__Research Paper__

Rice Response to Phosphorus and Potassium in Fluvisol of Second Order Lowland in a Guinea Savanna Zone of Sub-Saharan Africa

ABSTRACT

Aims: Poor management of P- and K-fertilizers can affect Nitrogen effect in rice grain yield and nutritional quality as the most limiting nutrient for rice production in second order lowland of Guinea savanna in West Africa. For development of best management strategy of N, P and K fertilizers in this agro-ecosystem, the response surface curve of rice to P- and K-fertilizer rates was assessed with the recommended rate of nitrogen.

Study design: An agronomic trial including eleven (11) treatments in three replications was laid out in a complete randomized blocks design.

Place and duration of the study: During three successive cropping cycles of rice in 2012, the study was conducted in M'be II valley of the Centre Cote d'Ivoire, a Guinea savanna zone.

Methodology: Three rates of P- $Ca(H_2PO_4)_2H_2O$ [30, 60 and 90 kgPha^{-1}] as well as three of K-KCl [25, 50 and 75kg Kha^{-1}] and their recommended rates (13kgPha^{-1} and 25kgKha^{-1}) in the humid forest zone were the treatments. A total of 80kgNha^{-1}(urea) was applied in three splits to each of the micro-plots except in the control including no fertilizer. The rice variety named NERICA L19 was transplanted.

Results: The results showed a synergism between K- fertilizations and N-nutrition of rice likewise for P-fertilizer which has limited effect on K-nutrition.

Conclusion: The rates of 10kgPha^{-1} and 75kgKha^{-1} were recommended for the production of high grain yield and nutritional quality of rice when applying 80kgNha^{-1}. However, further assessments of K and N were suggested for sustaining rice production in the studied agro-ecology.

Keywords: Lowland rice, mineral nutrition, Fluvisol, phosphorus, potassium, synergism.

1-INTRODUCTION

In West Africa and especially in Cote d'Ivoire, there is increasing of rice (*Oryza sativa* L) importance as population principal food (56kg/person/year) whereas, the supplying depend on foreign rice importation for about half of the annual local need which account for about 683 671 tons ([1],[2]). The gap observed in local production is due to the predominance of rainfed rice cultivation (80%) with an average low yield of 1 tha^{-1} according to Audebert *et al*. [3]. Therefore, the development of irrigated lowland rice with a higher potential yield [4] is required. For this purpose, the savanna zone extending over the 2/3 of the country [5] and including the most developed lowland [6] is an important potential ecology. However, the rice yield obtained in the lowlands in Cote d'Ivoire is still lower than the potential expected [2].

This reduction of yield was due to different constraints including the cultivars, the poor management of water and weed as well as the effect of other biotic constraints which are being resolved ([7], [8], [9]) unlikely for soil constraints.

In fact, only fertilizer recommendations including N, P and K were done for upland rice cultivation and for lowlands in the humid forest zone of Cote d'Ivoire ([10],[11]). These recommendations cannot be adopted in all the ecologies in the basis of site specific fertility management principle [12]. Moreover, the existing hydrographic hierarchy of lowland agro-ecologies affects the soil types and their physic-chemical properties according to the respective orders [13]. Therefore, a specific fertilizer management is required for each of lowland order for rice production when sound site specific nutrient management studies are limited to the Sahel plain agro-ecosystem in West Africa [14].

Knowledge gap was reduced by Nwilene et al. [15] when recommending N-P-K fertilizer rates for lowland rice in savanna zone of Sub-Sahara Africa. But, this ecology is subdivided into difference class including Sudan savanna, Derived savanna and Guinea savanna which are requiring specific management for rice production respectively [16]. In the Guinea savanna, morpho-pedological [17] and agro-pedological [18] characterizations showed the importance of nitrogen and/or potassium fertilizations for rice cropping in different lowland orders in the centre of Cote d'Ivoire (acid bed rock). Moreover, N-rate (about 80kgNha^{-1}) was identified by Becker and Johnson [19] for high production of lowland rice in Guinea savanna as similar in the forest zone. Still little is known about rice nutrition in phosphorus-P, meanwhile, this nutrient has high interactions with N and K [20] and account for a main component of the basal fertilizer when combined with K and N. Thus, it is important to determine the optimum doses of these nutrients in interaction with nitrogen for a rational fertilization in rice cultivation, especially in second order lowland which is more extended in Sub-Saharan Africa and particularly, in the Guinea savanna zone of Cote d'Ivoire.

In fact, the optimization of the best rate of 80kgNha^{-1}[19] for rice cultivation in lowland could decrease with inappropriate application of P and K fertilizers due to unbalanced nutrient effects, reducing rice grain yield and quality. Indeed, there is interaction between N and P [21] as well as for N and K [22]. Therefore, we assume existing interaction between P and K with synergistic or antagonistic effect on N valorization by rice, affecting its yield and nutritional quality.

The actual study is initiated to explore rice response to the rates of P and K in second order lowland of Guinea savanna zone in Côte d'Ivoire. The aim was to identify optimum rates of P and K combined with the best rate of 80kgNha^{-1} for the production of high yield and good nutritional quality of rice.

2. MATERIAL AND METHODS

2-1 Site characteristics

An on-farm trial was conducted in the irrigable valley of M'be II (8˚06N, 6˚00W, 180 m) as a semi-developed land in the centre of Cote d'Ivoire. The ecology is a Guinea savanna zone with a bimodal rainfall pattern. The average annual temperature and rainfall were 28˚C and 1200 mm respectively. A five years old fallow dominated by *Lersiahexandra* (Poaceae) and *Frimbristulis* spp (Poaceae) was preceding the experiment. The soil is a Fluvisol (Table 1) developed on granito-gneiss bed rock.

Table 1. Chemical characteristics of soil in 0 – 20 cm depth

Characteristics	Values
pH_{water}	5.5
C (gkg^{-1})	3.12
N (gkg^{-1})	0.31
P-total (mgkg^{-1})	365
Available-P (mgkg^{-1})	150
Ca (cmolkg^{-1})	3.05
Mg (cmolkg^{-1})	2.26
K (cmolkg^{-1})	0.08
Na (cmolkg^{-1})	0.17
CEC (cmolkg^{-1})	20.2

2-2 Rice variety

A rice variety named NERICA L19 (New Rice for Africa Lowland 19) was used for the study. It is an interspecific cultivar breaded by crossing *O. glaberrima* and *O. sativa* from Africa and Asia respectively. Its cropping cycle is about 90 days with a yield potential of 7-8 tha^{-1} in research station. This variety was released by Africa Rice Centre (ex-WARDA) and disseminated in 2008 belonging to the most popular cultivars for lowland agro-ecology.

