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Agricultural Optimisation in Côte d'Ivoire: Sustainable and Inclusive Development of Rainfed Rice

KOFFI Antoine[1*], YEO Lacina[2], KONAN Djézou[3], BAHAN Lemonou Franck Michaël[4], DIOMANDE Métangbo[1], SORO Dogniméton[2]

[1]Department of Geosciences, UFR of Biological Sciences, Péléforo Gon Coulibaly University of Korhogo, BP 1328 Korhogo, Côte d'Ivoire
[2]Department of Soil Science, Laboratory for the Improvement of Agricultural Production, UFR Agroforestry, Jean Lorougnon Guédé University, BP 150 Daloa, Côte d'Ivoire
[3]Laboratory of Agronomy and Physiology, Rubber Program, Bimbresso Research Station, National Center for Agronomic Research (CNRA), 01 BP 1536 Abidjan, Côte d'Ivoire
[4]Rice Program, Man Research Station, Man Regional Directorate, National Center for Agronomic Research (CNRA), BP 440 Man/ Côte d'Ivoire, Tel. (225) 27 33 79 22 79

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***Corresponding author:** KOFFI Antoine
Department of Geosciences, UFR of Biological Sciences, Péléforo Gon Coulibaly University of Korhogo, BP 1328 Korhogo, Côte d'Ivoire

Abstract **Original Research Article**

To improve upland rice (Oryza sativa) production in Côte d'Ivoire, where soils are increasingly depleted in essential nutrients, a study was conducted at the CNRA research station in Man. The objective was to assess the effectiveness of the organic fertiliser Green Amino on the growth and yield performance of upland rice. Two upland varieties (IDSA 10 and IDSA 85) and four fertilisation regimes were evaluated: no fertilisation; 1.25 kg/ha of Green Amino; the recommended mineral fertilisation of 200 kg/ha NPK + 100 kg/ha urea; and a combined treatment of 200 kg/ha NPK + 1.25 kg/ha Green Amino. The experiment followed a split-plot design with four replications, assigning varieties to the main plots and fertilisation regimes to the subplots. Analysis of variance revealed significant differences between varieties and between fertilisation treatments for all measured parameters, although no significant interaction was observed between the two factors. The combined application of 1.25 kg/ha Green Amino with 200 kg/ha NPK enhanced growth indicators such as tiller number, plant height, and biomass more effectively than the exclusive use of Green Amino. Growth improvements under the recommended mineral fertilisation were less pronounced than under the combined Green Amino + NPK treatment. Both the Green Amino alone and the Green Amino + NPK regimes significantly influenced paddy yield. The sole application of 1.25 kg/ha Green Amino increased paddy yield by 7% compared with unfertilised plots, while its combination with mineral fertiliser raised yields by 37%. These two regimes produced yields statistically comparable to those obtained with the recommended fertilisation. Overall, the fertilisation regimes of 1.25 kg/ha Green Amino and 1.25 kg/ha Green Amino + 200 kg/ha NPK can be recommended as effective alternatives for upland rice production.

Keywords: *Oriza sativa*, organic fertiliser, growth parameters, yield, Man, Côte d'Ivoire.

INTRODUCTION

Rice, the primary cereal consumed in Côte d'Ivoire, is cultivated in all agro-ecological zones of the country (Konan *et al.,* 2024). There are two types of rice cultivation in Côte d'Ivoire: irrigated and rainfed. The annual national production of milled rice is estimated at 952,600 tons, while the estimated demand is 1,343,000 tons. This situation forces the Ivorian government to resort to massive imports, the cost of which has been estimated at over 223 billion CFA francs (ONDR, 2023).

To ensure food security, the Ivorian government has implemented the National Rice Development Strategy (SNDR). The SNDR aims to achieve self-sufficiency and rice exports by 2030. To reach this goal, particular attention must be paid to rainfed rice. This type of crop, which is the most important in Ivorian rice production (95% of cultivated land and 80% of production) (Charpentier *et al.,* 1999; DESDP, 2018), faces numerous constraints that limit its yield. These constraints include low soil fertility and the complete absence or low level of fertilizer use. Chemical fertilizers are recommended (López-Bellido & López-Bellido, 2021). However, they have a financial burden that subsistence farmers cannot bear, in addition to their negative environmental impacts (Gala *et al.,* 2011; Bouchard *et al.,* 2011). Therefore, it is necessary to limit their use or find an alternative.

