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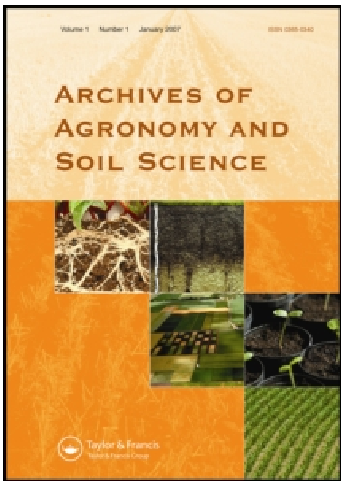

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Response of interspecific and sativa upland rices to Mali phosphate rock and soluble phosphate fertilizer

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In West Africa, two-thirds of upland rice is grown on acidic phosphorus (P)-deficient soils. Phosphorus is one of the most limiting-nutrients affecting crop productivity. A three-year field experiment was conducted on a Ferralsol in Côte d'Ivoire to study the response of four interspecific rice cultivars and a sativa (control cultivar) to Tilemsi phosphate rock (PR) and soluble triple superphosphate (TSP) fertilizer. PR was applied at 0, 150, 300, and 450 kg ha^{-1} P once in the first year and residual effects were measured in the following years. TSP (0, 50, 100 and 150 kg ha^{-1} P) was applied yearly. More significant yield increasing (38%) was observed in the second year. Annual application of 50 kg P ha^{-1} as TSP or a one-time application of 150 kg P ha^{-1} as PR was the optimum rate for the production of all cultivars. Higher rates of P from TSP (100 and 150 kg P ha^{-1}) gave 2–3 times greater residual P in soil than the optimum rate, inducing no further response of rice. Two interspecific cultivars were identified as the most acid- and low P-tolerant cultivars for improving rice production in West Africa humid forest zone.

Keywords: acid soil; interspecific rice; *Oryza sativa*; phosphorus; humid forest

Introduction

In West Africa (WA), two-thirds of upland rice is mainly cultivated on Oxisols and Ultisols (Sahrawat et al. 2001). These soils have a high acidity, which favors high available phosphate (Pa) fixation by iron (Fe) and aluminium (Al) oxides and hydroxides. Therefore, low Pa concentration and P deficiencies are commonly observed. This is a major soil constraint to sustainable rice production in the tropical humid forest agroecosystems (Sahrawat et al. 2001). Phosphate fertilization is, therefore, strongly recommended to increase crop yields. The use of 60 kg P ha^{-1} as water soluble P source (triple superphosphate-TSP) has been proposed for upland rice production in the acid soil of the humid forest agroecosystems of Côte d'Ivoire (Sahrawat et al. 1995; Somado et al. 2006). However, not many smallholder farmers can afford such high rates. Applying P from regionally available phosphate rock may be an affordable soil amendment technology to resource-limited farmers to enhance

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rice production. Large deposits of PR exist in many West African countries and their use efficiency has been shown to increase rice yields under acidic soil conditions especially with the highly soluble Mali-Tilemsi PR in rice cultivation (Sahrawat et al. 2001). This P source is effective in Ultisols and economically as profitable as the imported soluble triple superphosphate (Mokwunye 1995; Bationo et al. 1997).

Phosphate rock adoption by smallholder farmers is, however, limited particularly because of the large quantities required due to its low solubility, thus making its use impossible for farmers (Debrah 2000). As a result of the bulkiness of PR, a one-time application of a large quantity for three years cropping could be a cost-effective management strategy for smallholder farmers.

Genotypic differences have been reported among various crop species in the utilization of P from PR (Flash et al. 1987). This could be due to the increased production of organic acids excluded by roots of some crop species that enhance PR dissolution and P availability to the plants (Zapata and Roy 2004). Also, there are varietal differences for tolerance to soil acidity among *Oryza sativa* rice as reported by Sahrawat et al. (2000).

Recently, Oikeh et al. (2008a) reported the possibility of having enhanced solubilization of PR by upland New Rice for Africa (NERICA®). NERICA varieties are interspecific rice produced from crosses between high-yielding Asian rice (*O. sativa* L.) and low-yielding, resilient African rice (*O. glaberrima* Steud) reported to have high potential for enhancing upland rice production in Africa (Food and Agriculture Organization [FAO] 2007). In addition to enhancing P availability from PR, NERICA varieties may be more tolerant to soil acidity in Africa than its parent *O. sativa* because of the characters it received from *O. glaberrima*. This ability of NERICA varieties may have reduced the rate of P required for upland rice cultivation.

