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EFFECTS OF VARIETIES, WATER AND NUTRIENT MANAGEMENT PRACTICES ON RICE YIELD, WATER PRODUCTIVITY, NUTRIENT USE EFFICIENCY AND FARMERS' INCOME IN CÔTE D'IVOIRE

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1 Introduction

Water is an essential resource for humanity since it serves as a breeding ground for ecosystems and plays an important role in food security, both for human consumption and agricultural use. Agriculture cannot exist without water (FAO, 2020). Irrigation uses over 70% of the water taken from rivers and groundwater. Indeed, the amount of water required to create our food is a thousand times what is required to drink and a hundred times that is required to meet our fundamental personal needs (FAO, 2004).

Rice, a major water consumer (Dajaloo, 2016), is the world's second most extensively produced crop after wheat (Lage and El Mourid, 1996). It provides food for around 40% of the world's population (WARDA, 1996). Aside from food, it is used to manufacture alcohol, starch, glucose, vinegar, oil, medicines, and other products. Rice husks are burned as fuel, and the ashes are used as fertilizer. Paddy, flour, and straw can all be consumed by animals. The latter can be utilized to make paper pulp as a raw material (Moule, 1980). The majority of fertilizers used worldwide are geared toward grain crops (Dobermann, 2007). Essential elements, according to Dembélé (2000), are nutrients that are required for plant development and seed formation. Thus, Moule (1980) estimates that there are approximately 2 kg of nitrogen (N), 1 kg of phosphorus (P2O5), and 1,250 kg of potassium (K) in 100 kg of rice grains. These important components serve numerous functions in the plant. In the current setting of the Russian-Ukrainian crisis, with the cost of mineral fertilizers skyrocketing, it is critical to reduce fertilizer use while maximizing its efficiency.

Water and nutrient management strategies could efficiently achieve the combined goals of water conservation and mineral fertilizer profitability. Indeed, reducing the amount of irrigation water and fertilizer used has a double benefit, particularly in terms of significant savings in water resources (2 to 3 times less water utilized) and nutrient efficiency. The current study seeks to develop a low-input rice farming technology (water and fertilizer) while maintaining rice agronomic performance to reduce input use and increase farmers' income. Specifically, it aims to assess the effects of varieties, water management, and nitrogen fertilizer on rice yield, nutrient use efficiency, water productivity, and farmers' income.

2 Materials and methods

2.1 Study Sites

The experiments were conducted in three rice-producing areas in Côte d'Ivoire: Bouaké, Man, and Gagnoa. The Bouaké site is located at AfriRice's main research center located approximately 30 km north of Bouaké (7.5º - 8.5º N) and (4.5º - 5.5º W). It is an area with a bimodal rainfall regime characterized by a large dry season (early November to mid-March), a large rainy season (mid-July to mid-August), and an inter-rainy season (mid-August to late October). The average rainfall is 985 mm/year. The average annual temperatures recorded are 26.25°C, 34.15°C, and 21.25°C respectively for the monthly average, maximum and minimum temperatures. The average annual solar radiation is 19.30 MJ. The vegetation is mainly made up of semi-deciduous microforests, galleries, and grassy savannah. The bedrock is mainly composed of granite-gneiss. The experiments were conducted in three rice-producing areas in Côte d'Ivoire: Bouaké, Man, and Gagnoa. The Bouaké site is located at AfriRice's main research center located approximately 30 km north of Bouaké (7.5º - 8.5º N) and (4.5º - 5.5º W). It is an area with a bimodal rainfall regime characterized by a large dry season (early November to mid-March), a large rainy season (mid-July to mid-August), and an inter-rainy season (mid-August to late October). The average rainfall is 985 mm/year. The average annual temperatures recorded are 26.25°C, 34.15°C, and 21.25°C respectively for the monthly average, maximum and minimum temperatures. The average annual solar radiation is 19.30 MJ. The vegetation is mainly made up of semi-deciduous microforests, galleries, and grassy savannah. The bedrock is mainly composed of granite-gneiss. Man is a town located in the semi-mountainous west of Côte d'Ivoire, about 600 km from Abidjan (Economic Capital of Côte d'Ivoire). The climate of Man is tropical with only one rainy season, similar to that of Bouaké, but the differences in daily and seasonal temperature and humidity make it a typical transitional climate with the mountains, very close to the Guinean climate. The average monthly temperature and rainfall are 25 °C and 174 mm respectively. The department of Gagnoa, one of the poles of rice development, is located in the Goh Region, in the Centre-West of Côte d'Ivoire (6°072 543 North, 5°572 023 West). The climate of the department of Gagnoa is humid tropical, with four seasons, including two rainy seasons and two dry seasons, with an average annual rainfall of 1,459 mm. Both rainy seasons are characterized by a large rainy season that runs from March to July and a small rainy season that runs from September to October. The two dry seasons are divided into a very severe dry season from November to February and a very short dry season from August. The relief consists of a peneplain and low plateaus with an average elevation of 200 m (Kassin *et al*., 2008).