Thus, faced with the major challenges of sustainable development, and especially with climate change, direct or stimulation-based biofertilization offers an alternative to chemical fertilizers (Djogbede *et al.,* 2012). This type of fertilizer, which is less expensive, can be accessible to all farmers. However, its effectiveness on different crops, particularly rice, is not well understood. The impact of combining it with small quantities of mineral fertilizers on rice production in Côte d'Ivoire is also unknown. Therefore, this study was conducted to assess the effectiveness of this type of fertilizer.

The overall objective of this study is to contribute to improving the yield of upland rice. Specifically, it aimed to:

- determine the effectiveness of organic fertilizer on the yield of rainfed rice compared to the recommended fertilization;
- determine the impact of combining organic and mineral fertilizers on the yield of rainfed rice.

STUDY SITE

The study was conducted at the CNRA research station in Man (Figure 1). The rainfall pattern is unimodal, meaning it has only one rainy season. In 2014 and 2015, the rains began in March and ended in October. The dry season covered the period from November to February. In 2014, an annual rainfall of 1722 mm was recorded at the station. The trial was established on Ferralsol, a slightly humus-rich soil with a silty-sandy-clay texture (0-20 cm) and a clayey-sandy texture (20-60 cm). It has good internal drainage and is loose in the topsoil (0-5 cm) (Camara, 2019). However, it exhibits a compact horizon with coarse elements (> 50%) between 20 cm and 60 cm deep. These coarse elements are essentially made up of ferruginous nodules and quartz gravel.

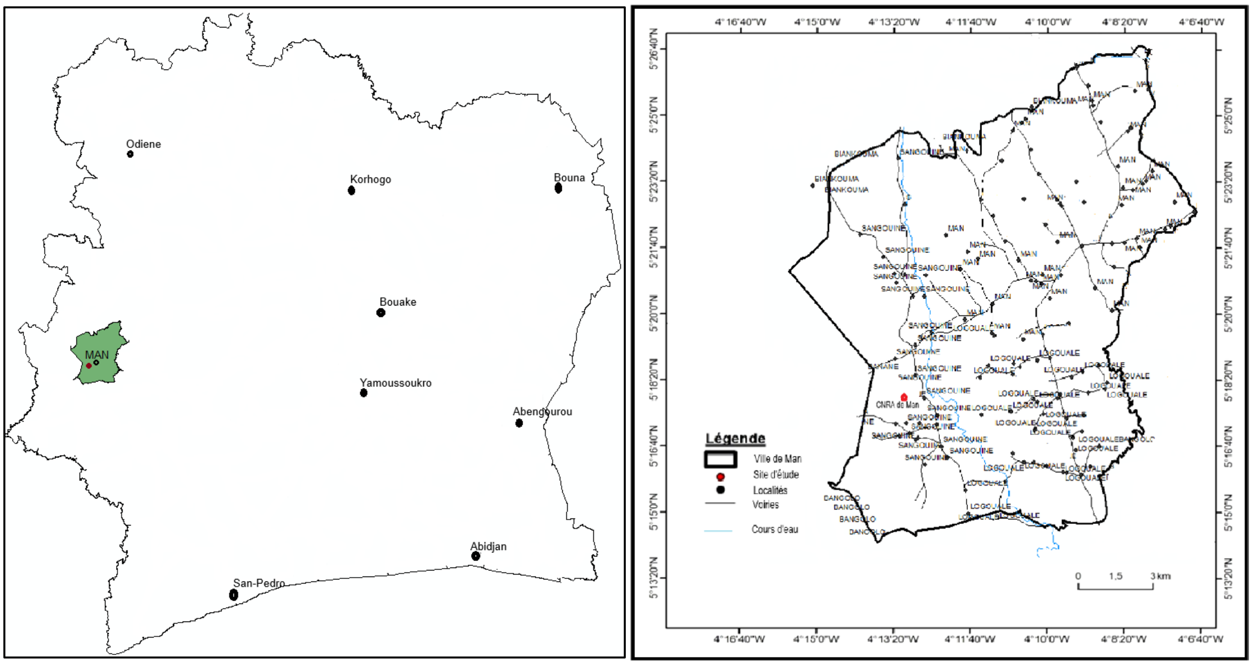

Figure 1: Location of the study site (Source: CNRA, 2022)

