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RICE RESPONSES TO LOW RATES OF SOLUBLE PHOSPHATE IN ACID SOIL OF A HUMID FOREST ZONE

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ABSTRACT

Heavy rate of chemical P-fertilizer application in acidic P-deficient soil was often characterized by lowest grain yield with declining trend over cropping seasons in spite of soil enrichment in available P. Two years (2011 and 2012), 5 × 2 factorial experiment comprising 5 rates of P (0, 2.5, 5, 10 and 60 kgPha^{-1}) and two cultivars (WAB 56-125 and NERICA 1) was conducted in a randomized complete block design with three replications. Highest rice grain yield was ranging about 3 – 4 tha^{-1} annually with outstanding yield reduction of 8-11% coupled with 36% lower agronomy efficiency P for WAB 56-125 in 2012 compared to that of NERICA 1. More stable yield of 3 tha^{-1} was observed for the rates of 2.5 and 5 kgPha^{-1} with NERICA 1 also attaining a yield of 4 tha^{-1} for the lowest P-rate of 10 kg ha^{-1} while similar yield was achieved for WAB 56-125 with 60 kg Pha^{-1}. No more additional P application was necessary for NERICA 1 from 34.15 kg P ha^{-1} against 57.9 kg P ha^{-1} for WAB 56-125 meanwhile, no significant difference was observed between the yields recorded respectively. Harmfulness of high rate of P (60 kg ha^{-1}) including unsuitable soil degree of phosphate saturation coupled with soil cations unavailability to plant was suspected. Overall, NERICA 1 could account for soil acidity tolerant cultivar most adapted to P-deficient prone environment but genetic improvement was required for developing more stable agronomic traits.

Key-words: NERICA rice, acid soil, soil degree of phosphate saturation, declining yield, Côte d'Ivoire

1. INTRODUCTION

Phosphorus (P) is an essential nutrient limiting for plant growth because of P-insoluble forms in the acidic soils [1, 2]: Soils may have large reserve of total P, but the amounts of P available to plants uptake is usually a tiny proportion [3]. A large portion of inorganic P fertilizer applied to soil is rapidly immobilized and become unavailable to plants due to fixation with Ca (calcium), Al (aluminium) and Fe (iron). Hence, phosphorus fertilizer strategy development has been studiously a major concern in crop productivity, especially for rice in tropical acid soils [4, 5, 6, 7]: Heavy rate of chemical P-fertilizer application was characterized by lowest grain yield which also declines over cropping seasons in spite of soil enrichment in available P. Rock phosphate was recommended as alternative source of P [8] but the yield was low in first cropping season because of the slowness of P-releasing and declining grain yield was still observed over cropping seasons even when combined with legume crop and organic matter application often advocated [9, 10]. Furthermore, common mineral, monazite, is often associated with phosphatic rocks what resulted in elevated amounts of some trace elements in phosphorus fertilizers potentially contributing to unknown levels of soil and plant pollutions [11]. In the light of achievements, chemical P-fertilizer is still required for boosting rice production in tropical acid soil but, low rate should be applied annually considering the potential of soil Degree of Phosphorus Saturation- DPS [12]: Highly fertilized upland soils under continuous cropping is prone to degradation (7.5YR or 10YR in colour) resulting poor contents of P sorbents Fe and Al oxides. Furthermore, the prevailing sand particles of topsoil [13] is favorable to highest DPS over the critical level (13 – 20%) supporting the vulnerability to P and K leaching as well as the downward mobilizations of Ca^{2+} and Mg^{2+} in the soil profile [14, 15]. Hence, heavy rate of P-fertilizer can induce unbalance of soil nutrients as cations [16, 17] while rice response to low rates of P is not explored as much as done [18, 19, 4] with high rates (> 60 kgPha^{-1}) in prevailing acid soils of tropical humid forest zone yet.

The actual study is volunteer to explore rice response to low rates of P as grain yield and fertilizer efficiency according to two popular rice varieties (NERICA 1 and WAB 56-104) in traditional rainfed rice cultivation area of Côte d'Ivoire. The aim was to identify a low rate of P for rice production when promoting a strategy for chemical P-fertilizer used.

2. MATERIAL AND METHODS

2.1: Experimentation site

A two-year on-farm experiment was conducted in the area of MAN, in Côte d'Ivoire (7º2 N, 7º4 W; 500 masl). The site is located in a tropical humid forest agroecological zone with a mono modal rainfall pattern. Rainfall during the growing seasons was: 1020 mm in 2011 (data missing for August) and 1124.4 mm (2012) against 928 mm for a long term mean value. The soil was characterized as Ultisol named Hyper Dystric Ferralsol [20], inherently low in fertility with a low pH (< 5; water) value and very low available P content (Table 1). The site had been under a 3-year bush fallow before the experiment.