The objective of this study was to evaluate the performance of NERICA cultivars and other new cultivars under different rates (0, 150, 300, 450 kg P ha^{-1}) of PR applied once as compared with annual application of soluble TSP (0, 50, 100, 150 kg P ha^{-1}) on an acidic Ultisol (Ferralsol) in the humid forest agroecosystems of Côte d'Ivoire.

Materials and methods

Experimentation site

A three-year field experiment was conducted at the research station of the National Center for Agronomic Research (CNRA) at Man, Côte d'Ivoire (7°2′ N, 7°4′ W; 500 miles above sea level). The site is located in a tropical humid forest agroecosystem with a mono modal rainfall pattern. Rainfall during the growing seasons (June–September) was suitable: 1020 mm in 1998 (data missing for August), 1124.4 mm (1999), and 1063 mm (2000); with a long-term mean of 928 mm. The dry season occurred from November to April followed by the rainfall season. Monthly mean temperature was ranging from 24–26°C every growing season. The soil was characterized as Ultisol, inherently low in fertility with a low pH (<5; water) and very low available P content (Table 1). The site had been under a three-year bush fallow before the experiment.

Field experimentation

Fallow land of 1000 m^2 was cleared with a cutlass and cleaned of plant debris. Ploughing and spraying operations were mechanized in the first year while manual

Table 1. Chemical characteristics of composite soil sample taken from 0–20 cm depth of the experimental field at the start of the experiment in 1998.

Soil characteristics	0–20 cm layer
pH (water)	4.9
pH (KCl)	4.0
Organic C (g kg^{-1})	13.5
Total N (mg kg^{-1})	950
Total P (mg kg^{-1})	155
Available P – Bray I (mg kg^{-1})	2.8
K ($cmol_+$ kg^{-1})	0.22
Ca ($cmol_+$ kg^{-1})	0.12
Mg ($cmol_+$ kg^{-1})	0.48
Ca: Mg	1: 4
Al ($cmol_+$ kg^{-1})	0.87

operations were carried out in the following two years. A 2 × 4 × 5 factorial experiment comprising two phosphate sources (Fert), four P application rates (Doses), and five cultivars (Cv), was conducted for three years (Y) in a randomized complete block design with three replications (Rep). The P sources were Tilemsi PR from Mali and soluble TSP. The TSP was applied annually at 0 (0P), 50 (50P), 100 (100P), and 150 (150P) kg P ha^{-1}. The corresponding rates of PR applied once (1998) for three years were 0 (0P), 150 (150P), 300 (300P), and 450 (450P) kg P ha^{-1}. PR rates were similar to TSP except that the application was carried out once in year 1 because of its low solubility and to achieve the objective of evaluating the residual P effects in the three-year study. Four interspecific cultivars (crosses between *O. sativa* [WAB 56-104] and *O. glaberrima* [CG14]): V2 = WAB450-1-B-P-38-HB; V3 = WAB450-11-1-P-40-HB; V4 = WAB450-11-1-P-40-1-H; V5 = WAB450-24-3-2-P-18-HB were used. A popularly grown variety, WAB 56-104 = V1 earlier reported to be P-efficient (Sahrawat et al. 2003) was included as a control cultivar. Only V2 (NERICA1) is among the new generation of 18 varieties named NERICA, while others are yet to be named.

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

Soil analysis

Before the trial, a composite soil sample was collected with an auger in the layer (0–20 cm) of maximum root density of rice from the experimental field. The sample was air-dried and sieved through 2 mm screen for analysis. The analytical procedures of the International Institute for Tropical Agriculture (1989) was used for the determination of soil pH (water as 1:2.5 ratio, 1 N KCl), soil organic C ($K_2Cr_2O_7$/ H_2SO_4 digestion and colorimeter), total N (Kjeldahl), available P (Pa) (Bray I), and exchangeable calcium, potassium and magnesium contents using a solution of 1N NH_4Ac and spectrometry measurements. Before and after the experiment, a composite sample of soil in 0–20 cm horizon from each micro plot was collected for the analysis of available P, respectively named Pa1 and Pa2.

Data collection

Number of tillers were counted in a square-meter area of each plot at maximum tillering (about 45 DAE in middle July), while the panicles were counted in the same square-meter area at maturity (middle September) every year before the harvest (end September) within a growing period of about 100 days. The rice was harvested from a net area of 8 m^2 for each treatment. After threshing and air drying, the straw and grains were separately weighed, and grain yield (GY) was corrected to 14% moisture basis. Dry matter yield (DM) was a summation of straw (SY) and grain yields (GY).