MATERIALS AND METHODS

MATERIAL

Plant material

The plant material used for this study consists of two improved varieties of upland rice obtained in Côte d'Ivoire by the National Center for Agronomic Research (CNRA): the short-cycle (105 days) variety IDSA 10 with a potential yield of 4.8 tha-1 and the medium-cycle (120 days) variety IDSA 85 with a potential yield of 3.5 tha-1. Both varieties have good resistance to drought, rice blast, lodging and also have good organoleptic quality.

Fertilizers

Four fertilization models were used to set up the experiment. These were:

The fertilizers used were:

- NPK fertilizers (12 24 18) and pearl urea (46% N) are the mineral fertilizers commonly used in rice cultivation in Côte d'Ivoire (Yahaya & Amadu, 2022). They are both packaged in 50 kg bags.
- An organic fertilizer: Green Amino. This is a product of the Korean company Green Harvest. It is a water-soluble compound containing 18

types of amino acids derived from animal proteins, and its nutrient content is: 11% N, 11% P, 7% K, 7% Mg and 1% B. It is packaged in a 200g airtight bag.

METHODS

Experimental setup

The experimental design used for the trial was a four-replication split-plot. The main plots were assigned to the variety with its two treatments (IDSA 10 and IDSA 85). The secondary plots (elementary plots) were assigned to the four fertilization models (Figure 2), which were:

- Model 1: no fertilizer added;
- Model 2: 200 kg/ha of NPK (12 24 18) + 100 kg/ha of urea (46% N) (recommended fertilization for rice cultivation);
- Model 3: 1.25 kg/ha of Green Amino organic fertilizer;
- Model 4: 200 kg of NPK (12 24 18) + 1.25 kg/ha of Green amino.

Each main plot measured 95 m² (19 m × 5 m) and each subplot 20 m² (5 m × 4 m). NPK fertilizer was applied before sowing at a rate of 200 kg/ha as a base dressing. Urea was applied as a maintenance dressing at a rate of 100 kg/ha, divided into two applications (50% at the beginning of tillering and 50% at stem elongation). Green Amino fertilizer was applied by spraying the plants at a rate of 1.25 kg/ha. It was used at a ratio of 5 g per 15 L of water, every 10 days from the second week after sowing until flowering. The trial was established on soil that had previously been a 3-year-old natural fallow dominated by Panicum maximum. Soil preparation consisted of clearing and removing existing vegetation, stump removal, and shallow tilling. Sowing was carried out in aligned hills spaced 0.20 m apart. Ten to fifteen days after sowing, the seedlings were thinned to a single stem. Plot maintenance consisted of manual weeding and insecticide treatments with lambdachlorthin (25 EC), applied as needed. In addition, the trial was guarded to prevent bird attacks.

