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# Phosphorus Response of *Oryza sativa, O. glaberrima,* and Hybrid Rice Cultivars on an Ultisol

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*Phosphorus (P) deficiency is a major constraint to upland rice production on Ultisols in the humid zone of West Africa. Integrated use of P-efficient cultivars and P nutrition is needed for enhanced sustainable productivity on these soils. This article reports on the P responsiveness of interspecific rice hybrids (crosses from* Oryza sativa *and* O. glaberrima*) along with* O. sativa *and* O. glaberrima *cultivars grown on an acidic Ultisol, low in available P. The cultivars differed in yield and P-uptake response to fresh and residual P. Two interspecific cultivars gave a linear response to P and produced the greatest grain yield under direct and residual P. The* O. glaberrima *cultivar CG 14 did not respond to the applied P, whereas the* O. sativa *cultivar was moderate in its performance. Our results show that the interspecific rice cultivars have the potential to adapt and perform well on acidic upland soils.*

**Keywords** Acidic soils, cultivar differences in P use, direct and residual P response, grain and biomass yield, interspecific hybrid rice, P management



## Introduction

Apart from water shortages and associated drought, soil infertility is the major constraint to crop production and productivity in most of the tropical regions of the world (Black 1993; Balasubramanian et al. 2007; Bationo et al. 2008). Worldwide, phosphorus (P) deficiency is identified as a major nutrient constraint to crop production on acidic tropical soils in the humid and subhumid tropical regions (Sanchez and Salinas 1981; Von Uexkull and Mutert 1995; Bationo et al. 2008). The situation is no different in West Africa, and P deficiency has been identified as a major constraint to crop production on the low-activity, acidic soils of the humid and subhumid regions of west and central Africa (Mokwunye, de Jager, and Smaling 1996; Sahrawat, Abekoe, and Diatta 2001; Bationo et al. 2008). The soils are inherently low in P, and the applied P is reverted into an insoluble form because of reactions with iron and aluminum oxides. The lack of sufficient concentration of soluble P in soil constrains upland rice production and productivity (Sahrawat, Abekoe, and Diatta 2001).

Our earlier research showed that upland rice is a robust crop and that rice cultivars adapted to acidic soil conditions perform well when fertilized with P (Sahrawat, Jones, and Diatta 2000). Upland rice cultivars differ in adaptation to acidic soil conditions and P-use efficiency (Fageria, Wright, and Baligar 1988). Previously, we reported research relating

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to the differences in P efficiency among *O. sativa* cultivars (Sahrawat, Jones, and Diatta 1995). Simultaneously, we have been evaluating *O. sativa* × *O. glaberrima* interspecific rice cultivars bred at West Africa Rice Development Association (WARDA) (Jones et al. 1997) for their performance on acidic, P-deficient soils (Sahrawat, Jones, and Diatta 2000). Some promising interspecific cultivars have been identified as a result. This article presents results obtained in a two-year field experiment on the P responsiveness of promising interspecific progenies in response to direct and residual fertilizer P on an Ultisol in the humid forest zone of the Ivory Coast.

## Materials and Methods

### *Experimental Site*

A field experiment was conducted for 2 years (1999–2000) at the Institute des savanes (IDESSA), now Centre National de Recherché Agricole (CNRA), station near Man (7.2° N, 7.4° W; 500 m altitude), Ivory Coast, to determine fertilizer P response of *O. sativa*, *O. glaberrima*, and *O. sativa* × *O. glaberrima* interspecific cultivars on an Ultisol, Typic Paleudult, in the humid forest zone. The site receives an annual rainfall of about 2000 mm in a monomodal rainy season. The site was under a bush fallow for the 4 years before initiation of the experiment. The fallow vegetation at the site was dominated by *Chromolaena odorata* (Compositae).



### *Soil*

The soil at the experimental site is an Ultisol with acidic pH and low in available P. Soil samples were collected from surface (0–0.2 m) and subsurface (0.2–0.4 m) layers before initiating the experiment. They were air-dried and ground to pass a 2-mm screen. Some chemical characteristics of the soil are given in Table 1. For soil analyses, pH was measured by a glass electrode using a soil to water or 1 M potassium chloride (KCl) solution ratio of 1:2.5. Organic carbon (C) was determined using the Walkley–Black method