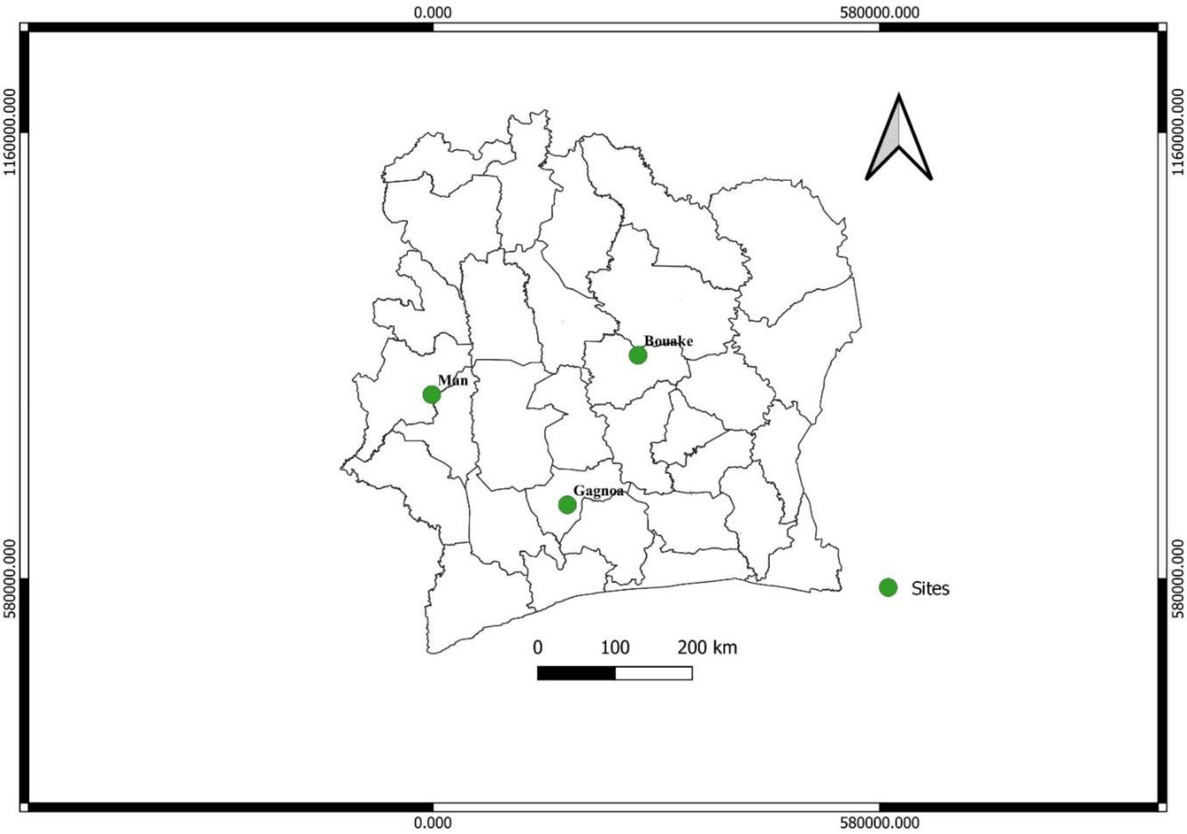

Figure 1 : Location of sites

2.2 Data collection and analysis

Following the clearance of 2,000 m^2 and the construction of bunds and canals for water management, 90 micro-plots of 3 m 5 m were delineated before two human ploughing and harrowing operations (the second ploughing occurs 10 days following the first). A three-replicate split-split-plot experiment was used (Figure 1). Its purpose is to investigate the interplay of two irrigation techniques, three fertilizer rates, and five rice types. Each replication is divided into two major plots, one for each of the two water management approaches. Specifically, the irrigation, alternate drying (AWD), and continuous flooding (CF) systems.

After the clearing of an area of 2,000 m² and the construction of bunds and canals for water management, 90 micro-plots of 3 m × 5 m were demarcated before two manual ploughing and harrowing (the second ploughing takes place ten days after the first). The experimental setup is a three-replicate split-split-plot. It is designed to study the interaction between two water managements, three fertilizer rates, and five rice varieties. Each replicate is divided into main plots representing each of the two water management practices: alternating drying (AWD) system, and continuous flooding (CF). Transplanting was done with a spacing of 20 cm × 20 cm with one seedling per hill. At the maturity of the grains (about 120 days after transplanting), the rice was mowed on two areas of 4 m² in each micro-plot from the surface of the land. After drying, threshing, and winnowing, the grains were weighed and the moisture content of the kernels was recorded. Grain yields (GDR) were calculated by reducing grain weights to 14% moisture with the following formula:

GDI (t/ha) = (dry weight grain (kg) / 8 m2) × (10000 / 1000) × ((100-H) / 86) Equation (1)

To assess nutrient efficiency, the agronomic nutrient use efficiency (EA) was calculated. In the following, RDG0 is the grain yield obtained for the control and RDGX is the grain yield obtained at the "DoseX".