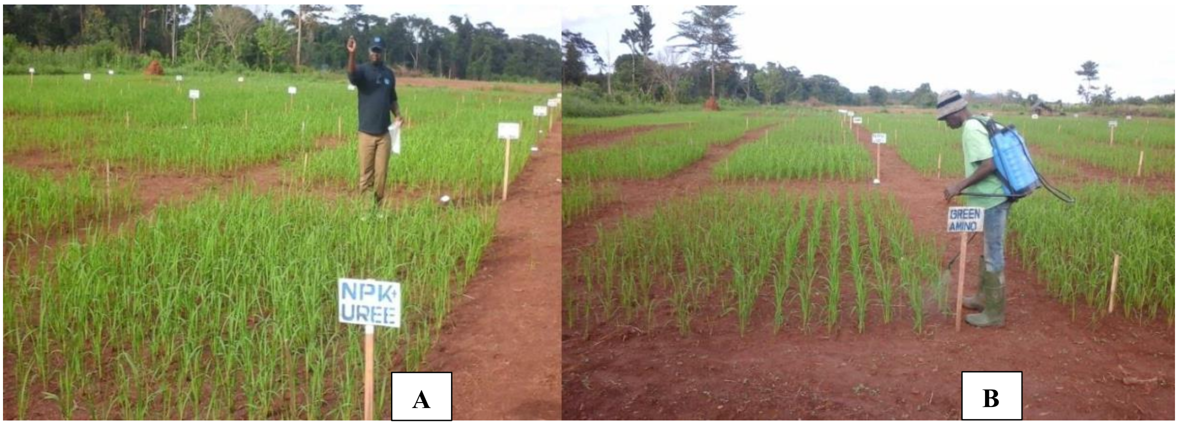

Figure 2: Application of two fertilization models in the experimental setup
A: Urea input on the IDSA 10 variety in replicate 1
B: Application of Green amino acid to the IDSA 8 variety in replicate 2

Measured variables

Physico-chemical components of the soil

Soil samples were collected using an auger in the 0–20 cm soil horizon, both before setting up the trial and after harvest. Three soil samples per plot were mixed to form a composite sample. The physicochemical components of the soil (particle size distribution, pH, organic matter content, available phosphorus) were determined at the Plant, Water and Soil Analysis Laboratory of the Higher School of Agronomy of INP-HB Yamoussoukro.

Growth parameters

The growth parameters included the number of tillers per m2, plant height and aboveground biomass.

The average number of mature tillers was estimated by counting them in the yield plots. Plant height was measured from the root collar to the tip of the longest tiller. This measurement was taken on 10 plants per plot. Aboveground biomass was determined after harvest by weighing the fresh straw on an electronic scale. This measurement was taken in the 1 m² yield plot.

Yield

The yield of paddy rice at 14% moisture content was estimated from the average weight of the grains harvested from three yield squares of 1 m × 1 m (1 m²) each, arranged diagonally within each elementary plot. The formula is as follows (Corderio *et al.,* 2021) :

$$RDT\ (14\ \%) = \left[PDG\ x\ \frac{(100 - \%\ humidity\ at\ harvest)}{1000 - 14}\right] x\ 10\ 000$$

RDT (14%): yield of paddy rice at 14% moisture;
PDG: weight of the grains after drying

Statistical analysis of data

The statistical analysis of the data consisted of an analysis of variance followed by a comparison of the Newman and Keuls means at a 5% risk level on paddy yield when differences are observed between groups.

The analyses were performed using GENSTAT software version 10.1

RESULTS

Physico-chemical parameters of the soil

Particle size analysis of the soil (0-20 cm) shows a high proportion of sand (62.53%) and clay (22.66%). Chemically, the soil is acidic (Table I). Organic matter content is relatively low, as is the cation exchange capacity (CEC) (9.76 meq 100 g soil). According to recommendations, for a CEC below 10 meq 100 g soil, fertilization is necessary for at least two growing seasons.

Table I: Physical and chemical characteristics of the 0-20 cm soil horizon before the test was set up

Site	Physical parameters					pH water	Chemical parameters							
	Particle size (%)						Organic matter (%)			Pass (ppm)	Absorbing complex (meq. 100 g-1 sol)			
	Clays	Fine silts	Coarse silt	Fine sands	Coarse sands		C	N	MO		Ca2+	Mg2+	K+	CEC
Plateau	22.66	6.96	7.55	17.83	44.7	5.5	1.5	0.13	2.58	40	0.582	0.294	0.0116	9.76

Growth parameters

Analysis of variance reveals highly significant differences between varieties and fertilization patterns for all growth parameters (Table II). However, the interaction between variety and fertilization is not significant ($P > 0.05$).

In terms of tiller density per square meter, the fertilization models using 200 kg/ha of NPK + 1.25 kg/ha of Green Amino and the research-recommended fertilization model showed significantly better performance than the 1.25 kg/ha Green Amino fertilization model and the model with no fertilizer application. These observations were identical for height and aboveground biomass (Table III).