Agronomic Efficiency of P (AEP) was calculated for each treatment per year (Fageria and Baligar 2003):

$$\mathrm{AEP} = (\mathrm{GYx} - \mathrm{GY0})/\mathrm{X} \tag{1}$$

AEP was expressed in kg grain/kg P; $\mathrm{GY_x}$ being the GY in plot receiving 'X' amount of P and $\mathrm{GY_0}$ is the control plot yield without P-fertilization.

Statistical analysis of the data

Grain yield (GY), SY, DM, and PUE were analyzed using the mixed model procedure with Y, Fert, Rates, and Cv as fixed terms in the model, while Rep was used as the random term. Soil Pa1 content was used as a covariate. Means were separated using the least significant difference (LSD) at $p = 0.05$ of GenStat (2003) software.

Results

Dry matter yields

Grain yield was significantly influenced by year, cultivar, fertilizer rate and their interactions (Table 2). Mean yield of cultivars was increased significantly by 38% in the second year compared with the first year of study but did not increase beyond 1.1 t ha^{-1} in the third year. The interaction of cultivar × year showed that cultivar V1 (control cultivar) had the lowest yield in year 1. But its yield increased steadily to a maximum of 1.3 t ha^{-1} in 2000, whereas the other cultivars attained maximum yield of 1–1.2 t ha^{-1} in 1999 and decreased slightly thereafter (Figure 1a). However, there was no significant difference in grain yield between cultivars V3 and V1 in 2000.

Grain yield of the cultivar V5 was the lowest with zero- and low-P supply, but ranked among the highest with the highest P rate (Figure 1b). There were no clear differences between the other interspecific cultivars and the control with increase in P rates up to 100 kg P ha^{-1} per year. All cultivars had similar grain yield of 1.0 t ha^{-1} with the application of either source of P except cultivar V5, which had the lowest yield of 0.87 t ha^{-1} with application of TSP (Table 3). Averaging across years, P sources and rates, grain yields were similar among the cultivars, except cultivar V5, which gave significantly ($p = 0.02$) lower yield than cultivars V2, V3, and the control V1 (Figure 2).

Table 2. Analysis of variance for yields and components of yield of interspecific rice as influenced by year, cultivar, and P source and dose.

		Probability level of *F*					
				Dry matter			
Source of variation	D.f.	Tillers	Panicles	Grain	Straw	Total	HI
Year (Y)	2	0.038	<0.001	<0.001	<0.001	<0.001	<0.001
Cultivar (Cv)	4	<0.001	<0.001	0.002	0.011	0.003	<0.001
P source (Fert)	1	<0.001	0.632	0.091	0.735	0.875	0.067
P dose (Dose)	3	<0.001	<0.001	<0.001	<0.001	<0.001	0.004
Y × Cv	8	<0.001	<0.001	<0.001	<0.001	<0.001	0.010
Y × Fert	2	0.745	0.392	0.440	0.807	0.890	0.031
Y × .Dose	6	0.968	0.002	0.001	0.306	0.106	<0.001
Cv × .Fert	4	0.100	<0.001	0.022	0.333	0.258	0.074
Cv × .Dose	12	0.591	<0.001	0.045	0.303	0.121	0.024
Fert × Dose	3	0.116	0.409	0.132	0.417	0.430	0.267
Y × Cv × Fert	8	0.271	0.209	0.926	0.228	0.399	0.018
Y × Cv × Dose	24	0.661	0.829	0.877	0.141	0.263	0.078
Y × Fert × Dose	6	0.447	0.959	0.982	0.299	0.339	0.772
Cv × Fert × Dose	12	0.875	0.829	0.563	0.669	0.468	0.621
Y × .Cv × .Fert × Dose	24	0.966	0.771	0.826	0.978	0.989	0.459
Grand mean		213	136	0.990	2.382	3.374	0.32
Standard error ($p = 0.05$)		16	11	0.077	0.200	0.255	0.003

D.f. = Degree of freedom; HI = Harvest index.

The interaction of year × cultivar on straw yield (Figure 3a) showed that the cultivar V1 had the lowest straw yield in 1998 but the highest yield in 2000. All the other interspecific cultivars had similar straw yields. Straw yields were about 3–4 times greater in 2000 than in the previous years. Total dry matter followed a similar trend as the straw yields (data not shown). Straw yield increased ($p < 0.001$) from 1.7–2.3 t ha^{-1} with the application of the lowest rate of P, but there was no significant increase in straw yields (2.3–2.7 t ha^{-1}) with further increase in P rates. No significant difference was observed between cultivar (Figure 3b).