2-3 Experiment lay out

An area of 1500 m^2 of bush fallow was cleaned before doing bounds and canals for water management. Thirty three (33) micro-plots of 5 m × 3m in dimension were tilled manually. The treatments were composed of P-TSP (30, 60, and 90 kgha^{-1}) and K-KCl (25, 50 and 75kgha^{-1}) and applied as basal fertilizer combined with 1/3 (27kgha^{-1}) of 80kgNha^{-1} (Urea). Recommended rates of 13kgKha^{-1} and 25kgKha^{-1} were also applied as treatment in addition to a no-fertilizer treatment as control in a randomized complete blocks design with three replications. The trial was set for three cropping cycles (Trial 1, Trial 2 and Trial 3). After 21 days, seed line nursery of rice variety NERICA L19 was transplanted per 2 plants and spaced by 20 cm × 20 cm in row and between rows. At rice tillering and panicle initiation stages, two splits of the 2/3 of N-fertilizer (80kgNha^{-1}) were applied respectively after drainage to reduced N-loss. Ten days after transplantation, about 5 cm of irrigation water was recommended until the rice maturity except during N-fertilizer application requiring drainage. Manual weeding was done at 45 days after transplantation and the harvest was done in $8m^2$ at the maturity leaving two lines in the borders.

2-4 Data collection

Before the experiment, a soil sample was done in 0 – 20 cm depth for each micro-plot (centre) using augur. Hence, a composite sample of soil was taken in order to process the physic-chemical characterization (particle size, pH_{water}, C-organic, N-total, available-P, exchangeable Calcium-Ca, magnesium-Mg, potassium-K and cation exchangeable capacity-CEC). The date of 50% of rice flowering was recorded per treatment for calculation of the physiological cycle duration. At rice maturity, the numbers of tillers (TILL) and panicles (PAN) were counted in a square meter of each micro-plot. The plant height (HEIG) was also measured for each treatment. After the harvest, the rice was threshed and the grains and straw were separately dried and weighed. The moisture content of the grain was measured and the grain yield (GY) was determined at a moisture content of 14%. But the straw yield (SY) was directly determined after the weighing operation.

Samples of grain (100g) and straw (300 g) were collected for determining N, P and K exportation in the basis of their concentrations ([N], [P] and [K]) in the samples and the yield of the concerning treatment.

2-5 Laboratory analysis

The composite soil sample was air-dried at room temperature and sieve (2mm) before it was grounded. The pH water was determined in a soil/solution ratio of 1: 2.5 using glass electrode [23]. Soil content in organic-C was determined by the method of Walkley and Black [24] and that of Olsen and Sommers [25] for total and available phosphorus contents in soil. The exchangeable cations (Ca, Mg and K) and the cation exchangeable capacity (CEC) were extracted by ammonium acetate (pH= 7) before using atomic spectrometry (Ca and Mg) and flame spectrometry (K) for reading the concentrations respectively. The total-N in soil was also determined using Kjeldahl method [26].

The concentrations of N, P and K were determined in grain and straw using Kjeldahl and mineralization method as described by Pinta [27] respectively.

2-6 Statistical analysis of data

GenStat discovery, edition 4 was used to process analyze of variance (ANOVA) of the studied parameters. Indices of mean classification were generated by XLSTAT. Pearson correlation analysis was done between P-rate, the total concentrations of N, P and K in both grain and straw using the package of SAS version 9. This software was also used for analysis of surface curve response was done for P and K respectively as well as for their interaction. Critical error for all the analysis was fixed at 5% (α = .05).

3. RESULTS

3-1 Treatment effects on yield parameters

Table 2 shows the mean values of plant height as well as the numbers of tiller and panicle per square meter in each treatment. There is higher significant ($p<.001$) effect of treatment on the plant height and number of panicles for the three cropping cycles respectively compared with that of the number of tillers. The highest mean values of plant height are observed for the treatments T4 (60P-25K), T5 (60P-50K) and T6 (60P-75K). Whereas, the treatments T3 (30P-75K), T6 (60P-75K) and T9 (90P-75K) did so for the numbers of tiller and panicle. The treatment T6 (60P-75K) is likely to be the best according to rice vegetative growth parameters. However, there is a slight decrease of the overall mean values of the studied parameters from the first to the last Trial.

Table 2: Mean values of plant height (HEIG), and numbers of tiller (TILL/m^2) and panicle (PAN/m^2) per square meter.

Treatments	HEIG (cm)				TILL/ m^2				PAN/m^2			
	Trial 1	Trial 2	Trial 3	**Mean**	Trial 1	Trial 2	Trial 3	**Mean**	Trial 1	Trial 2	Trial 3	**Mean**
$T_1(P_{30}K_{25})$	104.06a	99.63ab	100.66a	101.45a	347ab	354ab	356ab	352ab	274a	311bcd	272ab	286b
$T_2(P_{30}K_{50})$	104.2a	95.03b	96.32a	98.51a	411ab	370ab	374a	385ab	259b	261cd	248ab	256b
$T_3(P_{30}K_{75})$	101.46a	99.83ab	101.2a	100.83a	463a	383a	400a	415a	373a	357b	344a	358b
$T_4(P_{60}K_{25})$	105.13a	100.53a	97.88a	101.1a	398ab	357ab	367ab	374ab	305ab	287bcd	202ab	265b
$T_5(P_{60}K_{50})$	102.13a	101.4a	101.4a	101.6a	389ab	372ab	390a	384ab	318ab	318bcd	274ab	303b
$T_6(P_{60}K_{75})$	104.3a	97.43ab	97.43a	99.72a	444a	431a	396a	424a	258a	426a	330ab	338a
$T_7(P_{90}K_{25})$	102.56a	100.13ab	99.34a	100.67a	378ab	441ab	363ab	394ab	268b	277cd	275ab	273b
$T_8(P_{90}K_{50})$	100.86a	99.87ab	98.87a	99.86a	377ab	370ab	377a	375ab	301ab	334bc	211ab	282b
$T_9(P_{90}K_{75})$	104a	99.6ab	100.44a	101.34a	433a	395a	424a	417a	352a	336bc	372a	353a
$T_0(P_0K_0)$	90.6b	88.18c	87.8b	88.86a	235b	222b	265b	241b	193c	160 e	160b	170c
$T_F(P_{13}K_{25})$	100.8a	98.8a	93.58a	97.71a	354ab	333ab	334ab	340ab	250b	247d	247ab	248b
G. Mean	101.83	98.4	98.38	99.54	384	357	368	370	295	301	267	288
CV(%)	4.53	4.59	4.39	3.95	34.98	31.08	30.73	31.26	19.6	23.32	30.19	21.30
Pr>F	.001	.002	<.0001	<.0001	.034	.023	.026	.059	<.0001	<.0001	.012	<.0001
$LSD_{.05}$	5.08	5.21	4.3	3.48	119.6	98	104.5	103.7	52.06	49	105.7	51.05