Table II: Analysis of variance of rice growth parameters

Statistical elements	Variables		
	Tiles/m²	Height (cm)	Aerial biomass (tha-1)
Probability factor variety	0.005HS	<0.001HS	<0.001HS
Probability factor fertilization	< 0.001 HS	< 0.001 HS	0.004 HS
Probability of variety-fertilization interaction	0.750 NS	0.250 NS	0.110 NS
Overall average	126.75	107.44	1.42
CV (%)	20.2	5	37

*NS: not significant, at the 5% probability level; HS: highly significant, at the 5% probability level; CV: coefficient of variation at the 5% level.

Table III: Comparisons of fertilization models for growth parameters

Fertilization models	Variables		
	Tiles/m²	Height (cm)	Aerial biomass (tha^{-1})
Without fertilization	108b	99.2b	1.11b
1.25 kg of Green amino	98.27b	98.27b	1.11b
200 kg/ha NPK +100 kg/ha Urea	148a	115.4a	1.64a
200 kg/ha NPK + 1.25 kg/ha Green amino	153.25a	116.8a	1.80a
ppds	0.856	2,207	1.42 0.438

Ppds: smallest significant difference; numbers with the same letter in the same column are not significantly different at the 5% probability threshold.

Paddy yield

Analysis of variance shows a significant difference ($P < 0.001$) between fertilization methods at the variety level (Table IV). However, no significant difference is observed in the variety × fertilization interaction. Paddy yield increases (2.04 to 2. 80t.ha-1with the fertilization treatments (Table V). The fertilization treatments of 1.25 kg/ha of Green Amino, 200 kg/ha of NPK + 100 kg/ha of Urea, and 200 kg/ha of NPK + 1.25 kg/ha of Green Amino resulted in significantly higher paddy yields compared to the model without fertilizer application ($P < 0.63$). The paddy yields of the treatments with 1.25 kg/ha of Green Amino, 200 kg/ha of NPK + 100 kg/ha of Urea, and 200 kg/ha of NPK + 1.25 kg/ha of Green Amino were not significantly different. However, a paddy yield gain of 3.7% compared to the dose recommended by rice farming in Ivory Coast (200 kg/ha NPK + 100 kg/ha Urea) is observed with the combined use of 200 kg of NPK + 1.25 kg of Green Amino.

Table IV: Analysis of variance of paddy yield

Statistical elements	Effects		
	Variety Factor	Fertilization Factor	Variety-fertilization interaction
Probability	< 0.001	0.024	0.812
Statistical interpretation	HS*	S	NS
Overall average		2.39	
resume		31.6	

*NS: not significant at the 5% probability level; CV: coefficient of variation at the 5% level.

Table V:Comparison of fertilization models for paddy yield

Fertilization models	Paddy yield (tha^{-1})	Yield gains (%)
Without fertilization	2.04b	
1.25 kg/ha Green amino	2.20a	7.84
200 kg/ha NPK + 100 kg/ha Urea	2.70a	
200 kg/ha NPK + 1.25 kg/ha Green amino	2.80a	3.7
ppds	0.63	

ppds: smallest significant difference; figures followed by the same letter in column are not significantly different at the 5% risk.

DISCUSSION

The physicochemical analysis revealed a sandy-clay soil texture with a predominance of sand. Chemically, the soil is acidic (pH 5.5) and has low levels of organic matter and cation exchange capacity (CEC). This soil is therefore suitable for upland rice cultivation, given its sandy-clay texture. However, it is poor in minerals. These results are consistent with those of Koné et al. (2010), who showed that upland soils are poor in minerals. The application of mineral fertilizers is therefore justified. Indeed, chemical fertilizers and biofertilizers increased growth parameters and paddy yield compared to plots that did not receive fertilizer.

The biofertilizer (1.25 kg/ha of Green Amino) performed less well than the recommended fertilization (200 kg/ha NPK + 100 kg/ha Urea) for all growth parameters ($P < 0.001$). However, it optimizes these parameters when combined with 200 kg/ha of NPK. Indeed, the combination of 200 kg/ha of NPK + 1.25 kg/ha of Green Amino was not significantly different from the recommended fertilization for any growth parameters. Therefore, the combination of 200 kg/ha of NPK + 1.25 kg/ha of Green Amino proves more effective than the exclusive use of 1.25 kg/ha of Green Amino.

