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Plant Phosphorus and Rice Yield in an Ultisol of the Humid Forest Zone in West Africa

K. L. Sahrawat, M. P. Jones, and S. Diatta

West Africa Rice Development Association (WARDA), 01 BP 2551 Bouake, Ivory Coast, West Africa

ABSTRACT

Little attention has been devoted to calibrating plant tissue tests for phosphorus (P) in the field for upland rice in West Africa, although information is needed for improving crop production through efficient P nutrition. A field experiment was conducted under rainfed conditions in the 1994 season to establish the relationships between plant P content and grain yield of upland rice grown on an Ultisol, having a range in extractable P, in the humid forest zone of Ivory Coast. The critical limit of P content in the whole rice plant tops at the tillering stage, at 90% relative grain yield, was found to be 2 g kg^{-1} P for the four upland rice cultivars tested. Total P uptake in the biomass was significantly correlated with rice grain (r=0.81, n=20) and straw (r=0.79) yields of the cultivars.

INTRODUCTION

The upland ecosystem in West Africa is very important to rice production (Enyi, 1984). A large area of upland rice is in the humid zone of the subregion. Phosphorus (P) deficiency has been identified as one of the major limiting factors for crop production in highly weathered Ultisols and Oxisols in the tropics (Sanchez

TABLE 1. Physical and chemical characteristics of the soil at the experimental site near Man, Ivory Coast, 1994.

Soil characteristic	
pH (water)	4.9
pH (KCl)	4.0
Clay (g kg^{-1})	220
Sand (g kg^{-1})	490
Silt (g kg^{-1})	290
Organic C (g kg^{-1})	0.135
Total N (g kg^{-1})	0.925
Total P (mg kg^{-1})	155
CEC (cmol kg^{-1})	5.4
Exchangeable cations (cmol kg^{-1})	
K	0.18
Ca	0.56
Mg	0.26
KCl extr. Al (cmol kg^{-1})	1.05
DTPA extr. Zn (mg kg^{-1})	1.0

and Salinas, 1981; Warren, 1992). In the highly weathered upland soils of West Africa, P deficiency is a major constraint to rice production.

A study was initiated for developing P management strategy for upland rice grown on acid soils in the humid zone of West Africa. Phosphorus deficiency is a major constraint to rice production on these soils (Sahrawat et al., 1995). Phosphorus responsiveness and P requirements of promising, acidity-tolerant upland rice cultivars were measured by growing them on low P status Ultisols in the humid forest zone of Ivory Coast. Initial results showed that P fertilization of soil acidity-tolerant upland rice cultivars significantly improved the fertility of Ultisols (Sahrawat et al., 1995).

TABLE 2. Range in grain yields of the four upland rice cultivars and Bray 1 P content in the Ultisol, Man, Ivory Coast, 1994.

	Rice cultivars			
Parameter	WAB 56-125	WAB 56-104	WAB 56-50	IDSA 6
Grain yield (t ha^{-1})	0.86-2.42	0.79-2.18	0.64-2.05	0.74-1.92
Bray 1 P (mg kg^{-1})	6-20	5-23	6-26	6-19