Averaging across year, P sources and rates, there were 19–51% more tillers produced by the interspecific cultivars compared with the control (V1 [WAB 56-104]). There were significant interactions of year × cultivar on number of tillers, and year × dose, year × cultivars, cultivars × fertilizer source, and cultivar × dose on panicle production (Table 2). The interspecific cultivars V2, V3, and V4 all produced similar tillers that were significantly higher than those produced by cultivar V5 or the control cultivar (WAB 56-104) in two (1998 and 2000) years within the three years of study (Figure 4a).

Although not always significant, more panicles were produced by the interspecific cultivars in the first and second year of study than in the third year (Figure 4b). Application of either TSP or PR produced more panicles in 1999 than in 1998, while the number of panicles was similar in 1999 and 2000 (Figure 4c). However, there was no influence of year on number of panicles when P was not applied to the cultivars, and in each year, there was no clear difference in panicle production with incremental P rates beyond the first rate (Figure 4c).

The interaction of P source × variety on number of panicles (Figure 5a) showed that there was no difference in the number of panicles produced from both

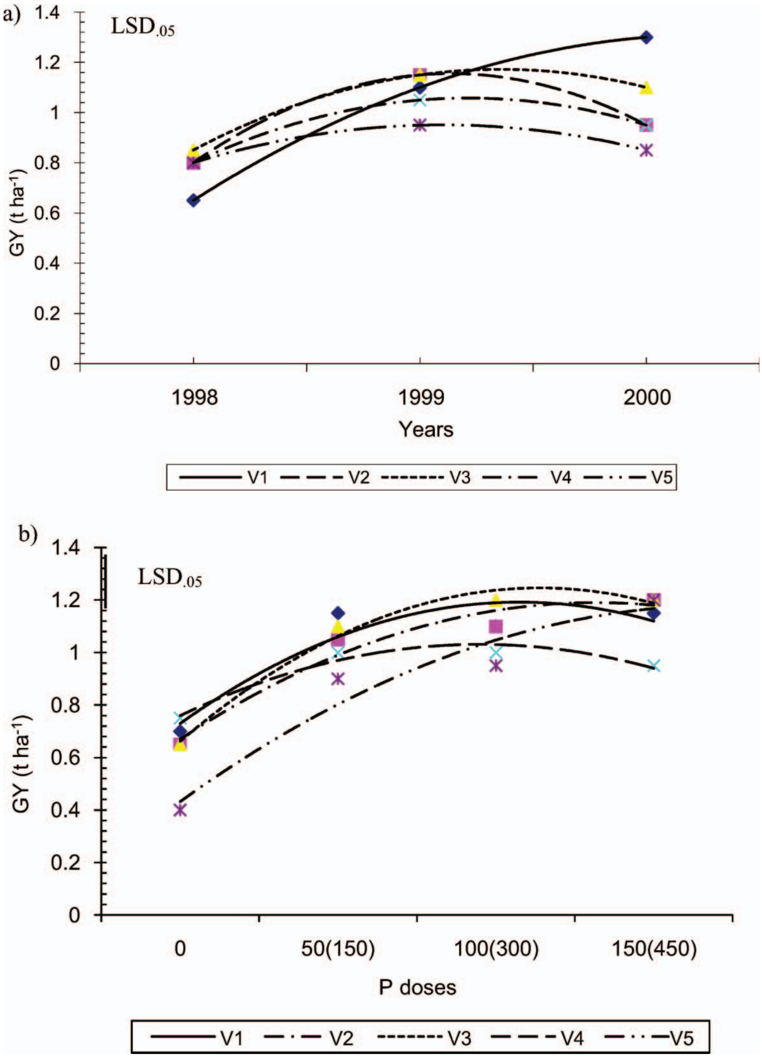

Figure 1. Influence of year and cultivar (averaged across P sources and doses) (a) and influence of P rate and cultivar (averaged across years and P sources) (b) on grain yield of interspecific cultivars (V2, V3, V4 and V5) and the control variety (V1). Sum in brackets is proportional rate of PR for three years' cropping.

sources of P. However, the application of PR to interspecific cultivars V2, V3 and V4 produced at least 23% more panicles than with the application of an equivalent amount of either TSP or PR to the control cultivar-V1 (WAB 56-104). Furthermore, averaging across year and P source, the increase in P rates only significantly enhanced panicle production in cultivar V5 but not in the others (Figure 5b). The application of 50P as TSP or 150P as PR to interspecific cultivars V2 and V3 (Figure 5b) produced significantly more panicles than the application of twice these rates to the control cultivar (V1), suggesting that cultivar V2 and V3 are more efficient than the control variety in utilizing P from both P sources for panicle production.