Table 1. Soil chemical properties in 0 - 20 cm depth before the experiment

Soil properties	Mean value
pH (water)	5.4
Organic-Carbon (g kg^{-1})	0.65
Total-N (g kg^{-1})	0.062
Bray-1 P (mg kg^{-1})	4.06
Ca (cmol kg^{-1})	0.88
Mg (cmol kg^{-1})	0.22
K (cmol kg^{-1})	0.10
CEC (cmol kg^{-1})	3.02
Al (cmol^{+} kg^{-1})	0.87
Fe (cmol^{+} kg^{-1})	35.17
Ca: Mg	4 : 1
K : Mg	1 : 2
K : CEC (%)	3
DPS (%)	36.34

2.2: Field experimentation

Fallow land of 900 m^2 was cleared with a cutlass and cleaned of plant debris. Ploughing and spraying operations were mechanized in the first year of experiment while manual operations were carried out in the following year. A 5 × 2 factorial experiment comprising 5 rates of P and two cultivars was conducted every year (2011 and 2012) in a randomized complete block design with three replications. The P source was soluble commercial Triple Super Phosphate (TSP). The TSP was applied annually at 0; 2.50; 5; 10 and 60 kg P ha^{-1}. Local popular rice cultivars were used as NERICA 1 (WAB450-1-B-P-38-HB) and WAB 56-125. NERICA 1 is an interspecific (crosses between *Oryza sativa* [WAB 56-104] and *Oryza glaberrima* [CG14]) released by WARDA (Actual Africa Rice Center) and WAB 56-125 is a sativa cultivar.

Five to seven rice seeds were sown per hill at a spacing of 20 cm × 20 cm in micro plots of 3 m × 5 m in dimension, and later, the hill was thinned at 21 days after emergence (DAE) to a final population of 3 plants per hill. Annually, 30 kg N ha^{-1} and 50 kg K ha^{-1} (KCl) were applied before sowing the rice seeds. Additional 35 kg N ha^{-1} was applied repeatively at early tillering and heading stages. Two manual weeding were carried out at 30 and 45 DAE.

2.3: Soil analysis

Before the trial, a composite soil sample was collected with an auger in the 0-20 cm layer from experiment field. The sample was air-dried and sieved through 2 mm screen for analysis. The analytical procedures of the [21] was used for the determination of soil pH (water), soil organic C (Walkley and Black), total N (Kjeldahl), available P (Bray I), and exchangeable calcium, potassium and magnesium contents as well as soil exchangeable cations contents (1 $\underline{N}$ NH_4OAc (pH 7.0)).

Degree of P saturation in soil (DPS) was calculated as:

$$DPS = [P / (Fe + Al)] * 100 \quad (1)$$

Where, P, Fe and Al are soil contents of these nutrients respectively.

2.4: Data collection

At maturity period (90 – 120 DAS), the rice was harvested from a net area of 8 m^2 for each treatment. After threshing and drying, the straw and grains were separately weighed, and grain yield (GY) was corrected to 14% moisture basis.

Agronomic Efficiency of P (AE) was calculated for each treatment per year [22]:

$$AE = (GYx - GY0) / X \quad (2)$$

AE was expressed in kg grain/ kg P; GY_x being the GY in plot receiving 'X' amount of P and GY_0 is the check plot yield.

Rice grain yield was also predicted base on yield model (PYG) determined by [4] in the same agro-ecology for higher P-rate (up to 150 kg P ha^{-1}) application using TSP:

$$PYG = 2.231 - 0.013 \times P - 6.95 \times 10^{-5} \times P^2 \quad (3)$$

Where P is the applied P-rate

2.5: Statistical analysis of the data

By descriptive statistic the grain yield (GY) was presented for each of the plots every years and the frequency of grain yield over 2 tha^{-1} was shown in 2011 and 2012 for P-rates using SPSS 9 package and for T-test between the observed and predicted grain yields. Analyse of variance was performed to determine the mean values of grin yield for each cultivar (NERICA 1 and WAB 56-125) according to P-rates. Similarly, mean values of GY and EA were determined in 2011 and 2012 indifferently to P-rates and cultivars. The mean values were classified by the test of Student-Newman and Keul. The surface response curve analysis was also done to identify the optimum P-rate for each rice variety. SAS (version 9) package was used for latest statistical analysis and the probability was judged at the critical level of $\alpha = 0.05$.

3. RESULTS

3.1: Effects of cultivars and P fertilizer rates

Rice grain yield is ranging up to 4 tha^{-1} and somewhat over (4.5 tha^{-1}) with obvious classification according to cultivars (Figure 1): Lower grain yield is characterizing NERICA 1 (< 2 tha-1) in both years while WAB 56-125 accounts for the yields ranging between 2 and 3 tha^{-1}. However, both cultivars are yielding indifferently between 3 – 4 tha^{-1} and the highest yield of about 4.5 tha^{-1} was observed for WAB 56-125 in 2011 outstanding with that of NERICA 1 which was about 4 tha^{-1}. In turn, there are similar highest yields (4 tha^{-1}) for both cultivars in 2012 as 11% of potential reduction of yield accounting especially for WAB 56-125.

Furthermore, highest agronomy efficiency (AE) ranging between 65 – 110 kg grains per equivalent unit of P-fertilizer applied is observed with no significant difference between the mean values according to cultivars every year of experimentation likewise for the average values. However, AE of NERCA 1 is about 37% higher than that of WAB 56-125 independently to the year of trial (Figure 2).

