International Journal of Plant & Soil Science
3(3): 232-247, 2014; Article no. IJPSS.2014.002

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

E. F. Akassimadou[1], B. Koné[1*], G. F. Yao[1], F. Zadi[1], F. Konan[1], M. J. Traoré[1] and A. Yao-Kouamé[1]

[1]Felix Houphouet Boigny University, Cocody, Abidjan, Earth Science Unit, Soil Science Department, 22 BP 582 Abidjan 22, Cote d'Ivoire.

Authors' contributions

This work was carried out in collaboration between all authors. Author BK designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author EFA managed the literature searches, analyses of the study performed the spectroscopy analysis and author MJT managed the experimental process and author GFY identified the species of plant. All authors read and approved the final manuscript.

Original Research Article

Received 24th August 2013
Accepted 9th December 2013
Published 3rd January 2014

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 the 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 (13 $kgPha^{-1}$ and 25 $kgKha^{-1}$) in the humid forest zone were the treatments. A total of 80 $kgNha^{-1}$(urea) was applied in

**Corresponding author: E-mail: kbrahima@hotmail.com;*

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- fertilization and N-nutrition of rice likewise for P-fertilizer which has limited effect on K-nutrition.
Conclusion: The rates of 10 $kgPha^{-1}$ and 75 $kgKha^{-1}$ were recommended for the production of high grain yield and nutritional quality of rice when applying 80 $kgNha^{-1}$. 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.

ABREVIATIONS

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

1. INTRODUCTION

In West Africa and especially in Cote d'Ivoire, there is increasing of rice (*Oryza sativa* L) importance as population principal food (56 kg/person/year) whereas, the supplying depend on foreign rice importation for about the 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 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 80 kgNha^{-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 80 kgNha^{-1} for the production of high yield and good nutritional quality of rice.

2. MATERIALS 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. It is a Guinea savanna zone with a bimodal rainfall pattern. The average annual temperature and rainfall were 28ºC and 1200 mm respectively. A five years old fallow dominated by *Lersia hexandra* (Poaceae) and *Frimbristulis* spp (Poaceae) was preceding the experiment. The soil is a Fluvisol (Table 1) developed on granito-gneiss as bed rock.

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.

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

2.3 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 × 3 m in dimension were tilled manually. The treatments were composed of P-TSP (30, 60, and 90 kg ha^{-1}) and K-KCl (25, 50 and 75 $kgha^{-1}$) and applied as basal fertilizer combined with 1/3 (27kg ha^{-1}) of 80 $kgNha^{-1}$ (Urea). Recommended rates of 13 $kgKha^{-1}$ and 25 $kgKha^{-1}$ were also applied as treatment in addition to 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 tillering and panicle initiation stages of rice, two splits of the 2/3 of N-fertilizer (80 $kgNha^{-1}$) were applied respectively after drainage in order 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 8 m^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). Data 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 (300g) were taken in order to determine their concentrations in N, P and K respectively.

2.5 Laboratory Analysis

The composite soil sample was air-dried at room temperature and sieve (2 mm) 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] was 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-rates, 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 done for P and K respectively as well as for their interaction. Critical error for all the analysis was fixed at 5% ($\alpha = .05$).

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.

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 across the three cropping cycles (Fig. 1) despite of yield reduction from 1 to 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.

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 the cropping cycles.