Table 3. Influence of P source and cultivar (averaged across doses and years) on grain yield of the interspecific rice (V2–V5).

Cultivar	Grain yield (t ha^{-1}) PR	Grain yield (t ha^{-1}) TSP
V1 (control)	1.11	0.98
V2 (NERICA1)	0.92	1.07
V3	1.06	1.04
V4	1.00	0.90
V5	0.96	0.87
Grand mean	1.00	0.97
LSD$_{.05}$ (Cv × Fert)	0.267	

TSP = Triple superphosphate; PR = Phosphate rock; Cv = Cultivar; Fert = P source.

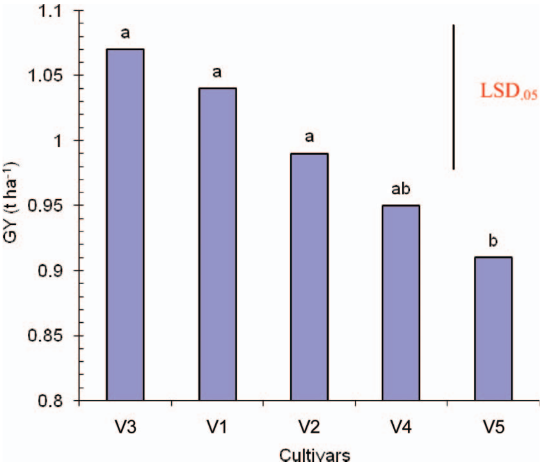

Figure 2. Mean grain yield obtained per cultivar (V1–V5), averaged across years, P sources and rates ($p = 0.02$).

Agronomic use efficiency of P

In each year, there was a significant interaction of cultivar × P source for agronomic efficiency of P (AEP) (Figure 6). The AEP was the lowest in 1998 but increased with years particularly in cultivars V1, V2 and V3. Cultivar V1 had the least AEP with application of TSP in 1998, while in the second year, application of both P sources gave significantly higher AEP (>8 kg grain/kg P) in cultivars V2 and V3 than the application of TSP to cultivar V1 or both P sources to cultivars V4 and V5. Similarly, cultivar V1 with application of both P sources and cultivar V2 with applied TSP ranked among the most efficient in utilizing P for grain production in the third year (Figure 6).

Residual soil available P

Residual P at the end of year 3 cropping was significantly increased with increasing in P rates (Table 4) compared to the value of 2.8 mg P kg^{-1} in the soil at the

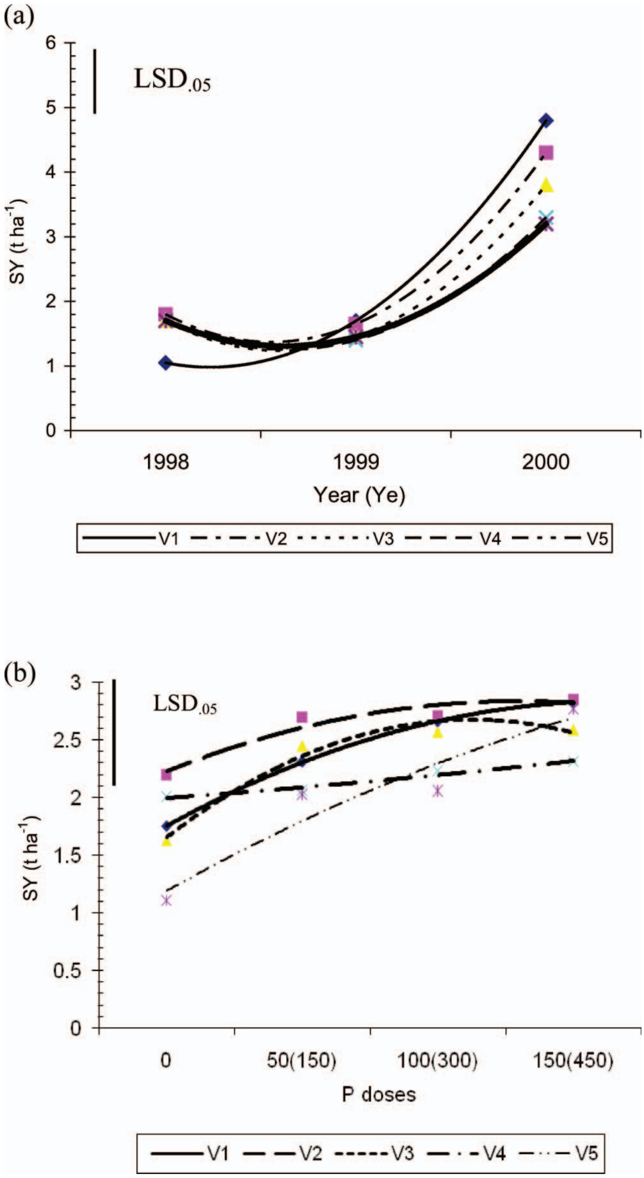

Figure 3. Influence of cultivar combined with year (a) and P doses (b) on mean straw yield of interspecific cultivars (V2, V3, V4 and V5) and the control cultivar (V1). Sum in brackets is proportional rate of PR for three years' cropping.