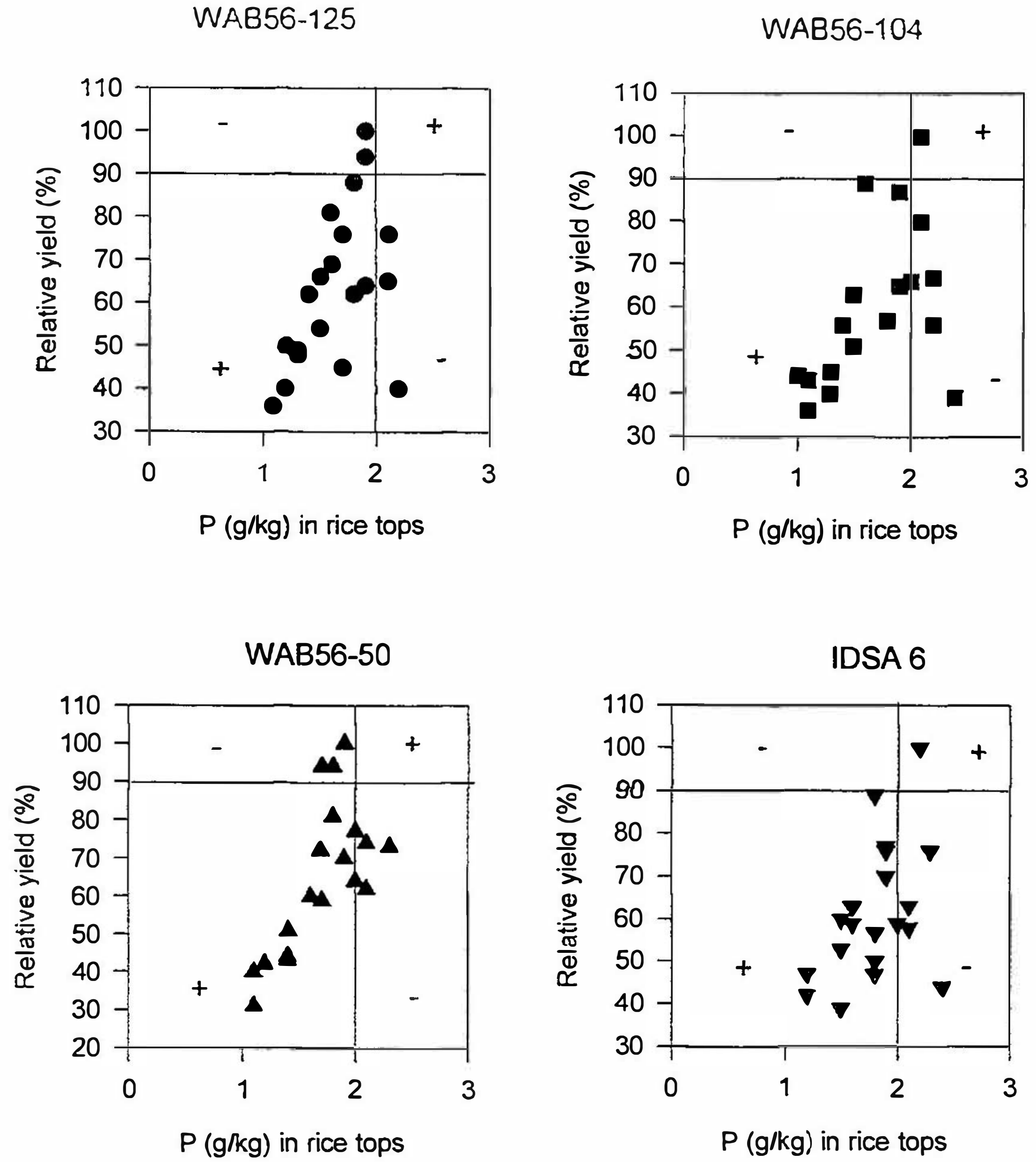

FIGURE 1. Relationship between P content in rice plant whole tops at tillering and relative grain yield for the four upland rice cultivars.

In order to improve fertilizer P recommendations, however, information is also needed on the calibration of soil and plant tissue tests for P in the field for upland rice. In a previous paper, results on the calibration of soil P test for upland rice grown under rainfed conditions were reported (Sahrawat et al., 1997). The work discussed in this paper was undertaken to calibrate plant tissue test by establishing the relationship between plant P content and the yield of upland rice cultivars.

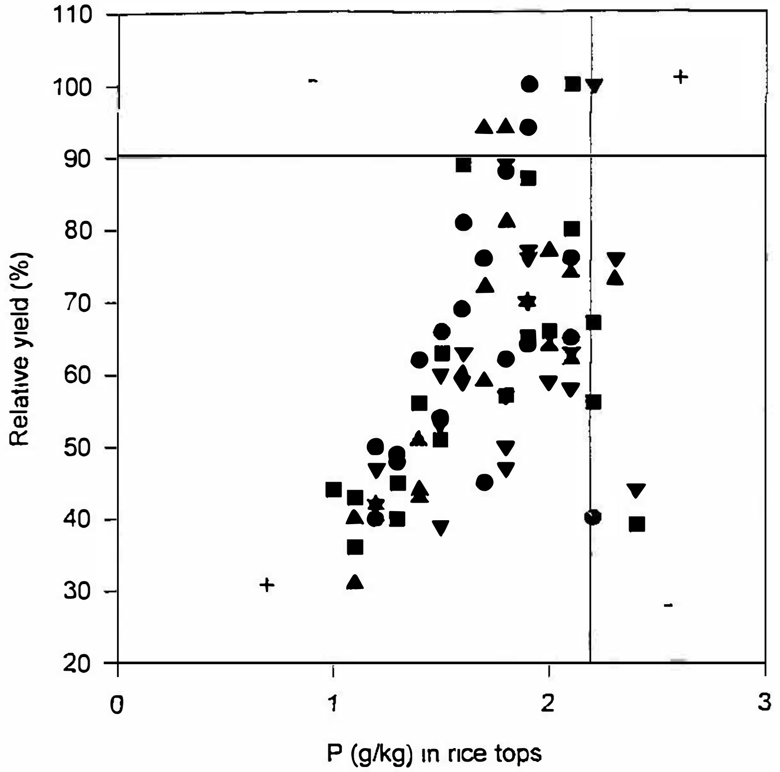

FIGURE 2. Relationship between P content in rice plant whole tops at tillering and relative grain yield with pooled data for the four upland rice cultivars.