Declining yield observed from 2011 to 2012 is likely to be specific to some rates of P fertilizer (Figure 3): Indeed, there is decreasing of high yield (> 2 tha^{-1}) frequency from 2011 to 2012 under fertilizer rates of 2.5 kg P ha^{-1} (60% - 40%) and 10 kg P ha^{-1} (80% - 40%) contrasting with the increasing trend (60% - 80%) observed with 5 kg P ha^{-1}. Highest (> 8%) and stable frequency is observed for 60 kg P ha^{-1} as fertilizer rate, however.

Exclusively, lower grain yields account for NERICA 1 indifferently to P-rate (Figure 4). However, it is also outstanding with highest yield except for the highest P-rate of 60 kgha^{-1} for which, the grain yield of NERICA 1 is evenly observed under 1 tha^{-1}. Nevertheless, NERICA 1 can achieve 2.5 t ha^{-1} as grain yield without P-fertilizer application and more stable yield of about 3 tha^{-1} is observed for the rates of 2.5 and 5 kgPha^{-1}. Further high yield of 4 tha^{-1} is observed for the P-rate of 10 kg ha^{-1} while WAB 56-125 does so for 60 kg Pha^{-1} and was roughly yielding in the range of 1.5 to 2.5 tha^{-1} according to P-rates.

3.2: Rice yield response to P rate

Rice grain yield prediction using model of high rates of P was somewhat fitting with the actual yield observed except for the rate of 60 kgPha^{-1} recording 3.03 tha^{-1} against 2.03 tha^{-1} for the yields observed and predicted respectively (Table 2). However, there is significant (P = 0.002) difference of 340 kgha^{-1} as positive gap induced by the observed rice grain yield during the experiment: The yield is underestimated by the model describing the response to high rates of P-fertilizer.

Table 2: Observed and predicted rice grain yields according to P-fertilizer rates

P-rates (kgha^{-1})	Observed Yield (tha^{-1})	Predicted Yield (tha^{-1})
0	1.75	1.20
2.5	2.09	2.23
5	2.29	2.19
10	2.49	2.16
60	3.02	2.09
Difference (Obs – Pred)		0.34 tha^{-1}
Probability of T-test		0.002

Table 3: Annual average yield of rice grain per rate of applied P according to rice varieties

	2011			2012		
Dose (kg P ha^{-1})	NERICA1 (t ha^{-1})	WAB (t ha^{-1})	Average (t ha^{-1})	NERICA1 (t ha^{-1})	WAB (t ha^{-1})	Average (t ha^{-1})
0	1.62a	1.94c	1.78b	1.51a	1.68d	1.60b
2,5	2.18a	2.20bc	2.19ab	2.05a	1.94cd	2.00ab
5	2.00a	2.56b	2.28ab	2.15a	2.39b	2.30ab
10	2.70a	2.41b	2.55ab	2.34a	2.23bc	2.29ab
60	2.50a	3.73a	3.12a	2.31a	3.54a	2.92a
Mean	2.20	2.57	2.39	2.06	2.36	2.18
lsd$_{.05}$	1.96	0.42	0.94	0.90	0.41	1.30
Pr>F	0.767	<0.0001	0.08	0.891	<0.0001	0.1000

a, b and c are indicating mean values with significant difference in column for α = 0.05

Table 4: Quadratic characteristic of rice varieties response to applied P rates

	NERICA 1		WAB 56-125	
	Value	Pr>| t|	Value	Pr>| t|
Constant	1.67	<0.0001	1.93	<0.0001
Dose	0.10	0.0122	0.05	0.003
Dose×Dose	-0.0014	0.0150	-0.0005	0.086
Critical (kg P ha^{-1})	34.15		57.9	
GY (t ha^{-1})	2.13A		2.46A	