G. Mean: Grand mean; a, b, c, d and e are indicating mean values with significant difference in column.

3-2 Rice physiological cycle duration and yields

According to the date of 50% of plant flowering, the duration of the physiological cycle was recorded per treatment as well as for the grain and straw yields (Table 3). The effect of applied treatments is highly significant (P<.001) on the studied parameters across the three trials. Highest grain yield (GY) of about 2.8 tha^{-1} was recorded for the treatments T3, T6, and T9 and the highest straw yield (SY) of about 5.2 tha^{-1} is further observed for T3 and T6. But there is no significant difference between the mean values of the physiological cycle duration of the above treatments. The overall mean value of yields is twice higher for SY than that of GY. Moreover, no significant difference is observed between the grain yield mean values of across the three cropping cycles (Figure 1) despite of 1 to 3% of reduction.

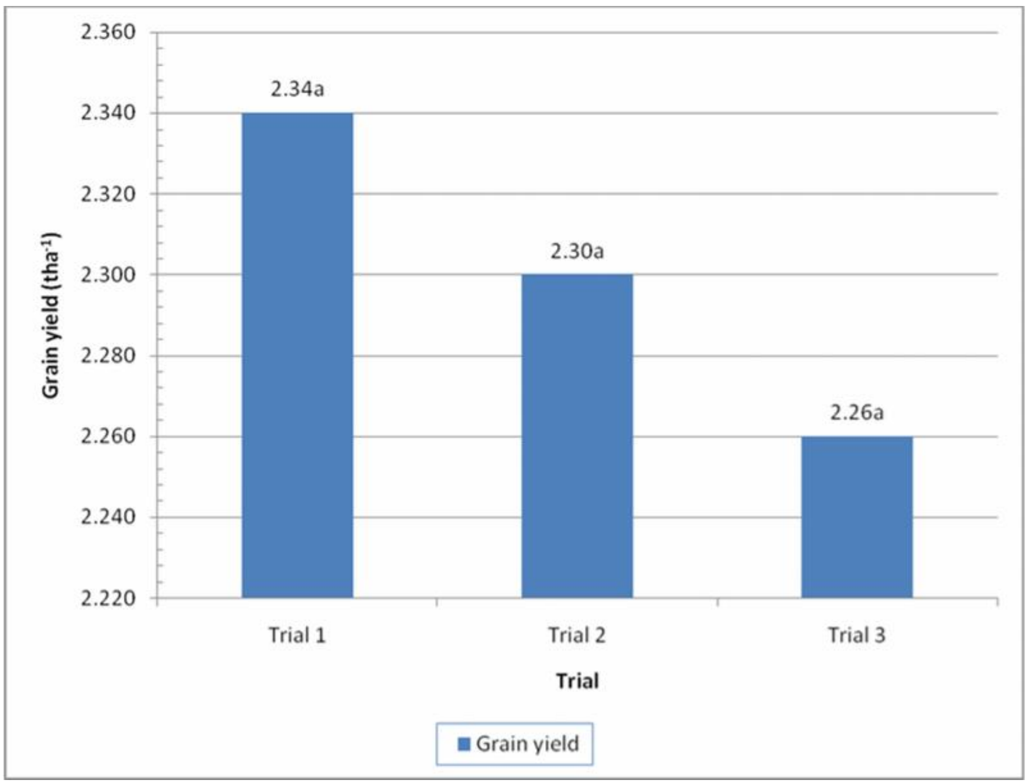

Figure 1: Rice grain yield mean values during the trials 1, 2 and 3.

3-4 Mineral concentrations in rice grain and straw

Table 4 shows the mean values of N, P, and K concentrations in rice grain per treatment for respective cropping cycles. There is significant (P<.001) effect of the treatment in these parameters. The mean values of N and P concentrations are ranging from 1.49% to 0.18% respectively with the highest values for the treatments T3, T6 and T9 while the highest concentration of K (0.26%) is determined for the treatment T3.

Table 3 : Mean values of rice grain and straw yields as well as physiological cycle duration per treatment

Treatments	Grain yield (tha^{-1})				Straw yield (tha^{-1})				Physiological cycle duration (days)			
	Trial 1	Trial 2	Trial 3	**Mean**	Trial 1	Trial 2	Trial 3	**Mean**	Trial 1	Trial 2	Trial 3	**Mean**
$T_1(P_{30}K_{25})$	2.19bc	2.11c	2.10d	2.13d	4.62bc	4.54cd	3.83 e	4.33cd	87 cd	89b	91b	89b
$T_2(P_{30}K_{50})$	2.34abc	2.34b	2.29bc	2.32bc	4.97ab	4.83bc	4.82b	4.88b	85d	88bc	91b	88b
$T_3(P_{30}K_{75})$	2.92a	2.79a	2.73a	2.81a	5.51a	5.14ab	4.96ab	5.20ab	85d	87bc	89bc	87b
$T_4(P_{60}K_{25})$	2.23bc	2.19bc	2.16d	2.19cd	4.86ab	4.54cd	4.02 e	4.47cd	89bc	85bc	89bc	88b
$T_5(P_{60}K_{50})$	2.49abc	2.28bc	2.31bc	2.36b	4.90ab	4.33de	4.72bc	4.65c	90b	86bc	87cd	88b
$T_6(P_{60}K_{75})$	2.864a	2.88a	2.77a	2.84a	5.23ab	5.33a	5.20a	5.25a	88bc	83c	88cd	86b
$T_7(P_{90}K_{25})$	2.16bc	2.13c	2.19cd	2.16d	4.84ab	4.44cde	4.44cd	4.57c	91b	87bc	86cd	88b
$T_8(P_{90}K_{50})$	2.33abc	2.32b	2.34b	2.33bc	4.51bc	4.34de	4.34d	4.40cd	91b	85bc	85de	87b
$T_9(P_{90}K_{75})$	2.74ab	2.75a	2.80a	2.76a	5.14ab	5.07ab	5.28a	5.16ab	86cd	85bc	83 e	85b
$T_0(P_0K_0)$	1.48d	1.43e	1.43f	1.44f	3.55d	3.14f	3.14f	3.27e	96a	96a	96a	96a
$T_F(P_{13}K_{25})$	1.99cd	1.89d	1.84 e	1.91e	4.05cd	4.03e	3.92e	4.00d	95a	94a	94a	94a
G. Mean	2.34	2.28	2.27	2.30	4.74	4.52	4.43	4.49	90	88	89	89
CV(%)	18.69	18.04	17.64	17.60	12.52	13.44	14.66	13.39	4.41	4.68	4.33	3.55
Pr>F	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
$LSD_{.05}$	0.35	0.13	0.10	0.275	0.53	0.33	0.28	0.123	2.88	3.2	2.16	1.9

G. Mean : Grand mean, a, b, c, d, e and f are indicating mean values with significant difference in column.

Table 4 : Mean values of N, P and K concentrations in rice grain.