EA = (RDGx-RDG0) / DoseX (Equation 2)

Water productivity has been determined by the following formula:

WE = RDG / WC (Equation 3)

With WE water efficiency and WC water consumption.

To justify the adoption of any technology, however, it must be ensured that its use will be able to generate a net benefit at least equal to that of the conventional method. To do this, we calculated the production costs taking into account the preparation of the land, the labour, and the cost of inputs except water. Profits were obtained by differentiating between the gross revenue and the cost of production.

Profit (FCFA/t) = Gross revenue (FCFA/ha) - Cost of production (FCFA/ha) Equation (5)

For statistical data processing, the Statistical Analysis System (SAS) version 9.0 software was used for this purpose. First, the dependent variables were subjected to a multi-factor analysis of variance (ANOVA Factorial) to assess the effect of the different treatments. This analysis was completed with Fisher's Minimal Significant Difference (LSD) test to classify mean values. The critical point for testing was set at 0.05. Relationships between dependent variables were assessed by calculating

Person's linear correlation coefficients. The Microsoft Excel 2013 spreadsheet was used to build the database.

3 Results

3.1 Grain yield

Grain yields are 5.31; 5.33 and 5.82 t/ha in Bouaké, Gagnoa, and Man, respectively. Rice yield increased with an increase in fertilizer application rates. The highest yield (6.8 t/ha) was achieved when the recommended level of fertilizer was applied, while the lowest yield was achieved in the plots that did not receive any fertilizer (Table 1). The agronomic efficiency of nitrogen associated was significantly higher for the half dose (70.92 kg/kg) than for the full dose (61.29 kg/kg) even though the analysis of variance does not reveal a significant effect for the level of fertilization (Table 1). On the other hand, the interaction between the level of fertilization and the site has a significant effect on the agronomic efficiency of nitrogen (Table 2).