A is indicating mean values with no significant difference in line

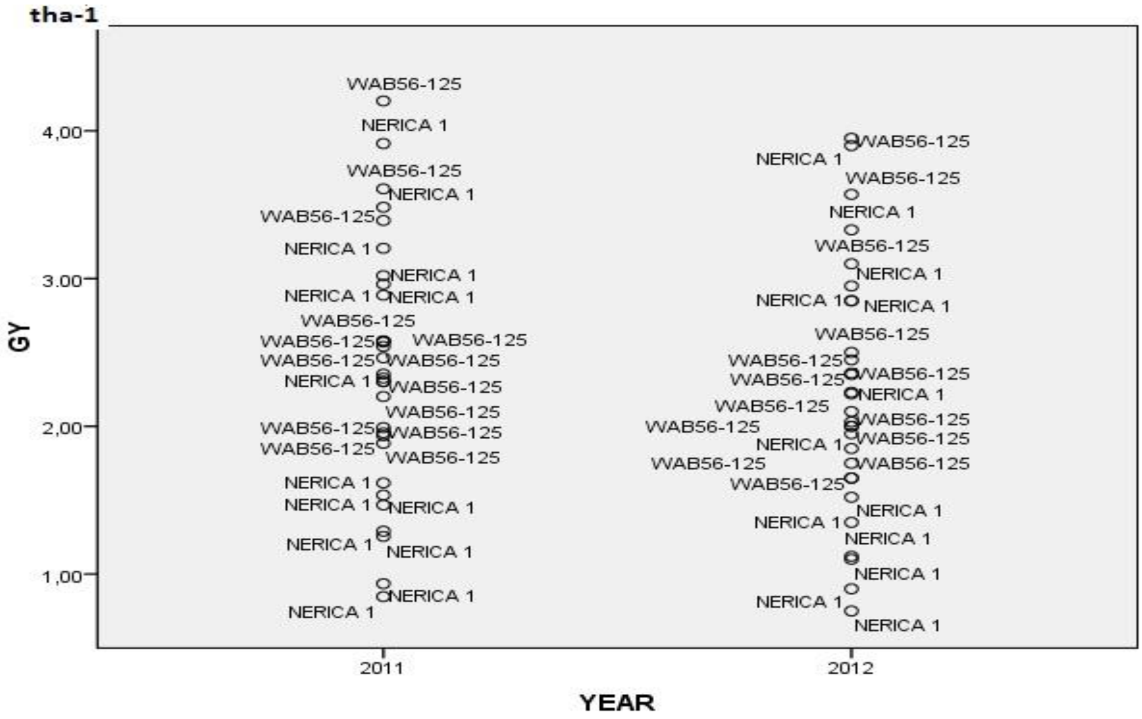

Figure 1: Rice grain yields as recorded per plot of rice varieties (NERICA 1 and WAB-56-125) in 2011 and 2012

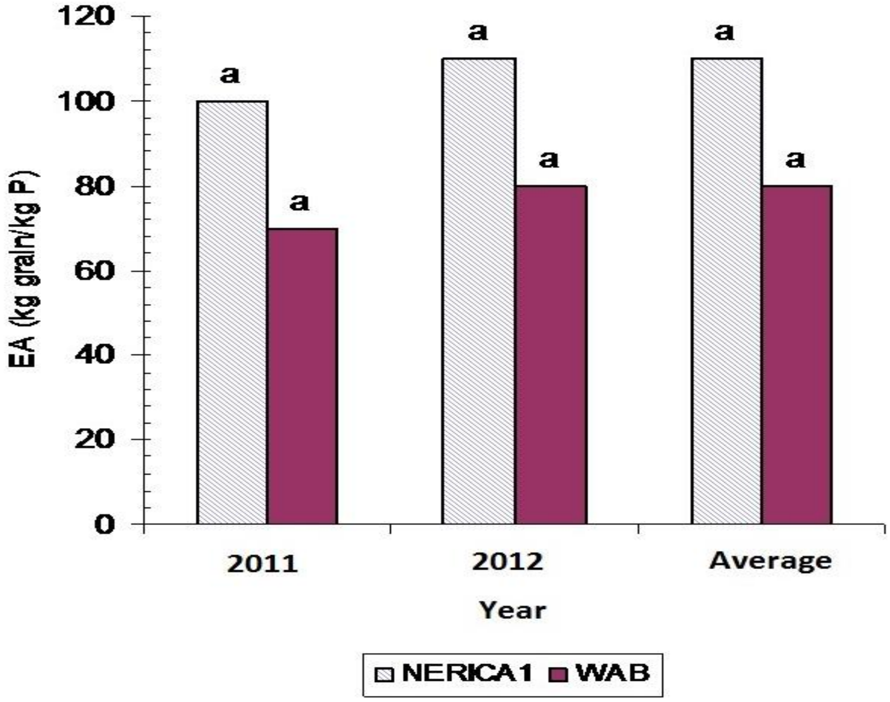

Figure 2: Overall mean values of P-Agronomy Efficient (EA) as recorded annually (2011 and 2012) and for both cropping seasons (Average) according to rice varieties (NERICA 1 and WAB)

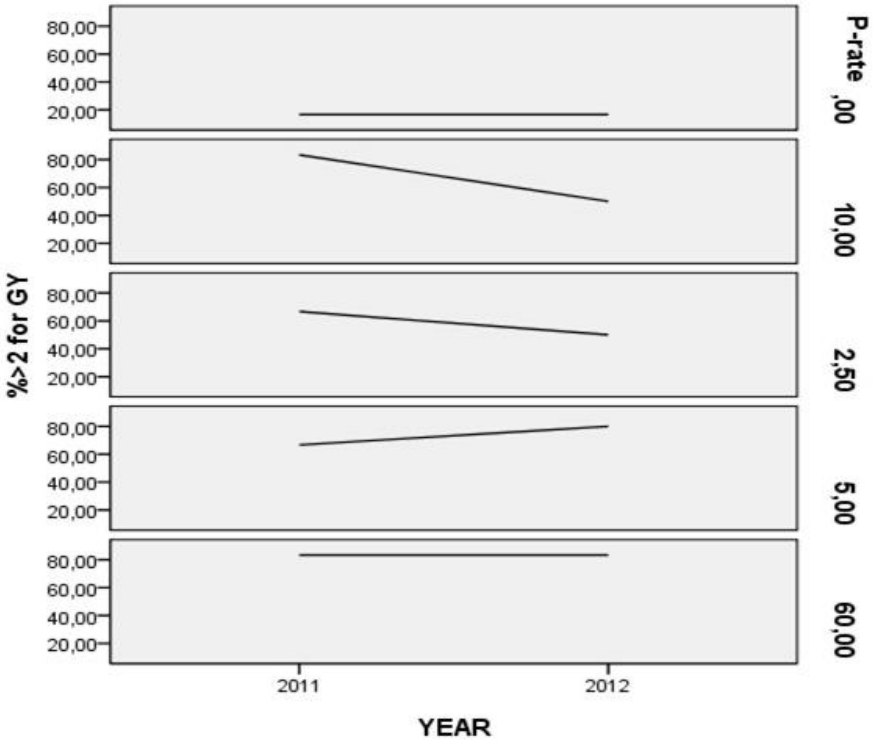

Figure 3: Frequency (%) of rice grain yield recorded over 2 tha^{-1} according to P-rates in 2011 and 2012