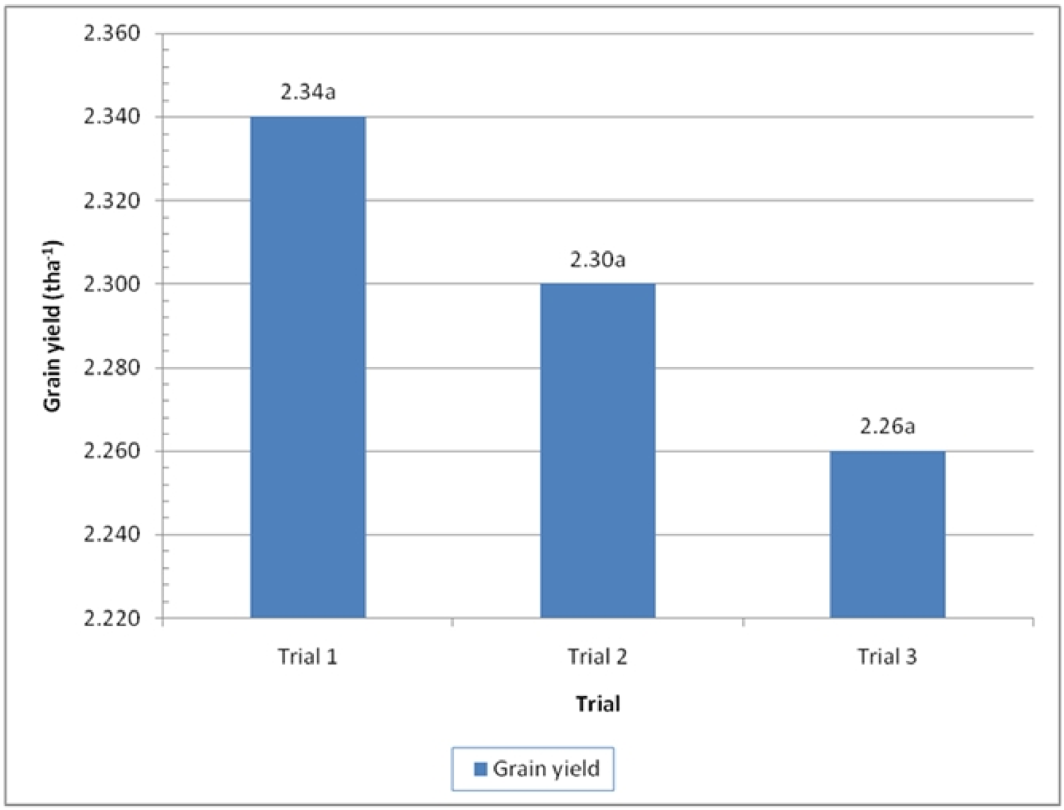

Fig. 1. Rice grain yield mean values during the trials 1, 2 and 3.

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.

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 (%) 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**
$T_1(P_{30}K_{25})$	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	1.08e	1.05f	0.127e	0.117d	0.110e	0.11d	0.15f	0.17d	0.18g	0.17f
$T_F(P_{13}K_{25})$	1.21c	1.18 d	1.13e	1.17e	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.

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>I t I				
K	R	0.53	1		
	P>I t I	.09			
N	R	0.60	0.99	1	
	P>I t I	.04	<.0001		
P	R	0.56	0.96	0.98	1
	P>I t I	.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

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

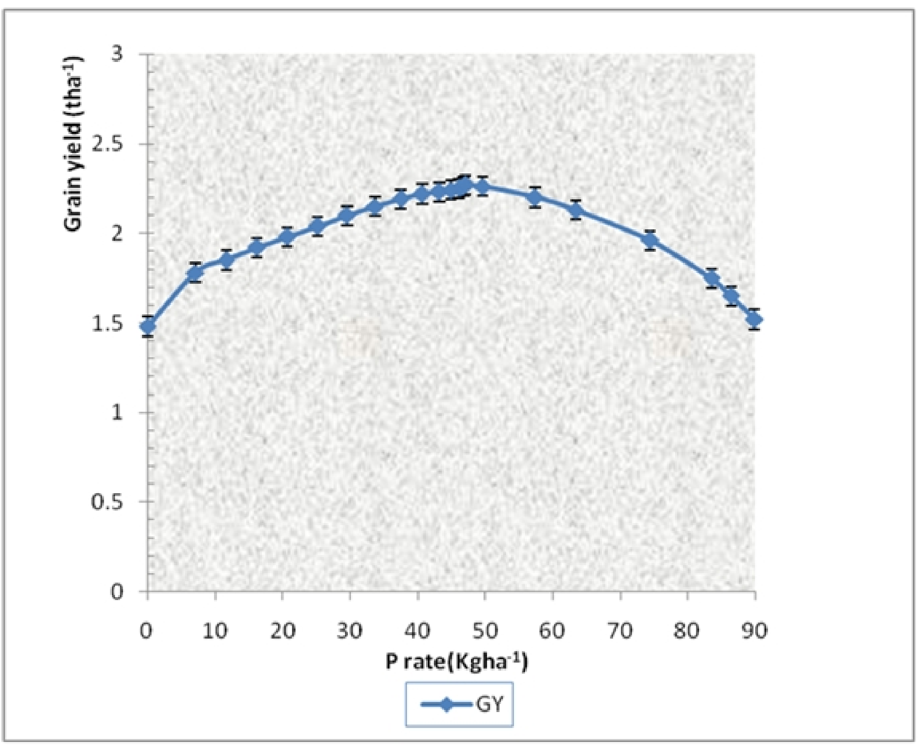

Fig. 2. Rice grain yield (GY) response curve to P-rates.