Fertilizer application has a significant effect on paddy yield ($P < 0.001$). Specifically, the fertilization regimes of 1.25 kg/ha of Green Amino, 200 kg/ha of NPK + 100 kg/ha of Urea, and 200 kg/ha of NPK + 1.25 kg/ha of Green Amino resulted in paddy yield increases ranging from 7% to 37% compared to the control (no fertilizer application). Fertilizer use is a key factor in increasing yield. These results are consistent with those of Fageria & Baligar (2001), who demonstrated that chemical fertilization increases paddy production.

The application rates of 1.25 kg/ha of Green Amino, its combination with 200 kg/ha of NPK, and the recommended fertilization regime did not significantly differ in paddy yield. The application rates of 1.25 kg/ha of Green Amino or 1.25 kg/ha of Green Amino + 200 kg/ha of NPK can be recommended.

Thus, in village settings, characterized by a complete absence of fertilizer use, a dose of 1.25 kg/ha of Green Amino could be offered to farmers. Indeed, the yield increase associated with this biofertilizer is estimated at 7% compared to plots without fertilizer. Furthermore, the application of this biofertilizer requires only 1.25 kg/ha (7 sachets of 200g), unlike the recommended fertilization which calls for 200 kg/ha of NPK + 100 kg/ha of urea. Adopting this biofertilizer can therefore reduce the amount of fertilizer applied to the plots and even lower the farmers' investment costs (Mounir & Hamza, (2023).

For intensive rice farming (good agricultural practices), a mixture of 200 kg/ha of NPK fertilizer and 1.25 kg/ha of Green Amino fertilizer can be used. This mixture results in an average increase in paddy rice yield of 3.7% compared to the recommended fertilization rate. Furthermore, it reduces the need for mineral fertilizers, particularly urea (1.25 kg/ha of Green Amino versus 100 kg/ha of urea).

CONCLUSION

To evaluate the effect of a biological fertilizer on upland rice, the biofertilizer "Green Amino" at a rate of 1.25 kg/ha, its combination with 200 kg/ha of NPK, and the fertilization recommended by research (200 kg/ha NPK + 100 kg/ha Urea) were used. This evaluation considered growth parameters (tillers/m², height, aboveground biomass) and paddy yield. The combination of 1.25 kg/ha of Green Amino + 200 kg/ha of NPK improved growth parameters compared to the exclusive use of 1.25 kg/ha of Green Amino. However, growth parameters did not improve as much with the recommended fertilization as with the combination of 1.25 kg/ha of Green Amino + 200 kg/ha of NPK.

The application rate of 1.25 kg/ha of Green Amino, combined with 200 kg/ha of NPK, has significant effects on paddy yield. Its sole application improves paddy yield by 7% compared to unfertilized plots. Combined with 200 kg/ha of NPK, it improves paddy yield by 37% compared to unfertilized plots. However, the application rate of 1.25 kg/ha of Green Amino and the combination of 1.25 kg/ha of Green Amino + 200 kg/ha of NPK are not significantly different from the recommended fertilization rate for yield. Therefore, the application rate of 1.25 kg/ha of Green Amino and the combination of 1.25 kg/ha of Green Amino + 200 kg/ha of NPK can be recommended for fertilizing upland rice.

In village settings, characterized by a complete absence of fertilizer use, a dose of 1.25 kg/ha of Green Amino could be offered to farmers. Its adoption could therefore reduce the amount of fertilizer applied to the plots. However, to promote these different fertilization methods, an economic study must be conducted on the costs of the quantities of Green Amino applied and the yield gains observed compared to the recommended fertilization. The application of 1.25 kg/ha of Green Amino is carried out every 10 days at a ratio of 5 g of product to 15 L of water; this equates to using 3750 L/ha of water. This application appears to be impractical under rainfed conditions for small-scale farmers. Green Harvest must therefore revise the dosage of its products to adapt them to the actual situation of farmers.

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