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 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 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.

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

35 cultivation (80%) with an average low yield of 1 tha[-1] according to Audebert *et al*. [3]. Therefore,
36 the development of irrigated lowland rice with higher potential yield [4] is required. For this
37 purpose, the savanna zone extending over the 2/3 of the country [5] and including the most
38 developed lowland [6] is an important potential ecology. However, the rice yield obtained in the
39 lowlands in Cote d'Ivoire is still lower than the potential expected [2].

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

43 In fact, only fertilizer recommendations including N, P and K were done for upland rice cultivation
44 and for lowlands in the humid forest zone of Cote d'Ivoire ([10],[11]). These recommendations
45 cannot be adopted in all the ecologies in the basis of site specific fertility management principle
46 [12]. Moreover, the existing hydrographic hierarchy of lowland agro-ecologies affects the soil
47 types and their physic-chemical properties according to the respective orders [13]. Therefore, a
48 specific fertilizer management is required for each of lowland order for rice production when
49 sound site specific nutrient management studies are limited to the Sahel plain agro-ecosystem in
50 West Africa [14].

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

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

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

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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. It 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 as 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 × 3 m in dimension were tilled manually. The treatments were composed of P-TSP (30, 60, and 90 kgha^{-1}) and K-KCl (25, 50 and 75 kgha^{-1}) and applied as basal fertilizer combined with 1/3 (27kgha^{-1}) of 80 kgNha^{-1} (Urea). Recommended

100 rates of 13 kgKha^{-1} and 25 kgKha^{-1} were also applied as treatment in addition to no-fertilizer
101 treatment as control in a randomized complete blocks design with three replications. The trial was
102 set for three cropping cycles (Trial 1, Trial 2 and Trial 3). After 21 days, seed line nursery of rice
103 variety NERICA L19 was transplanted per 2 plants and spaced by 20 cm × 20 cm in row and
104 between rows. At tillering and panicle initiation stages of rice, two splits of the 2/3 of N-fertilizer
105 (80 kgNha^{-1}) were applied respectively after drainage in order to reduced N-loss. Ten days after
106 transplantation, about 5 cm of irrigation water was recommended until the rice maturity except
107 during N-fertilizer application requiring drainage. Manual weeding was done at 45 days after
108 transplantation and the harvest was done in 8 m^2 at the maturity leaving two lines in the borders.

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110 **2-4 Data collection**

111 Before the experiment, a soil sample was done in 0 – 20 cm depth for each micro-plot (centre)
112 using augur. Hence, a composite sample of soil was taken in order to process the physic-
113 chemical characterization (particle size, pH$_{water}$, C-organic, N-total, available-P, exchangeable
114 Calcium-Ca, magnesium-Mg, potassium-K and cation exchangeable capacity-CEC). Data of 50
115 % of rice flowering was recorded per treatment for calculation of the physiological cycle duration.
116 At rice maturity, the numbers of tillers (TILL) and panicles (PAN) were counted in a square meter
117 of each micro-plot. The plant height (HEIG) was also measured for each treatment. After the
118 harvest, the rice was threshed and the grains and straw were separately dried and weighed. The
119 moisture content of the grain was measured and the grain yield (GY) was determined at a
120 moisture content of 14%. But the straw yield (SY) was directly determined after the weighing
121 operation.

122 Samples of grain (100 g) and straw (300 g) were taken in order to determine their concentrations
123 in N, P and K respectively.

124 **2-5 Laboratory analysis**

125 The composite soil sample was air-dried at room temperature and sieve (2 mm) before it was
126 grounded. The pH water was determined in a soil/solution ratio of 1: 2.5 using glass electrode
127 [23]. Soil content in organic-C was determined by the method of Walkley and Black [24] and that
128 of Olsen and Sommers [25] was for total and available phosphorus contents in soil. The
129 exchangeable cations (Ca, Mg and K) and the cation exchangeable capacity (CEC) were
130 extracted by ammonium acetate (pH= 7) before using atomic spectrometry (Ca and Mg) and
131 flame spectrometry (K) for reading the concentrations respectively. The total-N in soil was also
132 determined using Kjeldahl method [26].