Treatments	**N (%) c**oncentration				**P (%) c**oncentration				**K (%)** concentration			
	Trial 1	Trial 2	Trial 3	**Mean**	Trial 1	Trial 2	Trial 3	**Mean**	Trial 1	Trial 2	Trial 3	**Mean**
$T_1(P_{30}K_{25})$	1.40b	1.33c	1.29d	1.34d	0.177c	0.178b	0.157cd	0.17b	0.23cd	0.21bc	0.21 e	0.21d
$T_2(P_{30}K_{50})$	1.417b	1.36c	1.32d	1.36cd	0.183c	0.170b	0.147cd	0.16b	0.22cde	0.22bc	0.23de	0.22cd
$T_3(P_{30}K_{75})$	2.02a	1.79a	1.73a	1.85a	0.257a	0.223a	0.180ab	0.22a	0.27a	0.26a	0.27a	0.26a
$T_4(P_{60}K_{25})$	1.52b	1.43bc	1.39cd	1.44bc	0.190c	0.180b	0.150cd	0.17b	0.24bc	0.23bc	0.22de	0.22cd
$T_5(P_{60}K_{50})$	1.50b	1.47bc	1.51bc	1.49b	0.190c	0.190b	0.153cd	0.17b	0.21cde	0.21c	0.23de	0.21d
$T_6(P_{60}K_{75})$	1.89a	1.91a	1.75a	1.85a	0.233b	0.237a	0.190ab	0.22a	0.25ab	0.26a	0.25b	0.25b
$T_7(P_{90}K_{25})$	1.56b	1.47bc	1.41cd	1.48b	0.200c	0.180b	0.170bc	0.18b	0.20de	0.22bc	0.23cd	0.22cd
$T_8(P_{90}K_{50})$	1.57b	1.53b	1.57b	1.55b	0.197c	0.190b	0.160c	0.18b	0.23cde	0.24b	0.24bc	0.23c
$T_9(P_{90}K_{75})$	1.88a	1.87a	1.68a	1.79a	0.227b	0.224a	0.207a	0.21a	0.25ab	0.25a	0.26b	0.25b
$T_0(P_0K_0)$	1.04d	1.03 e	1.08 e	1.05f	0.127 e	0.117d	0.110 e	0.11d	0.15f	0.17d	0.18g	0.17f
$T_F(P_{13}K_{25})$	1.21c	1.18 d	1.13 e	1.17 e	0.147d	0.143c	0.130d	0.14c	0.20 e	0.18d	0.19f	0.19 e
G. Mean	1.55	1.48	1.43	1.49	0.19	0.18	0.16	0.17	0.22	0.22	0.23	0.22
CV (%)	6.3	4.7	4.1	3.3	5.3	4.3	6.9	4.1	4.8	3.3	3.0	2.3
Pr>F	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
$LSD_{.05}$	0.164	0.117	0.100	0.084	0.017	0135	0.018	0.012	0.018	0.012	0.011	0.008

G. Mean: Grand mean; a, b, c, d, e and f are indicating mean values with significant difference in column.

Table 5 : Mean values of N, P and K concentrations in rice straw.

Treatments	N (%) concentration				P (%) concentration				K (%) concentration			
	Trial 1	Trial 2	Trial 3	**Mean**	Trial 1	Trial 2	Trial 3	**Mean**	Trial 1	Trial 2	Trial 3	**Mean**
$T_1(P_{30}K_{25})$	0.64bcd	0.57de	0.69b	0.63d	0.10bc	0.10b	0.07bc	0.09b	1.28bcd	1.27cd	1.26cde	1.27de
$T_2(P_{30}K_{50})$	0.62bcd	0.59de	0.59bc	0.60d	0.11bc	0.11b	0.08b	0.09b	1.26bcd	1.24cd	1.22def	1.23de
$T_3(P_{30}K_{75})$	1.32a	1.02b	1.03a	1.12a	0.16a	0.15a	0.11a	0.14a	2.14a	1.84b	1.78a	1.91a
$T_4(P_{60}K_{25})$	0.71bc	0.70cd	0.67b	0.69cd	0.10bc	0.12bc	0.07bc	0.09b	1.32bc	1.33cd	1.32cd	1.31cd
$T_5(P_{60}K_{50})$	0.70bc	0.70cd	0.73b	0.71cd	0.12b	0.11b	0.06c	0.10b	1.43b	1.46c	1.38bc	1.42bc
$T_6(P_{60}K_{75})$	1.22a	1.08b	1.22a	1.17a	0.14a	0.16a	0.10a	0.14a	2.04a	2.07a	1.78a	1.96a
$T_7(P_{90}K_{25})$	0.92b	0.87c	0.80b	0.86b	0.12b	0.11b	0.07b	0.10b	1.48b	1.49c	1.41bc	1.45bc
$T_8(P_{90}K_{50})$	0.85b	0.78c	0.73b	0.78bc	0.13b	0.09bc	0.08b	0.09b	1.55b	1.53c	1.46b	1.51b
$T_9(P_{90}K_{75})$	1.22a	1.24a	1.14a	1.20a	0.15a	0.15a	0.11a	0.14a	1.95a	1.99ab	1.79a	1.91a
$T_0(P_0K_0)$	0.34d	0.38f	0.37d	0.36e	0.06d	0.06d	0.03e	0.05d	1.05d	1.06d	1.09f	1.06f
$T_F(P_{13}K_{25})$	0.44cd	0.44ef	0.47cd	0.45 e	0.08cd	0.08c	0.05d	0.07c	1.15cd	1.48d	1.13ef	1.14ef
G. Mean	0.81	0.76	0.78	0.78	0.11	0.11	0.08	0.10	1.52	1.50	1.42	1.47
CV (%)	17.4	10.0	10.9	8.2	8.9	9.1	7.2	5.5	7.6	8.0	4.8	4.7
Pr>F	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
$LSD_{.05}$	0.239	0.1288	0.1418	0.108	0.017	0.017	0.009	0.009	0.194	0.201	0.114	0.117

G. Mean: Grand mean; a, b, c, d, e and f are indicating mean values with significant difference in column.

There is also a significant effect of the treatments on the related mineral concentrations in rice straw (Table 5), and the highest concentrations are observed for treatments T3, T6 and T9 indifferently to cropping cycle.