MATERIALS AND METHODS

A field experiment was conducted in 1994 at the Institut des Savanes (IDESSA) Station near Man (7.2°N, 7.4°W; 500 m altitude) in Ivory Coast (West Africa). The site is located in the humid forest zone (total annual rainfall of about 1,700 mm) and has previously been used to determine P response of upland rice cultivars (Sahrawat et al., 1995).

The soil at the experimental site was an Ultisol. Soil samples were collected from the surface (0-20 cm) layer before initiating the experiment. They were air dried and sieved through a 2-mm screen before analysis. For organic carbon (C), total P, and total nitrogen (N) analysis, the soil samples were ground to pass a 0.25-mm screen. For the analysis reported in Table 1, soil pH was measured by a glass electrode using a soil to water or 1M KCl solution ratio of 1:2.5. Pipette method (Gee and Bauder, 1986) was employed for particle-size analysis. Organic C was determined using the Walkley-Black method (Nelson and Sommers, 1982). Total P content in the soil was determined by digestion with perchloric acid, and the Bray 1 extractable P (Bray 1 P) was determined using NH4F-HCl solution as the extractant using a soil to extractant ratio of 1:7 (Olsen and Sommers, 1982).

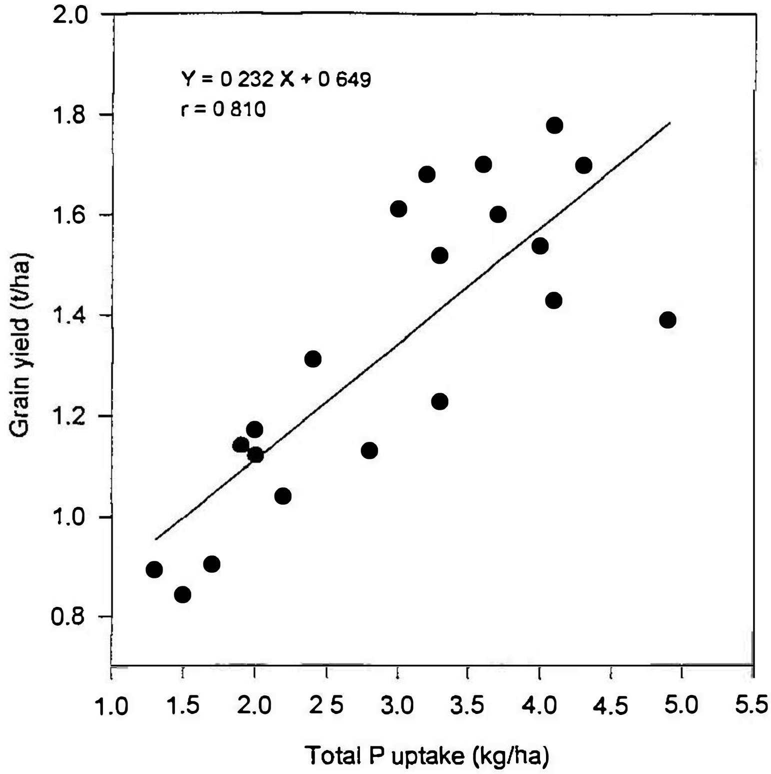

FIGURE 3. Relationship between grain yield and total P uptake of four upland rice cultivars. Each point represents an average value of four replications.

Phosphorus in the extracts were determined colorimetrically using the phosphomolybdate blue color method. Total N was determined as described by Bremner and Mulvaney (1982). Exchangeable potassium (K), calcium (Ca), and magnesium (Mg) (Jackson, 1967), KCl extractable Al (Barnhisel and Bertsch, 1982), cation exchange capacity (CEC) (Chapman, 1965), and DTPA extractable zinc (Zn) (Lindsay and Norvell, 1978) were also determined.