beginning of the experiment. The highest available P in the soil after the experiment was obtained with application of 150P as TSP, about 1.4 times higher than the residual P at 450P for PR applied once in year 1. The residual P was similar with application of the lowest P rate of TSP and PR, but the values were significantly greater with higher doses of TSP than of PR. There was no effect of cultivars on the soil available P.

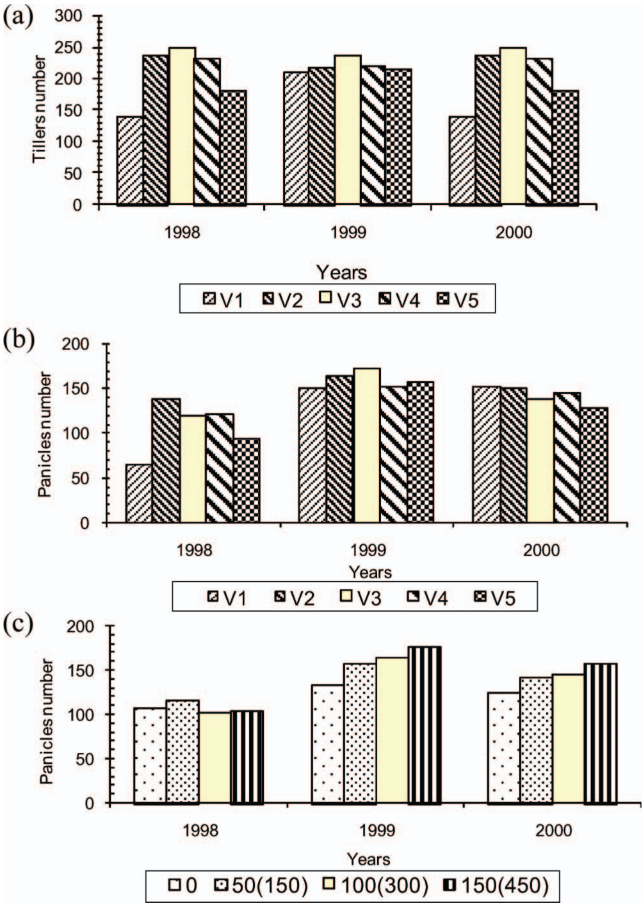

Figure 4. Influence of year and cultivar (averaged across P sources and rates) on number of tillers (a) and panicles (b); and influence of year and P rate (averaged across cultivars and P sources) on panicle production (c) of interspecific cultivars (V2, V3, V4 and V5) and a control (V1). Bar is LSD at $p < 0.05$.

Discussion

The combined use of acid- and low P- tolerant rice variety with potential to enhance the solubility of P from locally available phosphate rock could improve upland rice productivity in acid P-deficient soils. In this study, the site characterization indicated inherent poor fertility and strongly acidic soil condition as earlier defined by McKenzie (2003). The results obtained showed highly significant response to P from both P sources as frequently observed in such P-deficient soil conditions (Sahrawat et al. 1995, 1997, 2001; Somado et al. 2006; Oikeh et al. 2008b). The low yields (<2 t ha^{-1}) observed were similar to the values reported by Sahrawat et al. (2003) at the same experimental site using TSP at different rates (45, 90, 135 and 180 kg P ha^{-1}) applied once for six years of experimentation. However, mean yields reported here were much lower than those of NERICA varieties reported by Oikeh et al. (2008b) in the humid forest agroecosystem of Nigeria. The low C content and the imbalanced ratio of Ca:Mg in the studied soil (Table 1), and possible deficiency of micronutrients