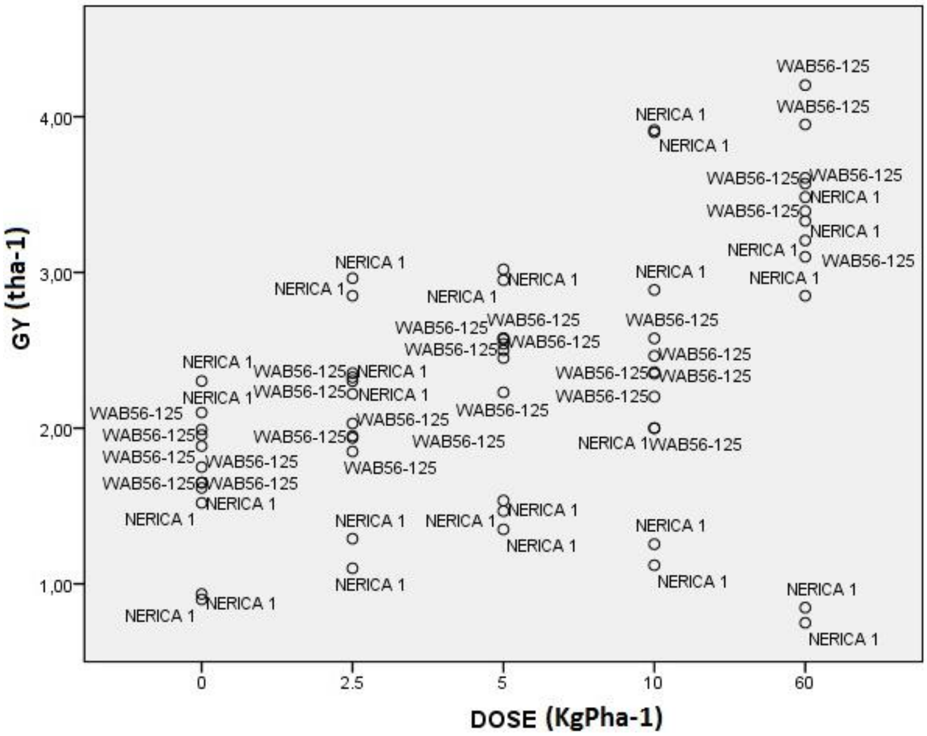

Figure 4: Rice grain yield recorded for each cultivar (WAB 56-125 and NERICA 1) according to P-rates

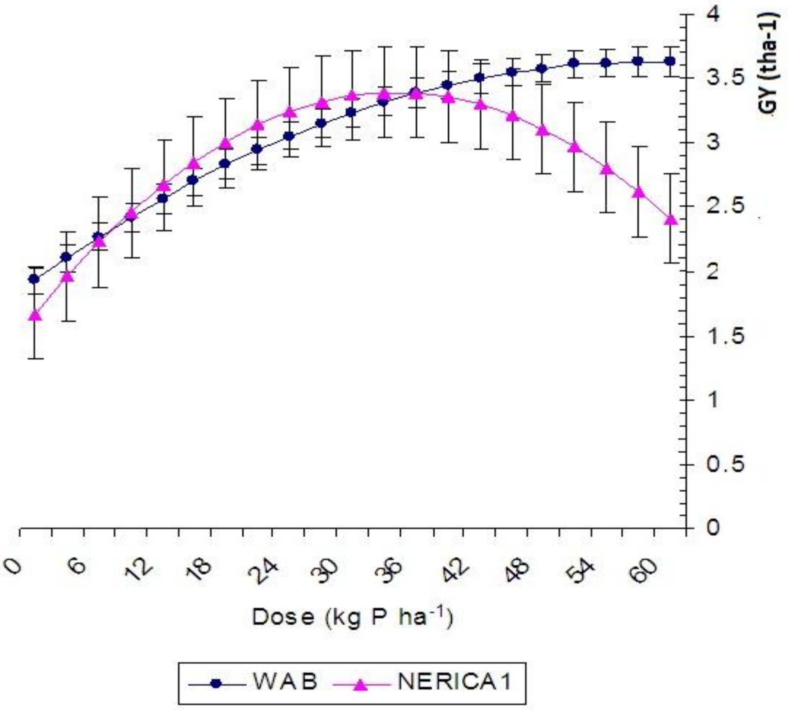

Figure 5: Rice response curve to P-rates according to rice varieties NERICA 1 and WAB (WAB 56 -125)

Table 3 is showing the mean values of rice grain yields as observed in 2011 and 2012 for each cultivar according to P-rates as well as the annual average yields. No significant difference accounted for NERICA 1 in both years in spite of apparent increasing with P-rate (0 – 60 kgPha^{-1}) contrasting with the difference significantly ($P < 0.05$) observed for WAB 56-125. However, there is slight declining of the yield as observed for WAB 56-125 from 3.73 tha^{-1} to 3.5 tha^{-1} in the course of the experiment duration (2011 to 2012). Of course, similar declining trend of yield was observed for the annual averages over cropping seasons meanwhile, NERICA 1 was outstanding with yield increasing from 2.00 to 2.15 tha^{-1} for the low rate of 5 kg ha^{-1} as P-fertilizer applied with more stable yield (2.28 – 2.30 tha^{-1}) for this cultivar. Moreover, the grand means were declined by 8% for WAB 56-125 and for annual averages from 2011 to 2012 meanwhile, only 6% of yield declining rate accounted for NERICA 1.