The experiment had a 2-factorial (P application and variety) randomized complete block design with four replications. There were a total of 80 plots, consisting of application of five rates of fertilizer P (0, 45, 90, 135, and 180 kg P ha^{-1}) on four upland rice cultivars (WAB 56-125, WAB 56-104, WAB 56-50, and IDSA 6). The WAB cultivars are WARDA-bred, improved, upland rice cultivars and IDSA 6 is an improved, traditional cultivar, widely grown in the subregion. The plots had received fertilizer P as triple superphosphate (TSP) ranging from 0 to 180 kg P ha^{-1} in the 1993 season. Soil samples collected after harvest of the 1993 season crop and before planting of the experiment in 1994, had a wide range in Bray 1 P (Table 2). Rainfall during the growing season (June-October) was 684 mm. The cultivars were sown in rows at spacing of 25 cm. Each plot (5 m x 3 m) received a total of 100 kg N ha^{-1} as urea in three splits at planting, tillering, and flowering. Plots were hand weeded at 3 and 6 weeks after seeding.

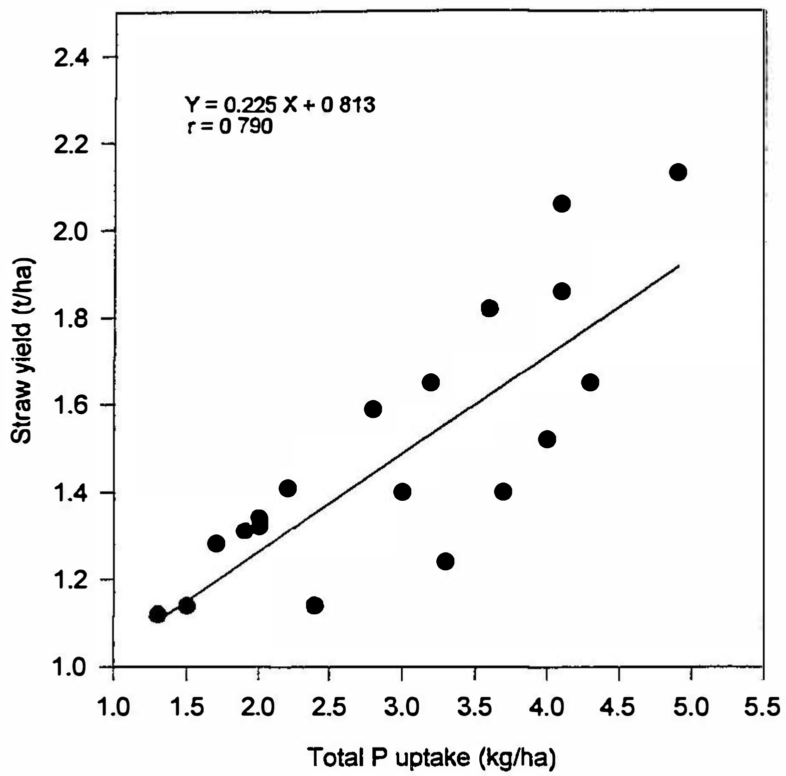

FIGURE 4. Relationship between straw yield and total P uptake of four upland rice cultivars. Each point represents an average value of four replications.

Plant samples, consisting of rice plant whole tops, were collected from five fertilizer P treatments for the four cultivars at the maximum tillering stage. Plant samples were analyzed for P content. Sampling of whole plant tops over the index leaf at tillering was preferred for P plant test calibration. Young plant tissue has higher capacity to accumulate P than leaves. Moreover, a young-plant test could be a useful tool to evaluate P availability early during the season, a period of critical importance for P nutrition (Walker and Peck, 1972). For plant sampling at the tillering stage or earlier, the entire above-ground portion of plant has been recommended (Westfall et al., 1990).

The crops were harvested at maturity and grain and straw weights were recorded at 14% moisture. Grain and straw samples were analyzed for P by digesting the samples with a 2:1 mixture of nitric and perchloric acids. The P in the digests was analyzed following the vanadomolybdate yellow color method.

The Cate and Nelson (1971) method of graphic presentation was used to establish the relationship between P content in rice tops and relative grain yield of the cultivars, to arrive at a critical value of P content in the rice plant tops for each of the cultivars. Relative grain yield was calculated relative to maximum yield. This method has been found to be useful and has practical advantages in addition to showing whether good correlation existed. It divided the data into responsive and non-responsive populations (Dahnke and Olson, 1990).