**Table 1**
Chemical characteristics of the Ultisol, Typic Paleudult (0- to 0.2-m and 0.2- to 0.4-m depths) at the experimental site near Man, Ivory Coast, at the initiation of the field experiment in 1999

| | Soil depth (m) | |
|---|---|---|
| Soil characteristic | 0–0.2 | 0.2–0.4 |
| pH (1 M KCl) | 3.9 | 3.9 |
| Bray 1 P (mg kg$^{-1}$) | 3 | 3 |
| Total P (mg kg$^{-1}$) | 228 | 208 |
| Organic C (g kg$^{-1}$) | 11.0 | 10.0 |
| Total N (mg kg$^{-1}$) | 600 | 500 |
| DTPA-extracted nutrients (mg kg$^{-1}$) | | |
| Fe | 114 | 79 |
| Zn | 1 | 1 |

(Nelson and Sommers 1982), and total N was determined as described by Bremner and Mulvaney (1982). Total P was determined by digesting the samples with perchloric acid, and extractable P was determined using Bray 1 extractant [ammonium fluoride ($NH_4F$)–hydrochloric acid (HCl) solution] using a soil/extractant ratio of 1:7 (Olsen and Sommers 1982).

### *Field Experiment*

The experiment was conducted during the wet season (June–October) in 1999 and 2000. The land at the experimental site was cleared by slashing the vegetation, and the slashed vegetation was removed from the plots. Land was prepared by disc plowing and harrowing the plots to obtain a good seed bed.

The experiment used a two-factorial randomized complete block design with three replications. Factor 1 was P application in 1999 at five rates of 0, 30, 60, 90, and 120 kg P $ha^{-1}$ as triple superphosphate (TSP). Factor 2 was upland rice cultivar, and the five rice cultivars used in the study were WAB 450-I-B-P-38-HB, WAB 450-11-1-P-31-1-HB, and WAB 450-I-B-P-160-HB (all three are interspecific progenies); CG 14 (*O. glaberrima* cultivar); and WAB 570-10-B-1A1.15 (O. *sativa* cultivar). Fertilizer P was applied only once in 1999, and the responses to direct and residual P were evaluated by growing the five cultivars on plots measuring 5 m × 3 m with a row spacing of 25 cm. All plots received uniform application of nitrogen (N) as urea at 100 kg N $ha^{-1}$ in three splits at planting, tillering, and panicle initiation. A uniform, basal application to all plots of potassium (K) at a rate of 80 kg K $ha^{-1}$ as potassium chloride (KCl) was also made. A pre-emergent herbicide, Ronstar, was used to control weeds. In addition, plots were hand-weeded at 4 and 6 weeks after emergence of the crop.

The experiment was repeated in the 2000 wet season as the five rice cultivars were grown on the same plots without any fresh application of fertilizer P to determine response to the residues of fertilizer P applied in 1999. All plots received an annual application of fertilizer N at a rate of 100 kg N $ha^{-1}$, applied in three splits at planting, tillering, and panicle initiation stages of the crop, and K at a rate of 80 kg K $ha^{-1}$ as basal application. All other details of the experiment were the same as in 1999.

The crops were harvested at maturity, and grain and straw yields were recorded. Grain yield was recorded at 14% moisture content. The straw yield was recorded on a dry-weight basis, by drying the samples at 60 °C for 48 h. Grain and straw samples were analyzed for P by digesting the ground samples with a 2:1 mixture of nitric and perchloric acids. The P in the digests was analyzed following the vanadomolybdate yellow color method (Jones, Wolf, and Mills 1991).

The data were analyzed statistically using the analysis of variance (ANOVA) procedure.

## Results and Discussion

### *Grain Yield Response to Direct and Residual P*

Results on direct and residual P response of the five cultivars are shown in Tables 2 and 3. The cultivars differed in their response to fresh P in 1999 and to the residual P in 2000. A severe lodging of the crop was observed in the case of *O. glaberrima* cultivar CG 14, especially in treatments where nutrients were added. Shattering of grains at maturity was also observed in CG 14.

**Table 2**
Grain and straw yields and P uptake of five upland rice cultivars in response to direct effect of fertilizer P in 1999 on an Ultisol at Man, Ivory Coast