Polynomial trends are characterizing rice responses to P-fertilizer rates indifferently to cultivars and yields recorded are somewhat similar (see standard errors) with increasing P-rate up to 50 kg ha^{-1} (Figure 5): No significant greater yield of NERICA1 is observed in the range of 6 kgha^{-1} to 31 kg ha^{-1} as P-rates. Highest yield of NERICA 1 is observed in within the interval of 24 – 42 kgPha^{-1} and additional application of P resulted in yield decreasing. In turn, there is studious increasing of yield as response of WAB 56-125 to P-fertilizer, but, it remained stable for the P-rates over 51 kgP ha^{-1}.

Indeed, the critical values of P-rates are 34.15 kg ha^{-1} and 57.5 kg ha^{-1} for NERICA 1 and WAB 56-125 respectively, and, similar grain yields are recorded for both cultivars when referring to the statistical difference (Table 4). The quadratic characteristics of NERICA 1 response to P-fertilizer rates are significantly higher for the coefficients of first (P) and second (P×P) orders of P-rate in the model, illustrating more sensibility of NERICA1 to P-fertilizer. However, 1.93 tha^{-1} accounts for WAB 56-125 as slightly greater model constant (intercept) compared to 1.67 tha^{-1} recorded for NERICA 1 pointing out more resilience of WAB 56-125 under no P-fertilizer application.

4: DISCUSSION

4.1: Varietal difference in response of P-fertilizer

There was insight of low-input growing ability of NERICA 1 rice cultivar according to the highest grain yields recorded for P-rate lower than 60 kgha^{-1} which was however, more suitable for WAB 56-125 outstanding with highest yield. Even, 2.5 t ha^{-1} could be recorded in some plots of NERICA 1 with no application of P-fertilizer (Figure 4) over the average grain yield of 0.8 – 1.0 tha^{-1} observed in local rice fields [23] and that observed for WAB 56-125 (1.5 tha^{-1} – 2 tha^{-1}). As consequence, P efficiency was 37% greater with NERICA 1 although not significantly different with that of WAB 56-125. These results are additional arguments in favor of the most adaptability of interspecific rice cultivars for African poor resource farmers' practice as early denoted by [24]. However, lowest yields were also exclusively accounting for some plots of NERICA 1 even when applying P-fertilizer. This contrast could resulted from high sensitivity to field management level (e.g. weed control, guarding against birds and rodents damage) and in more extend, because of genetic instability of NERICA 1. In fact, there is high contribution of genetic trait in rice grain yield potential in a given environment [25]. Therefore advance research is still required for interspecific (*O. glaberrima* × *O. sativa*) breeding for releasing cultivars with more stable agronomic traits.

Nevertheless, no more additional P application was necessary for NERICA 1 from 34.15 kg Pha^{-1} against 57.9 kg P ha^{-1} for WAB 56-125 meanwhile, no significant difference was observed between the grand mean values of yields recorded respectively. Highest reduction of the grain yield could be observed with NERICA 1 according to yield models (Table 4). Hence, NERICA 1 can account for soil acidity tolerant cultivar most adapted for P-deficient prone environment and low rate of P is advocated. Roughly, the model of rice yield obtained with high rate of P (0 – 150 kgPha^{-1}) did not fit much the yields observed with lower rates of P (0 – 60 kgPha^{-1}) independently to rice cultivar and was likely underestimating the yield as presuming consequence of some threat in soils.