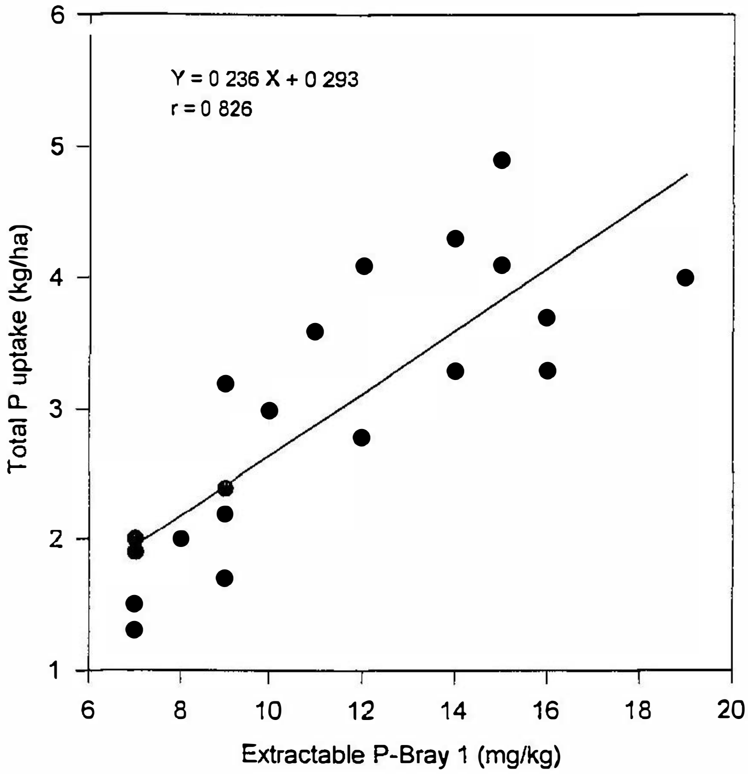

FIGURE 5. Relationship between total P uptake in the dry matter of four upland rice cultivars and Bray 1 extractable P in the soil. Each point represents an average value of four replications.

RESULTS AND DISCUSSION

The upland rice cultivars had a range in grain yields which varied from 0.64 to 2.42 t ha^{-1} for the four cultivars tested (Table 2).

The relationships between relative rice grain yield and P content in the rice plant tops for each of the four cultivars are shown in Figure 1. The data revealed that all four cultivars achieved 90% relative grain yield at a plant P content of 2 g kg^{-1} and there were no cultivaral differences in the internal P requirement. Our earlier results on the calibration of soil P test showed that P efficient rice cultivars achieved the 90% relative yield at relatively lower values of extractable P in the soil than P inefficient cultivar (Sahrawat et al., 1997).

When the data for all four cultivars were pooled to plot the relationship between P content in the plant and relative rice grain yield, a critical limit of 2.2 g kg^{-1} P was obtained at 90% relative yield (Figure 2).

Grain and straw yields of four rice cultivars (n=20) were significantly related to total P uptake in the biomass (Figures 3 and 4) and were described by the following regression equations:

$$\text{Grain yield} = 0.649 + 0.231 \text{ total P uptake}, r = 0.81 \quad [1]$$
$$\text{Straw yield} = 0.813 + 0.225 \text{ total P uptake}, r = 0.79 \quad [2]$$

Total P uptake in the plant biomass was also significantly related to Bray 1 P in the soil samples (Figure 5):

$$\text{Total P uptake} = 0.293 + 0.236 \text{ Bray 1 P}, r = 0.83 \quad [3]$$

Results of this study indicate that a P content of 2 g kg^{-1} in rice plant tops at the tillering stage may be required to achieve 90% relative yield in the Ultisol under rainfed cropping. The concentration appears to be similar for the four cultivars. There are few reports on P contents of plant tissue in relation to relative yield in the field, especially for rainfed upland rice. However, data compiled by Yoshida (1981) for irrigated lowland rice suggested that a P content of 0.1% in the leaf blade of the rice plant at tillering indicated P deficiency. Whereas Fageria et al. (1991) suggested that P content ranging from 0.25 to 0.48% in the rice plant whole tops at 75 days after seeding was considered adequate for P nutrition.

The calibration of soil and plant tests for P are essential for improved fertilizer recommendations and efficient P nutrition of upland rice growing on acid, P-deficient soils such as Ultisols. Information on the calibration of plant P tests clearly supplement the information on the calibration of soil tests for P. Such information can be utilized for diagnosing P deficiency and for follow-up fertilizer P recommendations. However, it is recognized that such information is generally site specific and tends to vary with crop cultivar, soil and crop management, and prevailing agroclimatic conditions.

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