Table 6: Pearson correlation coefficient (R) and probability (P) between P-rate and total concentrations of N, P and K in above ground biomass (grain and straw)

		P-rate	**K**	**N**	**P**
P-rate	R	1			
	P>| t |				
K	R	0.53	1		
	P>| t |	.09			
N	R	0.60	0.99	1	
	P>| t |	.04	<.0001		
P	R	0.56	0.96	0.98	1
	P>| t |	.06	<.0001	<.0001	

P-rate is positively (0.60) and significantly (p =.04) correlated with the total N concentration in above ground dry matter contrasting with the result observed for P-rate and K concentration. However, positive and significant correlations are also observed between K concentration and that of N (0.99) and P (0.96) respectively.

3-5 Rice response curves to the rates of P and K

Figure 2 shows rice response to the rates of P-fertilizer. A polygonal trend is observed showing a response of rice grain yield early at $10kgPha^{-1}$. The increase of P-rates further induces a slight increasing of grain yield up to $2tha^{-1}$ corresponding to the rate of $47.50kgPha^{-1}$. Further application of P-fertilizer provokes yield declining up to the rate of $90kgPha^{-1}$.

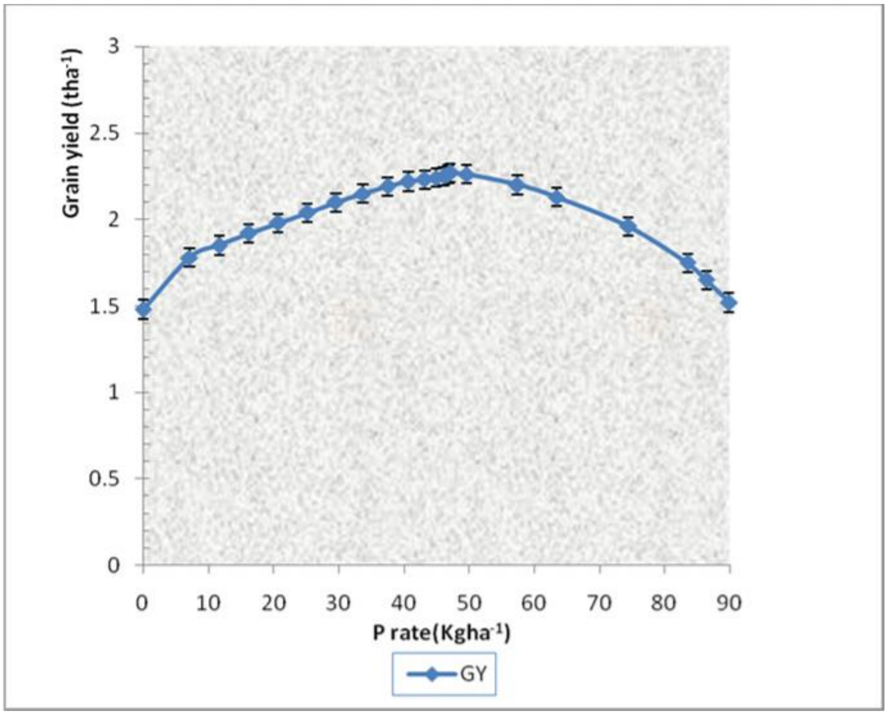

Figure 2: Rice grain yield (GY) response curve to P-rates.

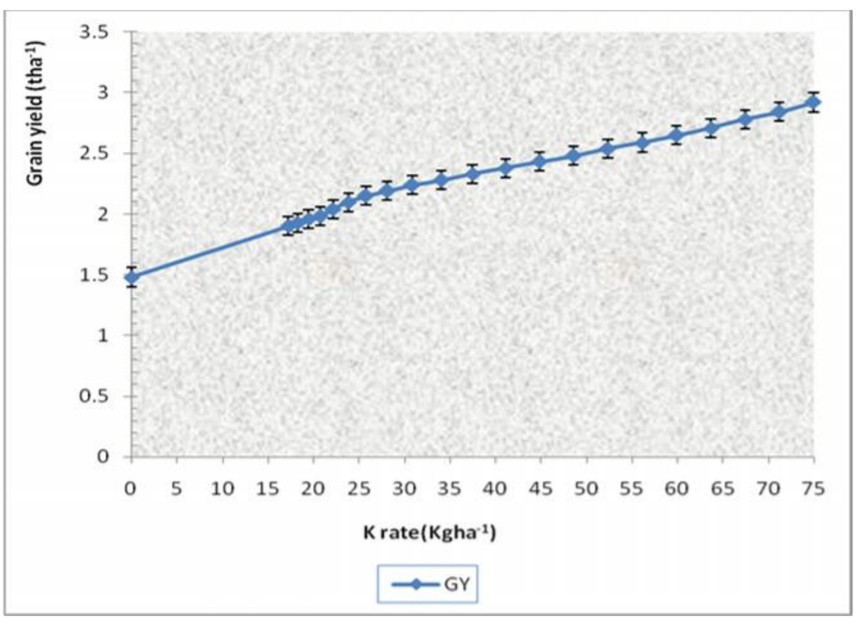

Figure 3: Rice grain yield (GY) response curve to K-rates.

Figure 3 shows a low response of rice grain yield (<1.75 tha^{-1}) to K-rates ranging from 0 to 20kgha^{-1}. Thereafter, an increasing of rice response to K-rates is observed as illustrated by a linear trend of grain yield according to the increase of the fertilizer application up to 75kgKha^{-1} for a grain yield of 3tha^{-1}.

The characteristics of rice response to the combination of different rates of P- and K-fertilizers are presented in Table 7 and Figure 4. There is a significant (*P*<.0001) linear trend with R^2 = .94 of rice response whereas, these parameters are minimized for the quadratic trend (*P*=.04; R^2=.037) according to Table 7. In addition to the information recorded in Figures 2 and 3, rice response is likely to be more depending to K-fertilizer when combine with that of P according to Figure 4.

Table 7: Characteristics of surface curve response of rice to P- and K- fertilizers rates.