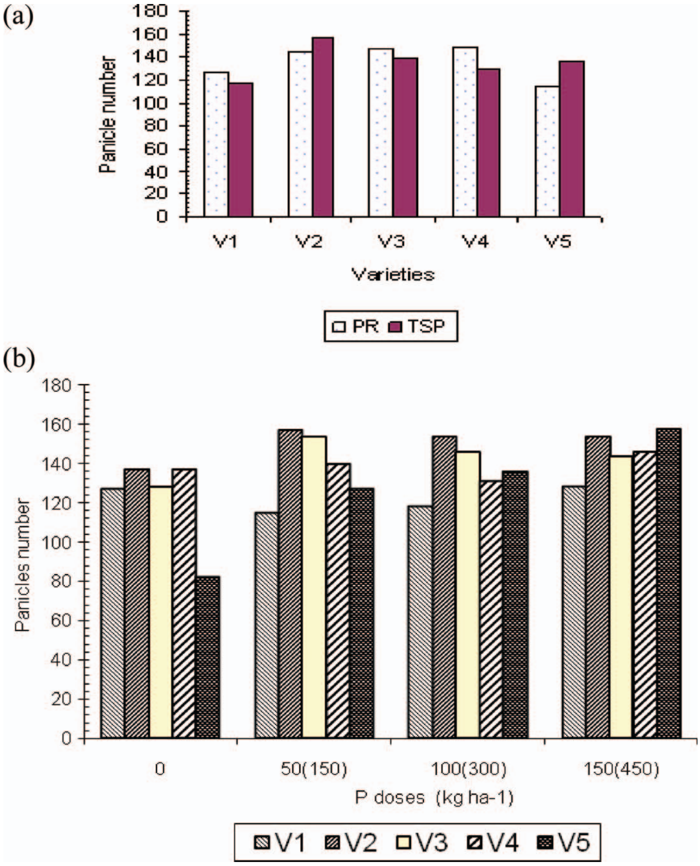

Figure 5. Influence of cultivar and P source (a), and cultivar and P rate (b) on panicle production of interspecific cultivars (V2–V5) and a control (V1). Bar is LSD at $p < 0.05$.

such as Zn might have inhibited P uptake (Yates 1964; Marschner and Cakmak 1986; Koné et al. 2009), thereby reducing the yield potential of the interspecific cultivars used in the present study. The combined use of P and organic manure can be recommended in this condition.

Sahrawat et al. (1995) and Somado et al. (2003, 2006) reported little further grain yield response of *O. sativa* rice varieties to an annual field application beyond 60 kg P ha^{-1} in the acid humid forest agroecosystems of Côte d'Ivoire. The present study showed that there was no significant response to P beyond the 50 kg ha^{-1} y^{-1}, suggesting that this rate was optimum for the crop. In fact, applying high rate of P can depress micronutrient especially Zn uptake by the crop (Neue et al. 1998; Alloway 2008). This factor could have significantly contributed to the lower values (1–10 kg grain kg^{-1} applied P) of AEP during the study as also observed by Sahrawat et al. (2003). Recently, Oikeh et al. (2008b) reported higher P-use efficiencies among the interspecific rice named NERICA, using a reduced P (TSP) rate of 26 kg P ha^{-1} in the humid forest agroecosystems of Nigeria. Therefore, moderate rates of P ranging from 26–50 kg P ha^{-1} y^{-1} could be recommended for NERICA production on acid P-deficient soil in the humid forest of WA.

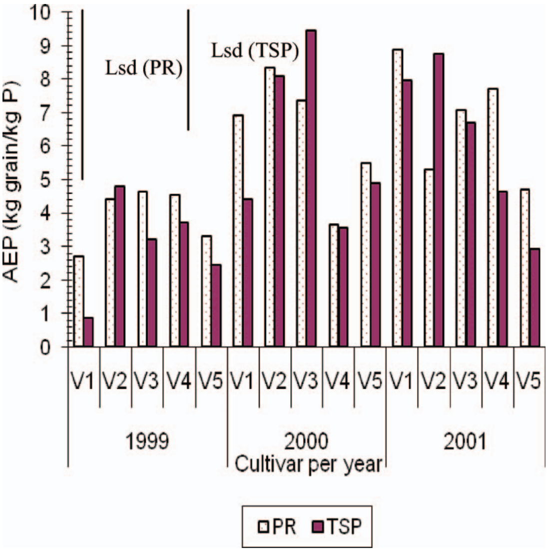

Figure 6. Annual (1999, 2000 and 2001) agronomic efficiency of P (AEP) from Mali phosphate rock (PR) and TSP for each cultivar.

Table 4. Influence of P sources and doses (average across cultivars and years) on residual soil available P contents (mg kg^{-1}) in 0–20 cm horizon.

kg P ha^{-1}	Soil available P (mg kg^{-1})	
	PR	TSP
0*	5.50	5.50
50 (150)[1]	8.80	10.20
100 (300)	12.30	19.30
150 (450)	17.95	24.30
$LSD_{.05}$	4.8	

[1] Values in parenthesis are phosphate rock (PR) rates. TSP = Triple superphosphate. *P value is not significantly different to the initial value of 2.8 mg kg^{-1}.

