Available P concentration in the PMC-treated soil increased mainly during the first 20 d after incubation (Table 2). The increase in available P in PMC-amended soil was about 70% relative to the nonamended soil. The increase in available P in the amended soil represented 31.4% of the total P in PMC.

Laboratory results show that a significant portion of N from PMC mineralized 20–30 d after application, meeting part of the crop N demand during the early period. The second phase of N release, appearing between 45 and 60 d, provided sufficient N to rice, thus eliminating the need to apply fertilizer N at this crop stage. In PMC-amended fields, supplemental application of fertilizer N may be more critical during the first 3 wk of rice growth. However, there is a need to study the optimum fertilizer N schedule for rice on PMC-amended fields to further increase the efficiency of N from both PMC and fertilizer. The sharp increase in P availability in PMC-amended plots and the maintenance of high P levels over a long period will help meet the crop's P requirements. Long-term application of PMC may even cover the whole fertilizer P needs of the rice-wheat system.

In conclusion, PMC is an excellent source of plant nutrient for increasing crop yield and improving soil fertility. The efficient use of PMC could supply a large amount of N and P fertilizer needed in the rice-wheat rotation and thereby increase farmers' profits. This sugar by-product is available locally at minimal rates. It is easy to use and no additional land preparation is required. The data show that N and P are quickly released in PMC-amended soil, contributing to improved nutrition and higher crop yield. In the rice-wheat rotation, the application of 5 t PMC ha^{-1} could save 33–42% of fertilizer N cost and 50% of fertilizer P cost, with no loss in yield.

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Phosphorus input-output on an Ultisol cropped to upland rice in West Africa

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Phosphorus (P) deficiency is a major constraint to crop production on highly weathered, low-activity clay soils in the humid tropics (Sanchez and Salinas 1981). Soils in the humid tropics of West Africa are no exception, and P is the most limiting nutrient, affecting crop production and productivity. Not only are these soils low in available P, but the applied P is quickly converted into insoluble forms (Sahrawat et al 2001a). In West Africa, 70% of upland rice is grown in the humid zone, mostly on Ultisols and some Alfisols and Oxisols.

There is a lack of information on the long-term effects of P fertilizer on its recovery and balance in an upland rice production system. We present results from a 6-year experiment on P input-output using improved upland rice cultivars. A long-term (1993-98) experiment was conducted at the Centre National de Recherche Agricole (CNRA) station at Man (7.2°N, 7.4°W; 500 m altitude), Côte d'Ivoire, West Africa, to study the response of four improved upland rice cultivars to direct P in 1993 and to residual P in 1994, 1995, 1996, and 1998, applied at five rates (0, 45, 90, 135, and 180 kg P ha^{-1}) only once in 1993 (Sahrawat et al 2001b). The experimental site receives an average annual rainfall of about 2,000 mm in a monomodal season. The rainfall received during the growing season (June to October) was highly variable during 1993-98, varying from 684 to 1,668 mm. The experimental site was under bush fallow for the last 3 years before the start of the study. The soil at the site in the humid forest zone is an Ultisol with acidic pH (pH water 4.9; pH KCl 4.0), low available P (2.7 mg Bray 1 P kg^{-1} soil) and total P (155 mg P kg^{-1} soil), and moderate organic C (14.7 g kg^{-1} soil) and total N (950 mg kg^{-1} soil). The soil was high in exchangeable acidity (19.5 g kg^{-1}), dithionite-citrate extractable Fe (3.3 g kg^{-1}), and oxalate extractable Fe (2.3 g kg^{-1}).

The four rice cultivars (WARDA-bred cultivars WAB56-125, WAB56-104, and WAB56-50 and check IDSA6) with five rates of P fertilizer, applied as triple superphosphate, were arranged in a randomized complete block design with four replications. The cultivars were sown in rows at a spacing of 0.25 m in plots measuring 5 m × 3 m. Each year, all plots received a uniform application of N (applied as urea at 100 kg ha^{-1} in three splits) and K (applied as KCl at 100 kg ha^{-1}).

Rice crops were grown in 1993, 1994, 1995, 1996, and 1998; P fertilizer was applied only in 1993. At harvest, grain and straw yields were recorded and total P uptake in rice biomass was computed by analyzing the P content of the grain and straw samples.

The P input-output values (input is the amount of P fertilizer applied and output is the amount of P taken up in the grain plus straw in five crops), averaged over four rice cultivars, are summarized in Table 1. The recovery of applied P was calculated by subtracting P uptake in the no-P control from the P uptake in the plus-P treatment. Input-output was negative in the no-P treatment but positive in treatments where P fertilizer was added. The results show that in five crops, only a small fraction of the applied P fertilizer was removed by the rice crop, which varied from 5.5% to 9.4%, and this value decreased with the increase in the rate of P applied. In 1998, however, after 5 years of successive cropping, available P in the soil (Bray 1) was found to be similar and not affected by the rate of P fertilizer applied in 1993 (Table 2). This indicates that the applied soluble P was rendered insoluble during a reaction with sesquioxides in the soil (Abekoe and Sahrawat 2001). However, total P content in the soil at the end of the experiment in 1998 was affected by the rate of P fertilizer applied. Total P content in the soil was highest in the treatment that received P fertilizer at 180 kg P ha^{-1} and lowest in the no-P treatment. Cropping did not affect total soil P content in the control treatment without P application.

The results of this study show that P input-output was negative in the treatment that did not receive P fertilizer but positive in the treatments that received added P. Available P was similar in all treatments receiving a range of applied P, although total P was higher in the treatments that received higher rates of fertilizer P. This also indicates that only a small fraction of the applied P was recovered from 5 years of continuous cropping; the rest of the P was rendered unavailable and became part of the soil P (indicated by total P content in the soil). The reversion of soluble P to insoluble forms is caused by phosphate reactions with iron and aluminum oxides (Abekoe and Sahrawat 2001).

Table 1. Phosphorus input-output, recovery, and balance on an Ultisol, Côte d'Ivoire, 1993-98.[a]

P input (kg ha^{-1})	P output (kg ha^{-1})	P balance (kg ha^{-1})	Fertilizer P recovered in crop (%)
0	9.1	–9.1	–
45	13.5	31.5	9.4
90	16.8	73.2	7.2
135	19.5	115.5	6.8
180	19.5	160.5	5.5
LSD (0.05)	1.04		

[a]Fertilizer P applied at five rates only once in 1993. Each value is average of four rice cultivars. P input is the amount of fertilizer P applied; P output is the amount of P removed by the crop in 1993-98. P recovery in a treatment is calculated by subtracting P uptake in the no-P control from the P uptake in the plus-P treatment.

Table 2. Extractable and total P in soil samples at the start and end of 6 years (1993-98) of cropping of an Ultisol.

	P rate (kg ha^{-1})[a]	Extractable P (mg kg^{-1} soil)	Total P (mg kg^{-1} soil)
1993	0	3	155
1998	0	3	150
	45	4	188
	90	4	213
	135	4	245
	180	4	267

[a]Fertilizer P was applied only once in 1993.

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