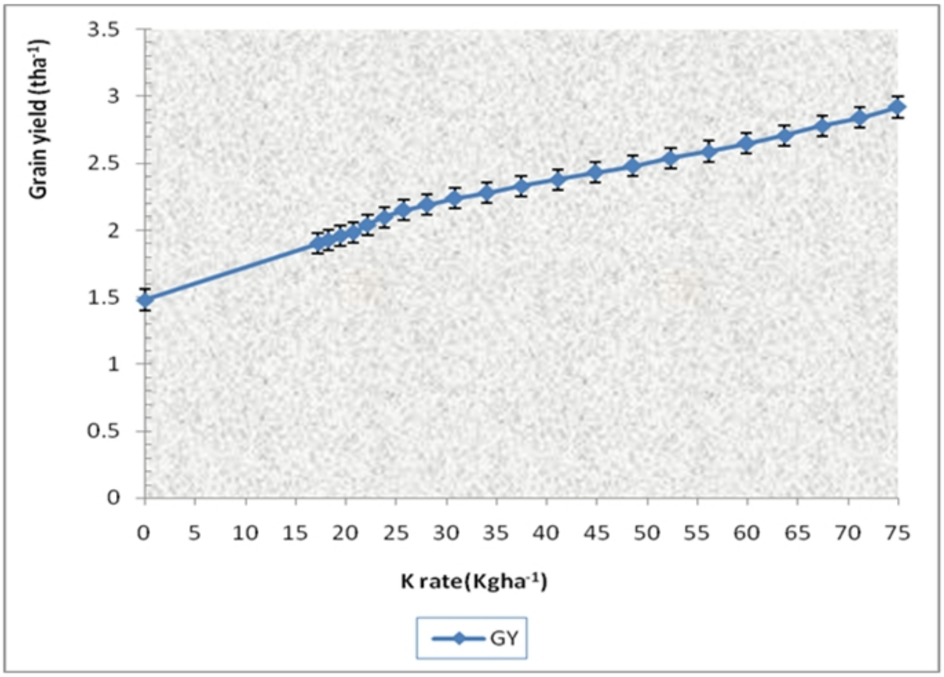

Fig. 3. Rice grain yield (GY) response curve to K-rates.

Fig. 3 shows a low response of rice grain yield (<1.75 tha^{-1}) to K-rates ranging from 0 to 20 $kgha^{-1}$. 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 75 $kgKha^{-1}$ for a grain yield of 3 tha^{-1}.

The characteristics of rice response to the combination of different rates of P- and K-fertilizers are presented in Table 7 and Fig. 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 Figs. 2 and 3, rice response is likely to be more depending to K-fertilizer when combine with that of P according to Fig. 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