| | Fertilizer P applied (kg $ha^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Cultivar | 0 | 30 | 60 | 90 | 120 | LSD (0.05) |
| Grain yield (t $ha^{-1}$) | | | | | | |
| WAB 450-1-B-P-38-HB | 1.22 | 1.82 | 2.41 | 2.16 | 2.59 | 0.87 |
| WAB 450-11-1-P-31-1-HB | 1.73 | 2.27 | 2.49 | 2.84 | 3.09 | 0.96 |
| WAB 450-1-B-P-160-HB | 1.29 | 1.69 | 1.91 | 2.09 | 2.68 | 0.52 |
| WAB 570-10-B-1A1.15 | 1.03 | 1.75 | 1.79 | 1.94 | 1.83 | 0.60 |
| CG 14 | 1.51 | 2.05 | 1.56 | 1.56 | 1.43 | 0.73 |
| Mean | 1.36 | 1.92 | 2.03 | 2.12 | 2.32 | |
| Straw yield (t $ha^{-1}$) | | | | | | |
| WAB 450-1-B-P-38-HB | 2.73 | 3.17 | 3.34 | 3.57 | 3.31 | 0.76 |
| WAB 450-11-1-P-31-HB | 2.37 | 3.21 | 3.16 | 3.60 | 3.65 | 0.31 |
| WAB 450-1-B-P-160-HB | 2.38 | 2.89 | 3.09 | 3.42 | 3.63 | 0.65 |
| WAB 570-10-B-1A1.15 | 2.46 | 3.26 | 3.76 | 3.65 | 3.79 | 1.00 |
| CG 14 | 3.81 | 5.79 | 5.61 | 5.91 | 5.92 | 0.95 |
| Mean | 2.75 | 3.66 | 3.79 | 4.03 | 4.06 | |
| Total P uptake (kg $ha^{-1}$) | | | | | | |
| WAB 450-1-B-P-38-HB | 2.4 | 4.1 | 6.1 | 6.4 | 7.5 | 1.92 |
| WAB 450-11-1-P-31-HB | 2.8 | 3.7 | 5.8 | 6.7 | 7.4 | 1.75 |
| WAB 450-1-B-P-160-HB | 2.7 | 4.0 | 4.8 | 5.4 | 7.0 | 1.38 |
| WAB 570-10-B-1A1.15 | 1.9 | 3.6 | 4.5 | 4.6 | 4.5 | 1.19 |
| CG 14 | 3.5 | 5.0 | 5.4 | 6.2 | 7.7 | 1.67 |
| Mean | 2.7 | 4.1 | 5.3 | 5.9 | 6.8 | |



Without application of P, the interspecific cultivar WAB 450-11-1-P-31-1-HB produced the greatest grain yield (1.73 t $ha^{-1}$) followed by CG 14 (1.51 t $ha^{-1}$), WAB 450-I-B-P-160-HB (1.29 t $ha^{-1}$), WAB 450-I-B-P-38-HB (1.22 t $ha^{-1}$), and WAB 570-10-B-1A1.15 (1.03 t $ha^{-1}$). In response to fresh P in 1999, the interspecific progenies generally gave better response to applied P, with WAB 450-11-1-P-31-1-HB giving a linear response and producing the greatest yield of 3.09 t $ha^{-1}$. CG 14, the *O. glaberrima* cultivar, did not respond to applied P, whereas the rest of the cultivars were moderate in response to the applied P (Table 2). In 1999, the direct P responses of the five rice cultivars were described by the following response equations:

WAB 450-I-B-P-38-HB:

$$\text{Grain yield (t ha}^{-1}) = 1.4240 \pm 0.2126 + 0.0103 \text{ P applied (kg ha}^{-1}), \quad \text{R} = 0.899 \tag{1}$$

WAB 450-11-1-P-31-1-HB:

$$\text{Grain yield} = 1.8260 \pm 0.0720 + 0.0110 \text{ P applied}, \quad \text{R} = 0.988 \tag{2}$$

**Table 3**
Grain and straw yields and P uptake of five upland rice cultivars in response to residual effect of fertilizer P in 2000 on an Ultisol at Man, Ivory Coast (fertilizer P was applied in 1999)