The farmers' benefits increased with an increase in the level of fertilization, with the highest yield (648,752 FCFA/ha) obtained by the full dose. The highest revenues were obtained with the varieties WITA 4 (V2) and ARICA 9 (V3) (Table 1).

The significant effect of fertilization level and variety on grain yield is highly site-dependent (Table 2). The highest yield (7 t/ha) was recorded at Man with the full dose. The best-performing varieties were WITA 4 in Bouaké and Gagnoa and ARICA 9 in Man.

The interaction between water management, fertilizer rate, and variety does not have a significant effect on grain yield (Table 2). We can then easily designate the AWD × F2 × V2 interaction as the best treatment because the average yield obtained is 7.57 t/ha on average.

3.2 Volume of irrigation water

Water management has a substantial impact on irrigation water volume (Table 1). The alternating irrigation and drying (AWD) approach provides for a significant reduction in irrigation water volume by utilizing only 17,777 m^3/ha, whereas continuous irrigation (CF) uses 27,299 m^3/ha. The AWD system saves around 9,522 m^3/ha of water. However, AWD had no significant effect on rice yield. Besides, the AWD system shows a little increase in agronomy use efficiency (Table 1).

Water management also has a significant effect on water productivity with higher water productivity in AWD compared to CF (Table 1). Water management had a significant effect on the production cost and the net profit (Table 1).

There is an increase in water productivity with the level of fertilization. Variety also had a significant effect on water productivity with the highest water productivity achieved with WITA 4 (Table 1). Site had a significant effect on water productivity (Table 2) with the highest water productivity at Man (0.31 $kg/m^3/ha$) (Table 1). The interaction between water management and fertilizer has a significant effect on water productivity (Table 2). The highest average was achieved with AWD × F2 × V2 (7.57 t/ha).

3.3 Relationships between variables

Overall, there are significantly positive correlations between the variables: grain yield and agronomic efficiency; grain yield and water productivity; grain yield and cost of production; grain yield and net gain; net gain and agronomic efficiency; net water gain and productivity; cost of production and productivity of water; cost of production and net gain. The correlation between irrigation water volume and water productivity is significantly negative (Table 3).

Table I : Effects of Primary Treatments on Dependent Variables

Independent Variables and Interaction	Grain yield (t/ha)	Efficiency agronomic nitrogen (N)	Water Volume Irrigation (m3)	Productivity Water (kg/m3)	Workforce Productivity (FCFA/H)	Profit (FCFA/ha)	Cost of production (FCFA/ha)
Site(s)							
Man (S1)	5.82 A	46.67 b	22.367 b	0.31 A	467.28 to	585.141 A	579.055 to
Gagnoa (S2)	5.33 b	92.64 A	26.863 a	0.21 c	426.73 b	485.553 b	579.055 to
Bouaké (S3)	5.31 b	59 b	18.384 c	0.26 b	426.17 b	483.161 b	578.855 to
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0,830
Water Management (G)							
Continuous Irrigation (G0)	5.40 A	61.33 A	27.299 a	0.20 b	430.978 b	496.784 b	583.981 to
Alternating Dry Irrigation (G1)	5.57 A	70.88 A	17.777 b	0.32 A	449.141 A	539119 a	573.996 b
P-value	0,118	0,074	< 0.0001	< 0.0001	0,029	0,041	< 0.0001
Fertilizer Level (F)							
Fertilizer-free (F0)	3.98 c	------	21,890 a	0.19 c	325 c	353.502 c	442.444 c
Full dose (F2)	6.80 A	61.29 A	22.926 a	0.32 A	543 a	648.752 to	710.967 to
Half dose (F1)	5.68 b	70.92 A	22,797 to	0.27 b	453 b	551.601 b	583.555 b
P-value	< 0.0001	0,071	0,494	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Variety (V)							
NERICA-L19 (V1)	5.79 ab	57.90 A	22,940 a	0.26 b	464 ab	578.156 ab	579.018 to
WITA 4 (V2)	6.07 A	66.23 A	22.006 a	0.30 A	486 A	632.949 to	579.018 to
ARICA 9 (V3)	5.51b	68.34 A	22,747 to	0.25 b	442 b	521.812 b	579.018 to
ARICA 18 (V4)	5.01 c	66.84 A	22.287 a	0.24 b	402 c	423.985 c	579.018 to
WITA 9 (V5)	5.05 c	71.21 A	22.711 a	0.24 b	406 c	432.857 c	579.018 to
P-value	< 0.0001	0,589	0,942	0,0009	< 0.0001	< 0.0001	1