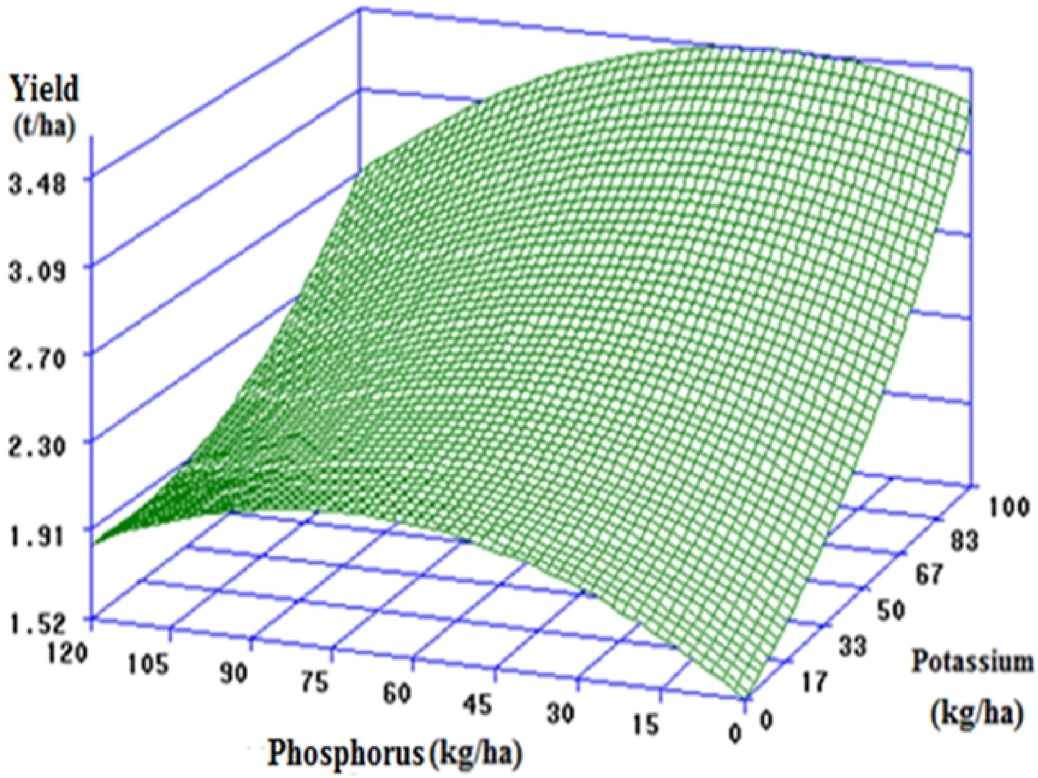

Fig. 4. Rice surface curve response to P- and K-fetilizer rates combined with 80 kgNha^{-1}.

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 less than 3 % confirming soil deficiency in this nutrient. This assertion is further supported by the response of rice yield to the rates of K as observed from 10 kgKha^{-1} with an increasing linear trend up to 75 kgKha^{-1}. Therefore, the recommended rate of 25 kgKha^{-1} by Sanogo *et al*. [11] for the humid forest ecosystem is not suitable for the studied agro-ecology. In fact, this recommendation will induce about 2 tha^{-1} as grain yield while it was possible to observed 3 tha^{-1} by applying 75 kgKha^{-1} according to our results (Fig. 3). However, there is a need to explore the net benefit of such yield gap according to related fertilizer strategies [28]. Anyway, these analyses justified our assumption of site fertility management [12] requirement for the improvement of K-fertilization strategy 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 (75 kgKha^{-1}). This aspect revealed high translocation of N into the grain depending in K-fertilizer supplying, hence, attesting a synergistic relation between both nutrients as mentioned by Slaton *et al.*[22]. A good water management is required to reduce the 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 10 $kgPha^{-1}$ which induced yield increasing by 0.3 tha^{-1} compared with that (1.5tha^{-1}) of the control treatment (T0). Further increasing of P-rate up to 45 $kgPha^{-1}$ has induced slight increasing of the grain yield to a maximum of 2 tha^{-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 60 $kgPha^{-1}$. In fact, the yields were significantly reduced from 45 $kgPha^{-1}$ to 90 $kgPha^{-1}$ (Table 3). However, similar contrast of rice response to P was also observed with 916 $mgPkg^{-1}$ (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 probably, as consequence of oxygen excretion by rice roots and/or bounding P by Ca under flooding condition ([34], [35]). However, increasing P availability was also observed by Jones et al. [36] under flooding condition.

Definitively, we assert that rice response to 10 $kgPha^{-1}$ can be observed even in a soil with 150 $kgPkg^{-1}$ (Olsen) as result of a probable P-immobilization with mitigated effect which is limited at 45 $kgPha^{-1}$ 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 N as 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 90 $kgPha^{-1}$ respectively which were combined with constant rates of N (80$kgha^{-1}$) and K (75$kgha^{-1}$) 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 30 $kgPha^{-1}$ and 75 $kgKha^{-1}$ can be recommended for rice production in the studied agro-ecology when applying 80 $kgNha^{-1}$. However, the yield observed for the rate of 10 $kgPha^{-1}$ (Fig. 2) did not differed significantly with that of 30 $kgPha^{-1}$ 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 (Figs. 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 to supply nutrient requirement of the crop [41]. In this basis, the rate of 75 $kgKha^{-1}$ 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 75 $kgKha^{-1}$ 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 80 $kgNha^{-1}$ 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 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 10 $kgPha^{-1}$ and 75 $kgKha^{-1}$ 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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