| | Fertilizer P applied (kg ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Cultivar | 0 | 30 | 60 | 90 | 120 | LSD (0.05) |
| Grain yield (t ha$^{-1}$) | | | | | | |
| WAB 450-I-B-P-38-HB | 1.04 | 1.25 | 1.61 | 1.52 | 1.53 | 0.54 |
| WAB 450-11-1-P-31-1-HB | 1.10 | 1.09 | 1.28 | 1.29 | 1.72 | 0.28 |
| WAB 450-1-B-P-160-HB | 1.62 | 2.02 | 2.05 | 1.87 | 1.98 | 0.31 |
| WAB 570-10-B-1A1.15 | 1.22 | 1.17 | 1.64 | 1.45 | 1.44 | 0.42 |
| CG 14 | 1.34 | 1.57 | 1.48 | 1.58 | 1.30 | 0.57 |
| Mean | 1.26 | 1.11 | 1.72 | 1.54 | 1.59 | |
| Straw yield (t ha$^{-1}$) | | | | | | |
| WAB 450-I-B-P-38-HB | 1.94 | 1.84 | 1.99 | 1.91 | 1.68 | 1.68 |
| WAB 450-11-1-P-31-1-HB | 1.78 | 1.61 | 1.63 | 1.63 | 1.83 | 0.48 |
| WAB 450-1-B-P-160-HB | 2.27 | 1.97 | 1.99 | 1.92 | 2.29 | 0.72 |
| WAB 570-10-B-1A1.15 | 1.90 | 1.79 | 2.03 | 2.00 | 2.05 | 0.65 |
| CG 14 | 1.94 | 2.18 | 2.56 | 3.24 | 3.24 | 1.72 |
| Mean | 1.97 | 1.88 | 2.16 | 2.14 | 1.91 | |
| Total P uptake (kg ha$^{-1}$) | | | | | | |
| WAB 450-I-B-P-38-HB | 1.9 | 2.7 | 3.9 | 4.1 | 4.2 | 1.02 |
| WAB 450-11-1-P-31-1-HB | 1.9 | 2.1 | 2.8 | 3.0 | 4.3 | 0.94 |
| WAB 450-1-B-P-160-HB | 3.1 | 3.5 | 3.9 | 4.1 | 4.9 | 0.70 |
| WAB 570-10-B-1A1.15 | 1.9 | 2.2 | 3.3 | 3.4 | 3.6 | 0.78 |
| CG 14 | 1.7 | 3.4 | 4.2 | 5.3 | 4.4 | 1.34 |
| Mean | 2.1 | 2.8 | 3.6 | 4.0 | 4.3 | 4.3 |



WAB 450-I-B-P-160-HB:

$$\text{Grain yield} = 1.2960 \pm 0.0943 + 0.0106\ \text{P applied}, \quad R = 0.979 \tag{3}$$

WAB 570-10-B-1A1.15:

$$\text{Grain yield} = 1.3100 \pm 0.2040 + 0.0060\ \text{P applied}, \quad R = 0.778 \tag{4}$$

CG 14:

$$\text{Grain yield} = 1.8520 \pm 0.1990 - 0.002\ \text{P applied}, \quad R = 0.419 \tag{5}$$

In 2000, grain yield responses to the residual P were considerably less than those obtained with direct P in 1999 across the five cultivars. Out of the five cultivars, only the interspecific cultivars WAB 450- I-B-P-38-HB and WAB 450-11-1-P-31-1-HB significantly responded to the residual P. As with the direct P, CG 14 failed to give significant grain yield response to residual P (Table 3). The response to the residual P was described by the following equations:

WAB 450-I-B-P-38-HB:

$$\text{Grain yield} = 1.1400 \pm 0.1190 + 0.0103\ \text{P applied}, \quad \text{R} = 0.833 \tag{6}$$

WAB 450-11-1-P-31-1-HB:

$$\text{Grain yield} = 1.0080 \pm 0.1035 + 0.0048\ \text{P applied}, \quad \text{R} = 0.891 \tag{7}$$

WAB 450-I-B-P-160-HB:

$$\text{Grain yield} = 1.7940 \pm 0.1340 + 0.0019\ \text{P applied}, \quad \text{R} = 0.515 \tag{8}$$

WAB 570-10-B-1A1.15:

$$\text{Grain yield} = 1.2400 \pm 0.1370 + 0.0024\ \text{P applied}, \quad \text{R} = 0.596 \tag{9}$$

CG 14:

$$\text{Grain yield} = 1.4680 \pm 0.1151 - 0.0002\ \text{P applied}, \quad \text{R} = 0.086 \tag{10}$$

The direct and residual effects of fertilizer P were also evaluated by comparing grain yield responses of the cultivars in 1999 and 2000. Grain yield response is the increase in grain yield due to fresh or residual P and was computed using the following formula:

$$\text{Grain yield in the plus P treatment} - \text{Grain yield in the control without P}$$

The rice cultivars differed in grain yield response to direct and residual P, and the response was greater with direct P than with residual P and was affected by the rate of fertilizer P applied. The interspecific cultivars generally gave the greatest grain yield response, followed by *O. sativa* cultivar and CG 14; the *O. glaberrima* cultivar gave the least grain yield response under both direct and residual P (Table 4).

In 1999, direct grain yield responses of the five cultivars with the exception of CG 14 were large, and the mean grain yield response (averaged over four rates of P) ranged from 160 to 1025 kg ha$^{-1}$. The mean grain yield response (averaged over five rice cultivars) increased from 560 to 984 kg ha$^{-1}$ with the increase in the rate of applied P from 30 to 120 kg P ha$^{-1}$. Among the five cultivars, the interspecific progeny WAB 450-I-B-P-38-HB gave the greatest grain yield response and the *O. glaberrima* cultivar CG 14 gave the lowest.