The interspecific rice varieties have been developed as low-management rice plant types targeted for resource-limited, smallholder production systems (Dingkuhn et al. 1998). Therefore, their improved performance with lower P than the recommended rates thus confirmed the significant role they can play in African smallholder production systems.

No significant change was observed in available P content in soil of control plot (0 kg P ha^{-1}) after the experiment compared to the initial value. Native P solubilization by root excretion can explain this (Saleque 1994; Kirk et al. 1999) in regard to the heavy rainfall amounts during the experiment. The significantly higher available P in soil from TSP compared to PR at doses above 50 kg P ha^{-1} y^{-1} show that application of high rates of P can build soil P status but a lack of response of rice to high rate of P suggests that such higher rates are not economical and sustainable for smallholder farmers cultivating NERICAs. The value of soil available P after the experiment built up by higher rates of P application has been reported to decrease rapidly as a result of rapid reversion to insoluble P by reacting with Fe and Al hydroxides on Ultisols and Oxisols, which have high P sorption capacity (Owusu-Bennoah and Acquaye 1989; Linquist et al. 1997; Sahrawat et al. 1997).

Zapata and Roy (2004) recommended application of PR at rates between 500 and 1000 kg ha^{-1} y^{-1} for acid soils. These recommended rates would translate into 69–138 kg P ha^{-1} y^{-1}, i.e. 30–176% higher than the optimum rate obtained in this study.

All the interspecific cultivars used in the present study except cv. V5 had similar grain yield and agronomic efficiency of P compared to cv.WAB 56-104 (control). In contrast, a recent study involving two parents of NERICA (*O. sativa* cv. WAB 56-50 and *O. glaberrima* cv. CG 14), a local *O. sativa* variety, and NERICA2 compared under Tilemsi Mali PR versus TSP reported that NERICA2 had greater potential to solubilize PR compared to the other cultivars (Oikeh et al. 2008a). These authors attributed this partly to the better rooting capacity of NERICA2 at 84 DAS compared to the other cultivars, which might have played a significant role in the acquisition of nutrients including P from the soil. Moreover, enhanced deeper rooting systems with application of P to upland rice had been reported (Sahrawat et al. 1995). The root system of the cultivars was not evaluated in the present study. The better performance of cultivars V2 and V3 (interspecific rice) in our study might be attributed to improved root systems and enhanced nutrients acquisition including P from the soil. However, further studies are needed on root morphological characterization of the existing NERICA varieties in relation to plant nutrition.

The enhanced tiller and panicle production among interspecific cultivars compared with the control cv. WAB 56-104 confirmed earlier reports about NERICA tiller production compared with *O. sativa* (Okeleye et al. 2006; Oikeh et al. 2009). Okeleye et al. (2006) reported that enhanced tiller and panicle production was mentioned as one of the reasons given by farmers in Western Nigeria for their preference for NERICA varieties compared to the other improved upland varieties. However, in the present study, the enhanced panicle production did not translate into significantly greater grain yield of interspecific cultivars than the control variety.

In fact, the control cultivar performed even better than some of the interspecific cultivars in the third year of the study. The observed polynomial trend showing declining yields of most interspecific cultivars in the third year is consistent with other studies (Barns 1971; Siband 1972; Kang et al. 1977; Lal and Cummings 1979) that indicated a downward spiral in productivity whenever cultivation was extended beyond two cropping seasons in continuous mono-cropping of cereal crops mostly due to the gradual depletion of plant nutrients and soil organic matter, and greater soil compaction. In the present study, there were no varietal differences in residual P values of the soil in the third year and depletion of nutrients other than available P was not studied. It is therefore proposed to have a crop rotation system in which interspecific rice cultivars are used for the first two years followed by N_2-fixing legumes with potential to solubilize PR as suggested by some workers (Somado et al. 2003, 2006; Oikeh et al. 2008a). However, if the rice crop must be grown in the third year, any of the high yielding P-use efficient *O. sativa* WAB series or the interspecific rice (V2 and V3) could be used to avoid decline in rice yield. Such a strategy is likely to improve upland rice production in the humid forest zone of West Africa.

Conclusion

The study revealed some rice interspecific cultivars (NERICA1, WAB450-11-1-P-40-HB) to be tolerant to soil acidity as well as *O. sativa* cultivar (WAB 56-104). They are recommended for improving upland rice production in the humid forest of West Africa when applying 50 kg P ha^{-1} y^{-1} as TSP or 150 kg P ha^{-1} as PR for three years' cropping. A further application of P was not economically and ecologically suitable.

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