Regression	DF	SSM	R^2	Pr> F
Linear	2	1.611	0.9402	< .0001
Quadratic	2	0.063	0.0372	.0406
Cross Produce	1	0.014	0.0083	.1481
Total model	5	1.689	0.9857	.0001
Optimum rate of P (tha^{-1})				47.27
Optimum rate of K (tha^{-1})				74.99

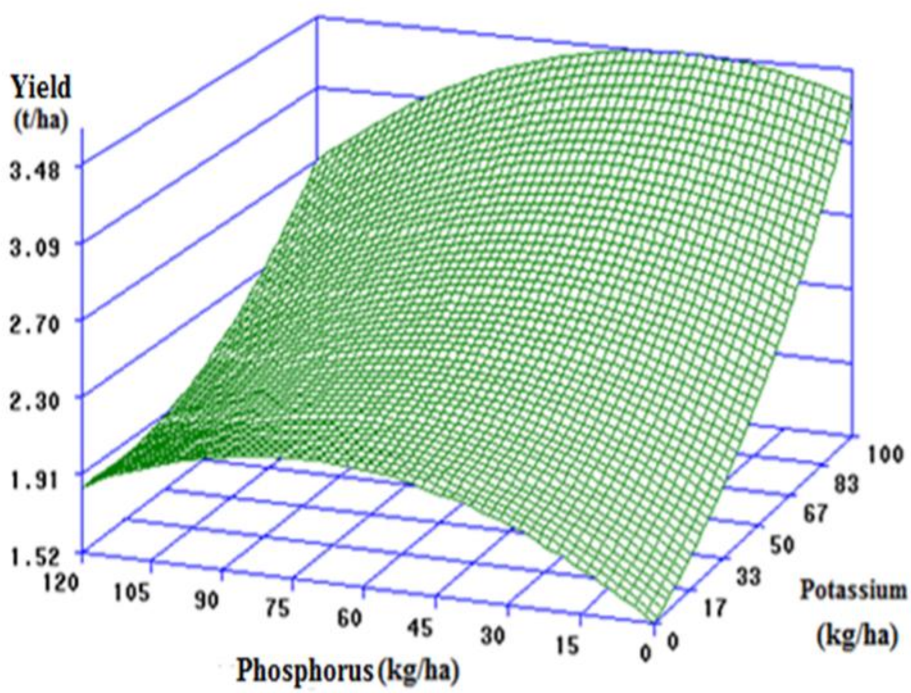

Figure 4: Rice surface curve response to P- and K-fetilizer rates combined with $80kgNha^{-1}$.

4. DISCUSSION

4-1 Quantitative and qualitative improvement of rice by potassium

The soil of the studied site has a low content of K (0.08 $cmolkg^{-1}$) with a K/CEC ratio of less than 3% confirming this nutrient deficiency. This assertion is further supported by the response of rice yield to the rates of K as observed from $10kgKha^{-1}$ with an increasing linear trend up to $75kgKha^{-1}$. Therefore, the recommended rate of $25kgKha^{-1}$ by Sanogo *et al*. [11] for humid forest ecology is not suitable for the studied agro-ecology. In fact, this recommendation will induce about $2tha^{-1}$ as grain yield while it was possible to observed $3tha^{-1}$ by applying $75kgKha^{-1}$ according to our results (Figure 3). However, there is a need to explore the net benefit of such yield gap according to fertilizer strategy [28]. Anyway, these analyses justified our assumption of site fertility management [12] requirement for K-fertilization strategy improvement in lowland rice cultivation. In fact, previous knowledge is related to the humid forest zone while our study was conducted in a Guinea savanna zone. In other hand, our finding corroborate with the results of Konan [18] concerning K-deficiency for rice cultivation in the studied agro-ecology emphasizing the increase of N concentration in the grain for the highest rate of K ($75kgKha^{-1}$). This aspect revealed high translocation of N into the grain depending in K-fertilizer supplying attesting a synergistic relation between both nutrients as mentioned by Slaton *et al.*[22]. A good water management is required to reduce leaching and denitrification process of N in order to enhance nitrogen use efficiency across seasons (dry and wet) [29]. As nitrogen is essential for protein synthesis ([30],[31]), we deducted that K-fertilization can improve rice grain nutritional quality particularly since this synergism also occurred for P and K (Table 6).

Therefore, our study pointed out quantitative and qualitative improvement of rice production in second order lowland in Guinea savanna depending in K-fertilization.

4-2 Limited and mitigated effect of phosphorus

The studied soil content (150 $mgkg^{-1}$) of available-P as determined by Olsen method was ten times higher than the critical level [32]. However, there was a response of rice to applied P-rates as observed significantly for the numbers of tiller and panicle (Table 2) as well as for the grain yield. The grain yield response was observed from the rate of $10kgPha^{-1}$ which induced yield increasing by $0.3tha^{-1}$ compared with that ($1.5tha^{-1}$) of the control treatment (T0). Further increasing of P-rate up to $45kgPha^{-1}$ has induced slight increasing of the grain yield to a maximum of $2tha^{-1}$ thereafter; the grain yield declined for additional application of P-rates. This result is further contrasting with the studied done by Konan [18] in the same ecology. But the quadratic trends of rice grain and straw yields according to P-rates as observed in the actual study can explain the low yield obtained by this author when applying $60kgPha^{-1}$. In fact, the yields were significantly reduced from $45kgPha^{-1}$ to $90kgPha^{-1}$ (Table 3). However, similar contrast of rice response to P was also observed with $916mgPkg^{-1}$ (Olsen) in a soil during the work done by Singh et al. [33] as consequence of negative balance of soil P content across successive cropping whereas, this response occurred early during the first cropping cycle of the actual study. It is likely that P-deficiency has occurred ongoing cropping similarly to the assertion of Alva, Larsen and Bille [34]: P-immobilization results to oxygen secretion by rice roots under submersion. Moreover, reversibility of P as resistant P-Ca can occurred because of the nature of the bed rock of the studied soil [35]. However, increasing P availability was also observed by Jones et al. [36] under flooding condition.

Definitively, we assert that rice response to 10kgPha^{-1} can be observed even in a soil with 150kgPkg^{-1} (Olsen) as result of P-immobilization with mitigated effect which is limited at 45kgPha^{-1} in the studied agro-ecosystem. Consequently, the increase of P-rate throughout the treatments T3, T6 and T9 did not induce significant difference between the concentrations of N, P and K in the grain and straw respectively. However, total N concentration in above ground dry matter was positively and significantly correlated to P-rate (Table 6). The calcium contained in phosphate fertilizer can contribute to this as synergism effect with described by Saijo et al. [37].

