feed and 0.38% day-1 with a mixture of agricultural by-products, respectively. The average survival rate of *O. niloticus* fry was between 69.77 and 92.53% with a higher rate at the AAf treatment. These survival rates are substantially identical to those reported by Bamba (2007) which was between 75 and 94 % despite the presence of piscivores. The high survival rate of *O. niloticus* fry in the AAf treatment would be attributable to the presence of rice plants and the formation of *Azolla filiculoides* mats in some places on the surface of the ponds. Indeed, the presence of rice plants and the *A. filiculoides* mat protect the fry against predators such as piscivorous birds and frogs. The AAf treatment made it possible to obtain a better fish yield with an average of 166.13 ± 26.94 Kg/ha unlike the other treatments. The observed fish yields are lower than those of

Avit *et al*. (2014) who recorded a production of 504 Kg/ha of fish in rice-fish farming against 370 Kg/ha in fish farming. The better yield obtained with the AAf treatment would be linked to the nutritional properties of *A. filiculoides* provided to the fish. Indeed, *Azolla* has a high nutritional value compared to rice bran (Hêdji *et al*., 2014). It improves the trophic conditions of ponds and consequently increases fish production with a relatively low input (Abou *et al*., 2007). Its crude protein content (more than 27 %) is close to that of soybeans and it is very rich in essential amino acids, vitamins and minerals (Alalade *et al*., 2006).

CONCLUSION

The findings of this study highlight the significant agronomic and zootechnical advantages of integrating *Azolla filiculoides* (AAf) into rice-fish farming systems. The AAf treatment notably enhanced key growth parameters of rice, including the number of tillers and leaf length, consistent with previous studies that emphasized the fertilizing potential of *Azolla* due to its richness in nitrogen and phosphorus. This natural fertilization, supplemented by fish excreta, creates a synergistic environment that promotes vigorous vegetative development. The AAf system also achieved the highest paddy yield (6.97 T/ha), outperforming conventional and other integrated systems, thereby confirming the superior nutrient contribution of *A. filiculoides*, especially its capacity to fix atmospheric nitrogen through its symbiosis with *Anabaena azollae*. From a zootechnical perspective, the integration of *Azolla* into fish diets improved the growth performance and survival of *Oreochromis niloticus* fry, with a specific growth rate of 2.24% day^{-1} and survival rates up to 92.53%. The nutritional profile of *Azolla*, combined with enhanced availability of natural food sources and shelter provided by rice plants and floating mats, contributed to better fish health and reduced predation. Although fish yields under the AAf treatment were lower than some previously reported figures, the system demonstrated higher efficiency and sustainability due to lower external input needs. Overall, the use of *A. filiculoides* in rice-fish systems presents a viable, eco-friendly approach to boosting both crop and fish productivity, improving resource utilization, and promoting sustainable agricultural practices in integrated farming systems.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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