4.2: Harmfulness of high rate of P-fertilizer in soil

Yet, there is clearness of ecosystem threat as induced by fertilizers use in livestock farms especially for P-fertilizer often resulting in over accumulation of P that can produce some risk of eutrophication of surface waters and surrounding terrestrial ecosystems [26, 27]. In contrast, there is limited knowledge concerning the effect of P accumulation in agricultural soil consecutively to P-fertilizer application as observed by [4] in the humid forest of Nigeria which underlined relevant aspects of unbalance ratios of Ca:Mg and K:Mg impairing rice mineral nutrition. Such of constraint could have contributed to rice yield decreasing by 6% - 11% from 2011 to 2012 during the actual study. In fact, the soil inherent degree of phosphorus saturation (30%) was over the critical level of 20% [12] in spite of the low content of available P (4.06 mgkg^{-1}) allowing assumption of richness of labile Ca-P in concordance with the value of soil CEC of 3.02 cmolkg^{-1} as revealed by [28]. This soil condition could have promoted downward mobilization of cations; particularly for Mg [14] meanwhile; soil inherent content of 0.22 cmol Mg kg^{-1} close to the threshold level constituted the single source of Mg during rice growing and, no restoring of the exported amount could induce soil Mg deficiency coupled with yield reduction during the subsequent cropping season as observed by [29, 30] in the humid forest zone of Côte d'Ivoire. Moreover, direct effects of soil P excess in plant mineral nutrition are extensively documented: The addition of P also caused small decreases in concentrations of other divalent cations. The P–Zn imbalance, resulting from excessive P accumulation, is known to induce Zn deficiency. This antagonism appears to be based in a large extent on chemical reactions in root media [16, 17]. However, [31] stated that Zn–P antagonism could not be explained by only mutual immobilization and this interaction is mainly according to plant physiological characteristic. In the light of these assumptions and the current results, we can also assert intra species difference regarding to NERCA 1 resilience to the declining of grain yield as compared to WAB 56-125 with greater yield reduction ratios of 8% – 11% and specific P-rates are concerned even at low rate of 2.5 and 10 kgha^{-1} while increasing frequency of high yield (> 2.5 tha^{-1}) accounted for 5 kgP ha^{-1} further characterized by more stable average grain yield (2.28 – 2.30 tha^{-1}).

Actual study pointed out the ability of low P-rate for sustaining upland rice production in acid soils of a humid forest of West Africa with varietal variance. However, further study should explore soil sorption isotherms as measurement of P quantity that must be added in soil to raise the P concentration in soil solution at equilibrium to a desired or maximum value [32] according to other soil properties.

5. CONCLUSION

Beside the economic advantage of applying low P-rate especially for NERCA 1 cultivar, soil health and environment quality can be saving. No more P application was necessary for NERICA 1 from 34.15 kg Pha^{-1} against 57.9 kg P ha^{-1} for WAB 56-125 meanwhile, no significant difference was observed between the grand mean values of yields recorded respectively. Additional justification was provided to support interspecific rice cultivar as most adapted for African poor resource farmers' practice but genetic trait improving was required for more stable agronomic traits of NERICA 1. Moreover, soil P-sorption capacity should be explored toward the humid forest of West Africa for generalization of the major finding.

6. REFERENCE

[1]. Sorho, F., Koné, B., Ettien, J.B., Migninna, J.T. and Akassimadou, E. F. 2013. Rice Growth and Yield in Humid Forest of Côte D'Ivoire as Affected by Different Sources of Phosphates in Ferralsol. Journal of Environmental Science and Engeneering B (2): 648 - 656.

[2]. Koné, B., Kouadio, K.H., Cherif, M., Oikeh, S., Akassimadou, E.F., Yao, G.F. and Konan, K.F. 2014a. Rice Grain Yield Gap and Yield Declining as Affected by Different Phosphorus Fertilizers in Acid Soil Over Successive Cropping Seasons. International Journal of Biological Sciences, 1 (1): 21 – 43.

[3]. Stevenson, F.J., Cole, M.A. 1999. Cycles of soil: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients, 2nd ed., Wiley, New York, US.

[4]. Koné, B., Diatta, S., Saidou, A., Akintayo I., and Cissé, B. 2009a. Réponses des variétés interspécifiques du riz de plateau aux applications de phosphate en zone de forêt au Nigeria. Canadian Journal of Soil Science,89: 555-565.

[5]. Koné B., Saïdou A., Camara M., et Diatta S. 2010a. Effet de différentes sources de phosphate sur le rendement du riz sur sols acides : Optimisation du phosphate sur un hyperdystric ferralsol. Agron. Afr. 22 (1) : 55 – 63.

[6]. Koné, B., Oikeh, S., Diatta, S., Somado, A., Kotchi, V., Sahrawat, K. S. 2011. Response of interspecifics and sativa upland rice to Mali phosphate rock and soluble phosphate fertilizer. Archieve of Agronomy and Soil Science, 57 (4): 421-432.

[7]. Koné, B. 2014. Sustaining rice production in Tropical Africa: Coping with rice yield gap and declining yield. Lap Lambert Publishing. 224p.

[8]. Koné, B., Ettien, J.B., Amadji, G. L., Diatta, S. et Camara, M. 2010b. Effets d'engrais phosphates de différentes origines sur la production rizicole pluviale des sols acides en zone de forêt semi-montagneuse sous climats tropicaux: Cas des hyperdystric ferralsols sous jachères en Côte d'Ivoire. ETUDE ET GESTION DES SOLS, 17 (1) : 7-17.

[9]. Somado, E. A., Becker, M., Kuehme, R. F. Sahrawat, K. L. and Vlek, P. L. G. 2003. Combined effect of legumes with rock phosphorus on rice in West Africa. Agronomy Journal. 95: 1172–1178.

[10]. Koné, B., Yao-Kouame, A., Sorho, F., Diatta, S., Sié, M. and Ogunbayo, A. 2010c. Long-term effect of Mali phosphate rock on the grain yield of interspecifics and sativa rice cultivars on acid soil in a humid forest zone of Côte d'Ivoire. Int. J. Biol. Chem. Sci. 4(3) : 563-570.

[11]. Christensen, J.T., Stipp, S.L.S., Baker, J.A. and Harstad, A.O. 2004. *Rare Earth Elements in Natural Calcite*. Goldschmidt, Copenhagen, A512.