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

135 **2-6 Statistical analysis of data**

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

142 **3. RESULTS**

143 **3-1 Treatment effects on yield parameters**

144 Table 2 shows the mean values of plant height as well as the numbers of tiller and panicle per
145 square meter in each treatment. There is higher significant ($p<.001$) effect of treatment on the
146 plant height and number of panicles for the three cropping cycles respectively compared with that
147 of the number of tillers. The highest mean values of plant height are observed for the treatments
148 T4 (60P-25K), T5 (60P-50K) and T6 (60P-75K). Whereas, the treatments T3 (30P-75K), T6 (60P-
149 75K) and T9 (90P-75K) did so for the numbers of tiller and panicle. The treatment T6 (60P-75K)
150 is likely to be the best according to rice vegetative growth parameters. However, there is a slight
151 decrease of the overall mean values of the studied parameters from the first to the last Trial.

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153 **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

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

156 **3-2 Rice physiological cycle duration and yields**

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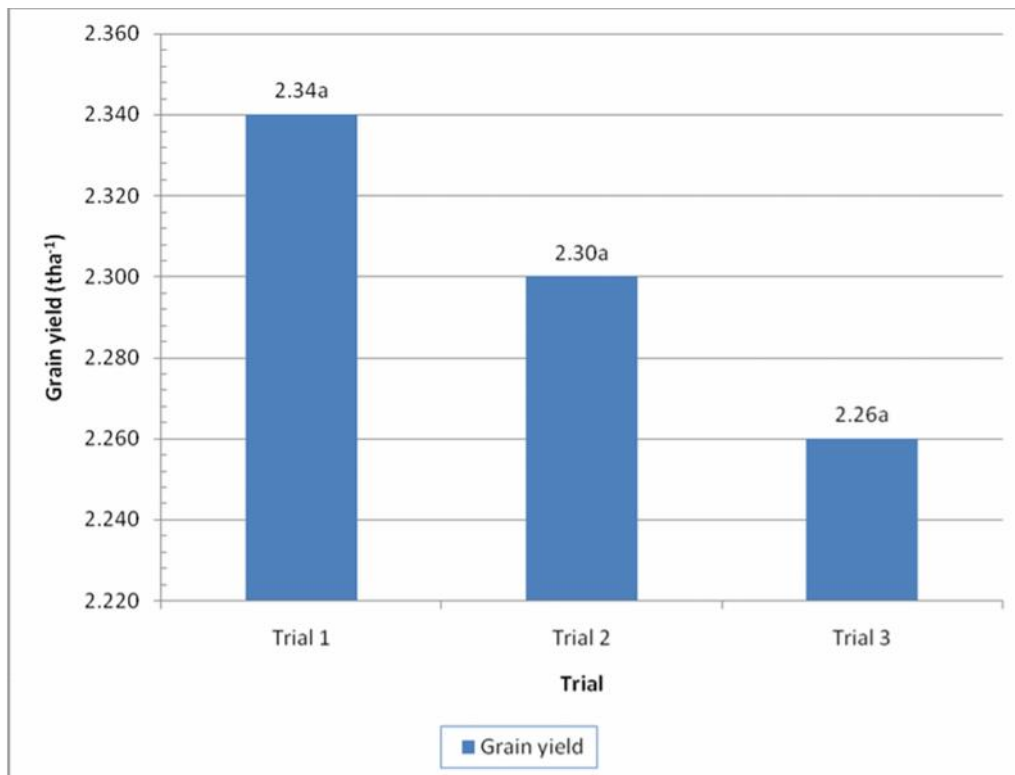165 (Figure 1) despite of yield reduction from 1 to 3%.