Therefore, in spite of the limited effect of P-rates on rice yield, it is likely to increase rice grain nutritional quality in relation to N uptake when increasing supplied P. In turn, P and K uptake were not concerned as much contrasting with the role of P-nutrition in the active transport of nutrients in plants [38].

In the basis of these analyses, there is a need of further investigations of rice P-nutrition in irrigated lowland where the submersion can confers some particularities to the soil properties [39] compared with the upland ecology.

4-3 Sustainability of rice production

The treatments T3, T6 and T9 including 30, 60 and 90kgPha^{-1} respectively which was combined with constant rates of N (80kgha^{-1}) and K (75kgha^{-1}) have induced the highest grain yields with shorter physiological cycles (Table 3) and contrasting with the recommended rates for lowland rice cultivation in the humid forest zone [11]. Unarguably, the rates of 80kgNha^{-1}, 30kgPha^{-1} and 75kgKha^{-1} can be recommended for rice production in the studied agro-ecology. However, the yield observed for the rate of 10kgPha^{-1} in Figure 2 did not differed significantly with that of 30kgPha^{-1} allowing change in fertilizer recommendation for rice cultivation in second order lowland of Guinea savanna zone for economical reasons that can influence the adoption of fertilizer recommendation [40].

There is also a possibility to increase the rice grain yield by further increase of K-fertilizer rate in the basis of the linear trend observed for the grain yield (Figures 3 and 4). Indeed, the increase of K-rate is necessary because of the exportation of about 61.20 kgKha^{-1} per cropping cycle and the low (<0.10 cmolkg^{-1}) K content in the soil. In fact, a best fertilizer management might be able to restore the fertility of the soil and supply the crop need of nutrients [41]. In this basis, the rate of 75kgKha^{-1} may be insufficient regarding to the yield reduction across the successive cropping cycles although not significant during the experiment, such trend of yields can impairs the sustainability of rice production in lowland as far as. Thus, we suggest the increase of applying rate of K over 75kgKha^{-1} and to assess rice response to N in order to determine their optimum doses during further study in the way of sustaining rice production in second order lowland of the Guinea savanna zone in Sub-Saharan Africa. In fact, the high production of rice as indentify for about 80kgNha^{-1} by Becker and Johnson [19] was not specific to lowland orders. Nutrient management tool as QUEFTS model ([42];[43]) should be use considering particularly season effect as it can be induced in different locations.

5. CONCLUSION

Our study revealed an optimization of rice nutrition in nitrogen due to potassium and phosphorus fertilizations on Fluvisols as induce by a synergism effect, resulting quantitative and qualitative improvement of rice production. It is recommended the application of 10kgPha^{-1} and 75kgKha^{-1}

for quantitative and qualitative rice production in irrigated second order lowland of Guinea savanna which is different with the previous recommended fertilizer practice in the forest zone.

However, for improving the sustainability of rice production, it is suggested to deepen knowledge of rice nutrition in phosphorus and to reassess K-rates in the studied agro-ecosystem using model and emphasizing site and season effects when specific rate of N should be identified.

REFERENCES

1. FAOSTAT. Aperçu du développement rizicole en Côte d'Ivoire. 2009. Accessed 17 May 2010. Available: http://www.faostat.fao.org/ site/567/DesktopDefault.a. French

2. MINAGRI-PNR. Note d'orientation et programmes de relance de l'activité rizicole en Côte d'Ivoire. Abidjan : Ministère de l'Agriculture, Ministère de l'économie et des Finances; 2008. French

3. Audebert A, Becker M, Johnson D. Differential response of rice to hydrological conditions and agronomic management. Afr Crops Sci J.1999; 4:107–111.

4. Touré A, Mahaman CM, Becker M, Johnson D. Approche diagnostique pour mieux cibler les interventions culturales dans les bas-fonds rizicoles de Côte d'Ivoire. Agron Afr. 2005 ; 17 (3) 219-225. French

5. MINAGRI. Présentation générale de la végétation de la Côte d'Ivoire. Abidjan : Ministère de l'agriculture. 2013. Accessed 16 April 2013. Available: http://www.agriculture.gouv.ci French

6. Eschenbrenner V. Etude géomorphologique et pédologique de la région de Tanda (Côte d'Ivoire). Abidjan: ORSTOM;1969. French

7. Becker M, Johnson DE. Rice yield and productivity gaps in irrigated systems of the forest zone of Côte d'Ivoire. Field Crops Res.1999; 60, 201–208.

8. WARDA (West Africa Rice Development Association). WARDA Annual Report 2001-2002: Breeding rice for the high-potentiel irrigated system. Bouaké: WARDA; 2002.

9. Nwlene FE, Nwanze KF, Okhidievbe O. African Rice Gall Midge: Biology, and control-Field guide and technical manual. Cotonou: AfricaRice center ; 2006.

10. Gala BTJ, Camara M, N'gbesso M, Keli ZJ. Bien fertiliser le riz pluvial en Côte d'Ivoire. Abidjan : CNRA ; 2010. French

11. Sanogo S, Camara M, Zouzou M, Keli Z, Messoum F, Sekou A. Effets de la fertilisation minérale sur des variétés améliorées de riz en condition irriguée à Gagnoa, Côte d'Ivoire. J Appl Biosci. 2010; 35: 2235 – 2243. French

12. Bationo A, Waswa B, Kihara J, Kimetu J. Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: challenges and opportunity. New York: Springer; 2007.

13. Raunet M. Bas-fonds et riziculture en Afrique : approche structurale et comparative. Agron Trop.1985 ; 40 (3) : 181-201. French

14. Haefele SM, Wopereis MCS. Combining field and simulation studies to improve fertilizer recommendations for irrigated rice in the Senegal River Valley. In : Dobermann A, Witt C, Dawe D, editors. Incresing productivity of intensive rice systems through site specific nutrient management. Enfield and Los Baños : Science Publishers, Inc.& International Rice Research Institute (IRRI); 2004.

15. Nwilene FE, Oikeh SO, Agunbiade TA, Oladime O, Ajayi O, Sie M, et al. Growing lowland rice: a production handbook. Cotonu: Africa Rice Centre; 2006.

16. Guei RG, Fagade SO. Promissing technologies for rice production in West and Central. Bouaké, Rome: WARDA, FAO; 2002.

17. Diatta S, Kone B. Etude de quelques petits bas-fonds dans la vallée du Bandama. Abidjan-Bouaké : PAM-ADRAO; 2001.French

18. Konan KF. Diagnostic minéral d'un sol de bas-fond secondaire sur granito-gneiss pour la riziculture irriguée en zone de savane guinéenne: les contraintes nutritionnelles et fumure de base. Mémoire de master. Abidjan: Université FHB; 2013. French

19. Becker M, Johnson DE. Improved water control and crop management effect on lowland rice productivity in West Africa. Nutr Cycl Agroecosyst. 2001 ; 59: 119 - 127.