[12]. Siemens, J., Ilg, K., Lang, F. and Kaupenjohann, M. 2004. Adsorption controls mobilization of colloids and leaching of dissolved phosphorus. *Eur. J. Soil Sci.***55**, 254-263.

[13]. Koné, B., Diatta, S., Oikeh, S., Gbalou, Y., Camara, M., Dohm, D. D. et Assa A. 2009b. Estimation de la fertilité potentielle des ferralsols par la couleur : usage de la couleur en morphopédologie. Canadian Journal of Soil Science, 89 (3) : 331-342.

[14]. Turner, B.L., Kay, M.A. and Westermann, D.T. 2004. Colloidal phosphorus in surface runoff and water extracts from semiarid soils of the western United States. *J. Environ. Qual*. 33:1464-1472.

[15]. Koné, B., Bognompke, J.P., Cherif, M., Oikeh, S., Konan F. and Traoré, M. J. 2014b. haracterization of Soil Nutrients Leaching in Perched Groundwater as Occurring in Bush Fallow of Forest Zone. 1International Journal of Ecology and Environmental Sciences 40 (2-3): 165-174.

[16]. Olsen, S. R. 1972. Micronutrient interactions, in *Micronutrients in Agriculture*, Mortvedt, J. J., Giordano, P. M., and Lindsay, W. L., eds., Soil Science Society of America, Madison, WI, 243.

[17]. Saeed, M. and Fox, R. L., Influence of phosphate fertilization on Zn adsorption by tropical soils, *Soil Sci. Soc. Am. J.*, 43, 683, 1979.

[18]. Sahrawat, K.L., Jones, M.P. and Diatta, S. 1997. Direct and residual phosphorus effects on yield and phosphorus efficiency of upland rice in an Ultisol. *Nutr Cycl Agroecosys,* 48: 209–5.

[19]. Sahrawat, K.L., Jones, M.P. and Diatta, S. 1998. Plant phosphorus and rice yield in an ultisol of the humid forest zone in West Africa. *Commun Soil Sci Plan* , 29: 997-5.

[20]. ISSS, ISRIC and FAO. 1998. World reference base for soil resources. World soil resources reports, 84, FAO, Rome. 88 pp.

[21]. International Institute of Tropical Agriculture.1989. Automated and semi-automated methods of soil and plant analysis. Manual series Nº1. IIITA, Ibadan, Nigeria.

[22]. Fageria, N.K. and Baligar, V.C. 2003. Methodology for evaluation of lowlands rice genotypes for nitrogen use efficiency. J. Plant Nutrition 26: 1315-1333.

[23]. Van Reuler, H. and Janssen, B.1998. Nutritional constraints in secondary vegetation and upland rice in south-west Ivory-coast. In: Proctor J, ed. *Mineral nutrients in tropical forests and savanna ecosystems.* Wageningen: BRITISH ECOLOGICAL SOCIETY. Pp : 371-381.

[24]. Jones, M.P., Dingkuhn, M., Aliko, G.K., and Semon, M. 1997. Interspecific Oryza Sativa L. × Glaberrima Steud. Progenies in upland rice improvement. Euphytica, 92: 237 – 246.

[25]. Liu, G.F., Yang, J., Xu, H.M., Hayat, Y and Zhu, J. 2000. Genetic analysis of grain yield conditioned on its component traits in rice (Oryza sativa L.). Australian Journal of Agricultural Research, 59: 189 – 195.

[26]. Gelbrech, J. and Driescher, E. 1998. Phosphorus in subsurface water- a potential eutrophication source of surface waters. W: Phosphorus in agriculture and water quality protection., Sielinko near Poznah, December 2-3 1997, Institute for Land Reclamation and Grassland Farming (IMUZ), Falenty.pp 66-72.

[27]. Sharpley, A.N., Daniel, T.C., Sims, J.T., Lemunyon, J.L., Stevens, R.G., and Parry, R. 1999. Agricultural phosphorus and eutrophication, USDA ARS. pp. 1-37.

[28]. Abekoe, M.K. and Tiessen, H. 1998. Phosphorus forms, lateritic nodules and soil properties along a hillslope in northern Ghana. Catena, 33: 1-15.

[29]. Koné, B., Fatogoma, S., Chérif, M. 2013. Diagnostic of mineral deficiencies and interactions in upland rice yield declining on foot slope soil in a humid forest zone. International Journal of Agronomy and Agricultural Research. 3 (7): 11-20.

[30]. Koné, B., Fofana, M., Sorho, F., Diatta, S., Ogunbayo, A., and Sie, M. 2014c. Nutrient constraint of rainfed rice production in foot slope soil of Guinea Forest in Côte d'Ivoire. Arch. Agron. Soil Sci. 60 (6): 735 – 746.

[31]. Smilde, K. W., Koukoulakis, P., and van Luit, B. 1974. Crop response to phosphate and lime on acid sandy soils high in zinc, *Plant Soil*, 41: 445,

[32]. Pierzynski, G.M., Sims J.T. and Vance, G.F. 2005. Soils and Environmental Quality. 3rd Edt.,Taylor and Francis, Boca Raton, USA.