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

168 **3-4 Mineral concentrations in rice grain and straw**

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

174 **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

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

176 **Table 4 : Mean values of N, P and K concentrations in rice grain**.
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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	1.08 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

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

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

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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

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

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

201 **Table 6: Pearson correlation coefficient (R) and probability (P) between P-rate and total**
202 **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	

203

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

208

209 **3-5 Rice response curves to the rates of P and K**

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

214

215
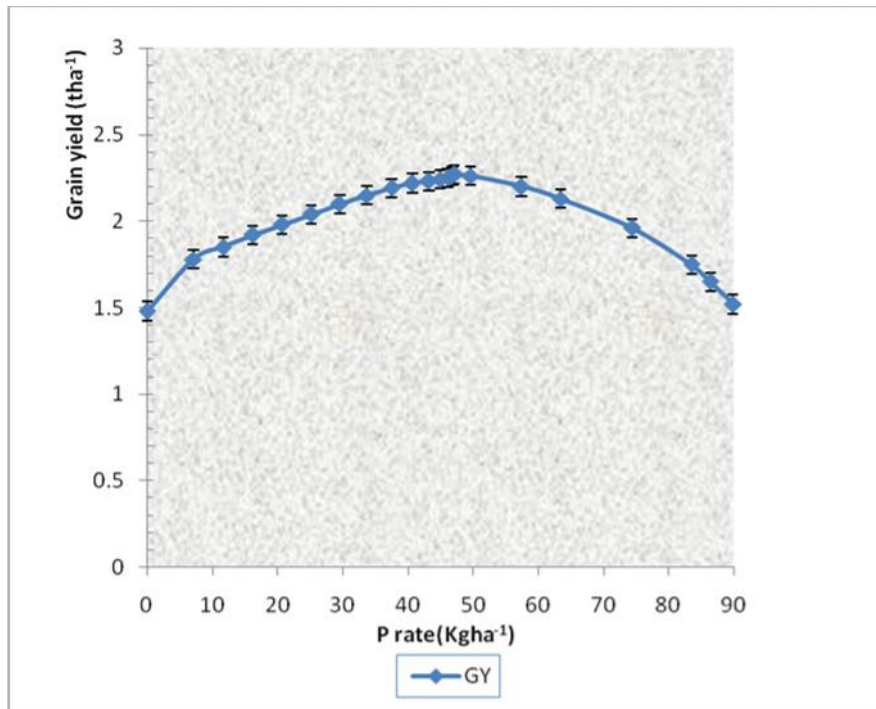
Figure 2: Rice grain yield (GY) response curve to P-rates.

217
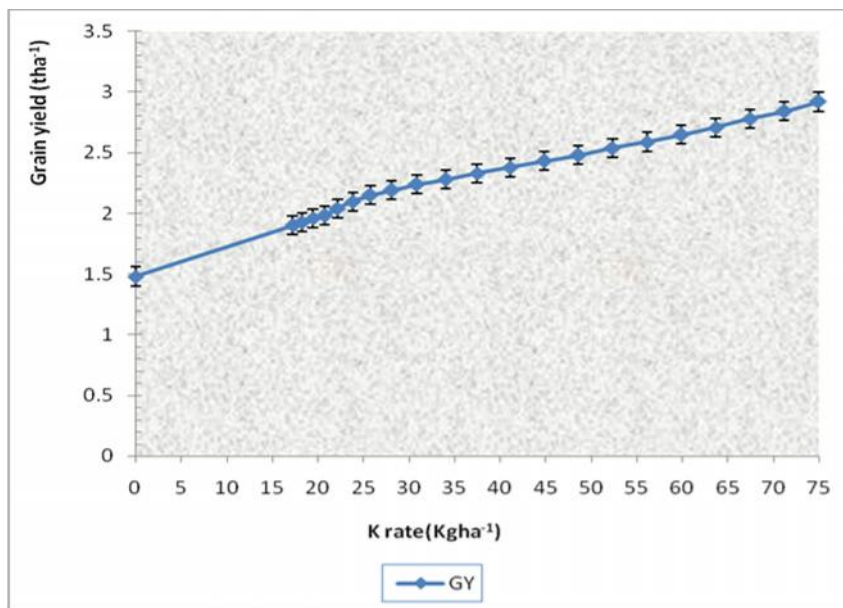
Figure 3: Rice grain yield (GY) response curve to K-rates.