20. Dobermann A, Fairhurst T. Rice: Nutrient disorders and Nutrient Managenament. Potash and Phosphate Institute, Phosphate Institute of Canada and International Rice Institute, editor, 1rst edition. Oxford : Graphic Printers Pte Ltd; 2000.

21. YosefTabar S. Effect of Nitrogen and Phosphorus Fertilizer on Growth and Yield Rice. Int J Agron Plant Prod. 2012. 3(12): 579-584.

22. Slaton NA, Roberts TL, Norman RJ, Massey CG, De Long RE, Shafer J, et al. Rice Response to Nitrogen and Potassium Fertilizer Rates. In: Norman RJ and Moldenhauer KAK. editors. B.R. Wells Rice Research Studies. Research Series 591. Fayetteville: University of Arkansas Agricultural Experiment Station; 2010.

23. Thomas GW. Soil pH and soil acidity. In: Sparks DL, Page AL, Helmke PA, Loeppert RH, editors. Methods of soil analysis. Part 3 - Chemical Methods. Book Series 5. Madison, Winsconsin: American Society of Agronomy, Soil Sciences Society of America; 1996.

24. Nelson DW, Sommers LE. Total carbon, organic carbon, and organic matter. In: Sparks DL, Page AL, Helmke PA, Loeppert RH, editors. Methods of soil analysis.Part 3 - Chemical Methods Book Series 5. Madison, Wisconsin : American Society of Agronomy, Soil Sciences Society of America; 1996.

25. Olsen SR, Sommers LE. Phosphorus. In: Page AL, Miller RH, Kenney DR, editors. Methods of Soil Analysis.Part 2. Chemical and Microbiological Properties, Agronomy 9, Second Edition. Madison, Wisconsin: American Society of Agronomy, Soil Sciences Society of America; 1982.

26. Bremner JM. Nitrogen-total. In: Sparks DL, Page AL, Helmke PA, Loeppert RH, editors. Methods of soil analysis.Part 3 - Chemical Methods.Book Series 5. Madison, Wisconsin: American Society of Agronomy, Soil Sciences Society of America; 1996.

27. Pinta M. Méthodes de référence pour la détermination des éléments minéraux dans les végétaux. ORSTOM. 16085, Bondy: ORSTOM; 1968. French

28. Law-Ogbomo KE, Emokaro CO. Economic Analysis of the Effect of Fertilizer Application on the Performance of White Guinea Yam in Different Ecological Zones of Edo State, Nigeria. World J Agric Sci. 2009; 5 (1): 121-125

29. De Datta SK, Buresh RJ. Integrated nitrogen management in irrigated rice. Adv Soil Sci. 1989; 10: 143 – 169.

30. DeDatta SK, Obcemea WN, Jana RK. Protein content of rice grain as affected by nitrogen fertilizer and some ureas. Agron J. 1972; 64: 785 – 788.

31. Crusciol CAC, Arl O, Soratto RP, Mateus GP. Grain quality of upland cultivars in response to cropping systems in the Brazilian tropical savanna. Sci Agric. 2008; 65 (5): 468 – 473.

32. Cooke GW. The control of soil fertility. London: Crosby-Lockwood; 1967.

33. Singh Y, Singh SP, Bhardwaj AK. Long-term effects of Nitrogen, Phosphorus, and Potassium Fertilizers on Rice-Wheat productivity and properties of Mollisols in Himalayan Foothills. In: Abrol, IP, Bronson KF, Duxbury JM, Gupta RK, editors. Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems. Rice-Wheat Consortium Paper Series 6. Rice-wheat consortium for the Indo-Gangetic plains. New Delhi: Rice-Wheat Consortium;2000.

34. Alva AK, Larsen S, Bille SW. The influence of rhizosphere in rice crop on resin extractable phosphate in flooded soils at various levels of phosphate applications. Plant Soil. 1980 ; 56: 17-25.

35. Abekoe MK, Tiessen H. Phosphorus forms, lateritic nodules and soil properties along a hillslope in northern Ghana. Catena. 1998; 33: 1 – 15.

36. Jones US, Katyal JC, Mamaril CP, Park CS. Wetland rice nutrient deficiencies other than nitrogen. In*:* IRRI (eds). Rice research strategies for the future. Manila : International Rice ; 1982.

37. Saijo Y, Kinoshita N, Ishiyama K, Hata S, Kyozukata J, Hayakawa T, et al. A Ca^{2+} - Dependent protein Kinase that endows rice plants with cold-and-salt stress tolerance functions in vascular bundles. Plant Cellphysiol. 2001; 42 (11): 1228–1233.

38. Palta JP. Stress Interactions at the Cellular and Membrane Levels. Horti Sci. 1990; 25(11): 1377- 1381.

39. Ponnamperuma FN.The chemistry of submerged soils. Adv Agron. 1972; 24:29– 96.

40. Pingali PL, Hossain M, Pandey S, Price LL. Economics of nutrient management in Asian rice systems: towards increasing knowledge intensity. Field Crops Res. 1998; 56:157-176.

41. Stoorvogel JJ, Smaling EM. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000. Main report.Vol.1.2nd ed. Wageningen: The Netherlands, Winand Staring Centre;1990.

42. Janssen BH, Guiking FCT, van der Eijk D, Smaling EMA, Wolf J, van Reuler H. A system for quantitative evaluation of the fertility of tropical soils (QUEFTS). Geoderma. 1990; 46:299-318.

43. Witt C, Dobermann A, Abdulrachman S, Gines HC, Wang GH, Nagarajan R, et al. Internal nutrient efficiencies in irrigated lowland rice of tropical and subtropical Asia. Field Crops Res. 1999; 63:113-138.

ABBREVIATION

CNRA : Centre National de Recherche Agronomique

FAOSTAT: Food and Agriculture Organization Statistics (United Nations)

FHB: Felix Houphouët Boigny

MINAGRA-PNR: Ministère de l’Agriculture (Côte d’Ivoire)- Programme National Riz

NERICA : New Rice for Africa

ORSTOM: Office de la Recherche Scientifique et Technique Outre-Mer

PAM-ADRAO: Programme Alimentaire Mondial - Association pour le Développement du Riz en Afrique de l’Ouest

QUEFTS : Quantitative Evaluation of the Fertility of Tropical Soils

WARDA: West Africa Rice Development Association