The grain yield responses to residual P in 2000 were considerably less across the cultivars and rates of fertilizer P applied in 1999. The mean grain yield response to residual P in 2000 ranged from 153 to 438 kg ha$^{-1}$ and was greatest for WAB 450-I-B-P-38-HB and least for CG 14 (Table 4).

The grain yields were considerably reduced in the second year in response to residual P. These results confirm our earlier finding that the residual effects of fertilizer P applied in the previous year are greatly reduced on Ultisols (Sahrawat et al. 2001) as a result of reversion of soluble P into insoluble P form by reactions with iron and aluminum oxides, leading to reduced availability of applied P (Abekoe and Sahrawat 2001, 2003).

**Table 4**
Grain yield response (kg ha$^{-1}$) of five upland rice cultivars to direct P in 1999 and to residual P in 2000 on an Ultisol at Man, Ivory Coast

| | Grain yield (kg ha$^{-1}$) | | | | |
|---|---|---|---|---|---|
| P rate (kg ha$^{-1}$) | 30 | 60 | 90 | 120 | Mean |
| Direct P response | | | | | |
| WAB 450-I-B-P-38-HB | 600 | 1190 | 940 | 1370 | 1025 |
| WAB 450-11-1-P-31-HB | 540 | 760 | 1110 | 1360 | 943 |
| WAB 450-1-B-P-160-HB | 400 | 620 | 800 | 1390 | 803 |
| WAB 570-10-B-1A1.15 | 720 | 760 | 910 | 800 | 798 |
| CG 14 | 540 | 50 | 50 | 0 | 160 |
| Mean | 560 | 676 | 762 | 984 | |
| Residual P response | | | | | |
| WAB 450-I-B-P-38-HB | 210 | 570 | 480 | 490 | 438 |
| WAB 450-11-1-P-31-HB | 0 | 180 | 190 | 620 | 248 |
| WAB 450-1-B-P-160-HB | 400 | 430 | 250 | 360 | 360 |
| WAB 570-10-B-1A1.15 | 0 | 420 | 230 | 220 | 218 |
| CG 14 | 238 | 140 | 240 | 0 | 155 |
| Mean | 168 | 348 | 278 | 338 | |



### *Straw Yield Response to Direct and Residual P*

As in the case of grain yield response, the response of straw yields to direct and residual P varied among the cultivars. The *O. glaberrima* cultivar CG 14, however, produced the greatest straw yield without and with the application of fertilizer P. In 1999, CG 14 produced a straw yield of 3.81 t ha$^{-1}$ without application of P fertilizer, and the yield was increased to 5.92 t ha$^{-1}$ with the greatest rate of applied P. The *O. sativa* and interspecific cultivars had straw yields ranging between 2.38 and 3.79 t ha$^{-1}$ (Table 2). With residual P in the second year, CG 14 maintained its ability to produce more straw yield than the rest of the cultivars, although at a reduced level (Table 3).

From these results, it would appear that rice straw yield is a sensitive indicator of the response to P concentration in the soil and can be used as a criterion for assessing the residual value of fertilizer P (Sahrawat 2000a).

### *Total P Uptake Response to Direct and Residual P*

CG 14 produced more biomass than rest of the rice cultivars and the total P uptake in the biomass was also greater for the cultivar both without and with the application of fertilizer P or in response to residual P (Tables 2 and 3). Phosphorus uptake response of the rice cultivars was greater in 1999 with fresh P, and the uptake of P was lower for the residual P in 2000 across cultivars and rates of P applied in 1999.

The results also indicate that the upland rice cultivars are P efficient and that a total P uptake of about 2 kg is needed to produce 1 t of rice grain yield. These results are in accord with those reported earlier for the improved *O. sativa* cultivars that show that the upland rice cultivars have a relatively low P requirement (Sahrawat 2000b). Soils that have high P sorption capacity, which results in reduced availability of the residual P, should be considered when developing P-management strategy (Linquist et al. 1996; Sahrawat et al. 2001).

## Conclusions

Based on the results of this 2-year study, two interspecific cultivars, WAB 450-11-1-P-31-1-HB and WAB 450-I-B-P-38-HB, appear promising. The lower grain yield in the case of *O. glaberrima* cultivar CG 14 was due to its lower harvest index (see results in Tables 2 and 3), despite the facts that the cultivar produced more biomass and that total P uptake in the biomass was also greater than in rest of the cultivars. Less grain in the case of CG 14 is also due to lodging of the crop and shattering of grain at maturity. Lodging of the crop was especially severe in the treatments where nutrients were added.



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