has; b ; c: grouping according to LSD

------: Missing value

Table II : Effects of Primary Treatments and Interactions on Dependent Variables

Independent variables & Interaction	Grain yield (t/ha)	Efficiency agronomy of nitrogen (N)	Water Volume Irrigation (m3)	Productivity Water (kg/m3)	Workforce Productivity (FCFA/H)	Profit (FCFA)	Cost of production (FCFA)
Site(s)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	<0.0001	< 0.0001	0,830
Water Management	0,118	0,074	< 0.0001	< 0.0001	0,029	0,041	< 0.0001
(G)	< 0.0001	0,071	0,494	< 0.0001	<0.0001	< 0.0001	< 0.0001
Fertilizer (F)	< 0.0001	0,589	0,942	0,0009	<0.0001	< 0.0001	1
Variety (V)	0,556	0,190	0,001	< 0.0001	0,534	0,539	0,137
S × G	< 0.0001	0,050	0,834	0,395	<0.0001	< 0.0001	0,962
S × F	< 0.0001	0,007	0,982	0,305	0.868	< 0.0001	1
S × V	0,415	0,630	0,878	0,0008	0.350	0,410	0,906
F × G	0,874	0,476	0,957	0,633	0.868	0,869	1
F × V	0,577	0,162	0,780	0,562	0.561	0,577	0,999
V × G	0,456	0,467	0,864	0,307	0.418	0,412	1
S × F × V	0,661	0,517	0,417	0,059	0.678	0,677	0,970
S × F × G	0,831	0,965	0,887	0,631	0.813	0,821	1
S × G × V	0,876	0,950	0,969	0,631	0.840	0,844	1
G × F × V	0,992	0,985	0,977	0,708	0.989	0,989	1
S × F × V × G							

Table III : Linear correlation coefficient between dependent variables

	Grain yield (t/ha)	Agronomic efficiency nitrogen	Water Productivity (kg/m3)	Profit (FCFA/ha)	Cost of production (FCFA/ha)	Volume of irrigation water (m3)	Workforce Productivity (FCFA/H)
Grain yield (t/ha)	1						
Agronomic efficiency nitrogen	0,36 **< 0.0001**	1					
Water productivity (kg/m3)	0,55 **< 0.0001**	0,04 0,609	1				
Profit (FCFA/ha)	0,95 **< 0.0001**	0,44 **< 0.0001**	0,53 **<0.0001**	1			
Cost of production (FCFA/ha)	0,75 **< 0.0001**	- 0,12 0,099	0,39 **< 0.0001**	0,79 **< 0.0001**	1		
Irrigation water volume (m3)	0,04 0,491	0,12 0,120	- 0,69 **< 0.0001**	0,01 0,82	0,08 0,17	1	
Productivity of the Work (FCFA/H)	1 < **0.0001**	0,36 < **0.0001**	0,56 < **0.0001**	0,96 < **0.0001**	0,73 < **0.0001**	0,02 0,70	1

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