Figure 3 shows a low response of rice grain yield (<1.75 tha[-1]) to K-rates ranging from 0 to 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].

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

228 **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

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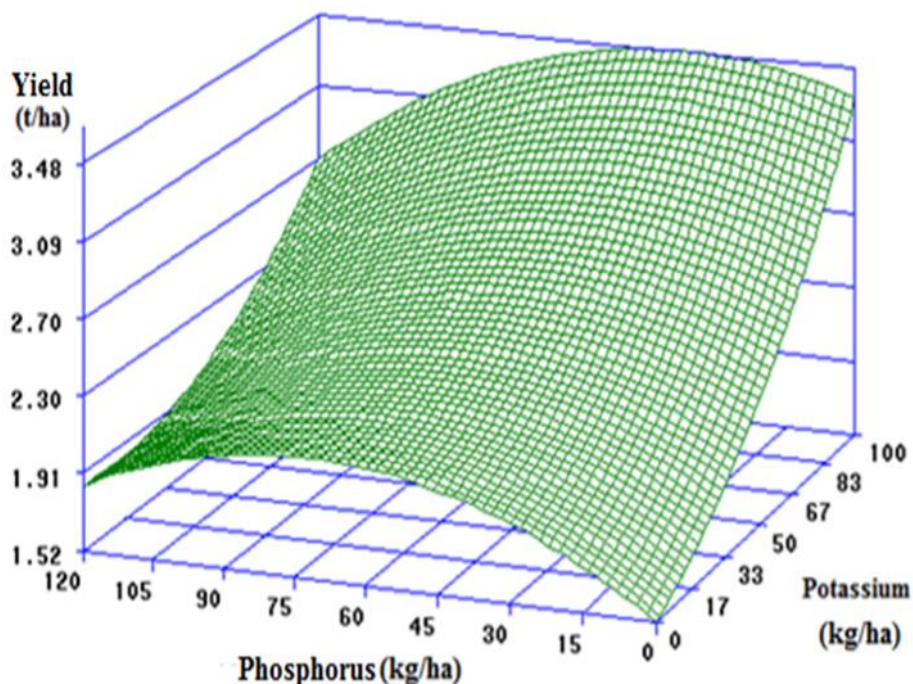
233 Figure 4: Rice surface curve response to P- and K-fetilizer rates combined with 80 kgNha^{-1}.

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 ecology 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 (Figure 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

278 45 kgPha^{-1} in the studied agro-ecosystem. Consequently, the increase of P-rate throughout the
279 treatments T3, T6 and T9 did not induce significant difference between the concentrations of N, P
280 and K in the grain and straw respectively. However, total N concentration in above ground dry
281 matter was positively and significantly correlated to P-rate (Table 6). The calcium contained in
282 phosphate fertilizer can contribute to this as synergism effect with N as described by Saijo et al.
283 [37].

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

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

291 **4-3 Sustainability of rice production**

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

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

315 **5. CONCLUSION**

316 Our study revealed an optimization of rice nutrition in nitrogen due to potassium and phosphorus
317 fertilizations on Fluvisols as induce by a synergism effect, resulting quantitative and qualitative
318 improvement of rice production. It is recommended the application of 10 kgPha^{-1} and 75 kgKha^{-1}
319 for quantitative and qualitative rice production in irrigated second order lowland of Guinea
320 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.

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ABBREVIATION

CNRA : Centre National de Recherche Agronomique

FAOSTAT: Food and Agriculture Organization Statistics (United Nations)

FHB: Felix Houphouët Boigny

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

453   NERICA : New Rice for Africa

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

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

457   QUEFTS : Quantitative Evaluation of the Fertility of Tropical Soils

458   WARDA: West Africa Rice Development Association