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The influence of soil phosphorus, pH and texture on the uptake of phosphorus from soil and fertilizer by upland rice

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Abstract

In the Taï region of south-west Côte d'Ivoire, shifting cultivation is the standard agricultural practice. A growing population requires an increase in crop production, among others by removing soil fertility constraints. At six sites in 1987, and two sites in 1988, long-term field trials were started to study the supply of nutrients from the soil and the response of food crops to fertilizers. This paper describes the results for P during the first season after removal of the primary or secondary forest vegetation. P rates were 0 and 50 kg ha^{-1} in 1987, and 0, 12.5, 25 and 50 kg in 1988.

The application of 50 kg P ha^{-1} resulted in a yield increase of upland rice of 0.5 to 1.0 t ha^{-1} at five of the six sites in 1987. In 1988, a similar response could be obtained with lower rates of 12.5 or 25 kg P ha^{-1}. At all sites, P application increased P uptake significantly, but the recovery of fertilizer-P by the rice crop decreased with increasing P-application rates. The soil P supply was best described by an equation including P-Dabin (a modified P-Olsen method), total P and pH. The recovery of fertilizer-P could best be described by equations including silt plus clay content, P-Dabin, and/or total P. Since some soils had a high gravel content, soil analytical data, referring to the fine earth (< 2 mm) fraction of the soils and expressed on a mass basis, were translated to values expressed on the basis of volume of total soil. This conversion substantially improved the relations between soil properties and P uptake or fertilizer-P recovery.

Keywords: Côte d'Ivoire, phosphorus, P uptake, recovery of fertilizer-P, shifting cultivation, soil P supply, soil properties on volume basis, Taï National Park, upland rice.

Introduction

Shifting cultivation can be defined as an agricultural system in which temporary clearings are cropped for fewer years than they are allowed to remain fallow (Sanchez, 1976). After a cropping period the land is abandoned and will be recultivated after its fertility is judged to be restored, or sooner if other land is not available for use (Greenland, 1974). In many parts of the world, increasing population demands an intensification of the extensive shifting cultivation system in order to produce enough food.

In the Taï region of Côte d'Ivoire, the main causes of decreasing yields are depletion of nutrients originating from the ashes of burnt fallow vegetation and weed infestation (Van Reuler & Janssen, 1993a,b). For the fallow vegetation as well as for the crops during the first season of a cultivation period P was the most limiting nutrient (Jaffré, 1985; Van Reuler & Janssen, 1989).

The present study deals with a search for appropriate soil properties to predict, for the first season of a cultivation period, (i) the soil supply of P to crops, and (ii) the recovery of fertilizer-P by crops. It forms part of a larger research on nutrient management in the shifting cultivation system of south-west Côte d'Ivoire. Only those soil properties were included in the study which belonged to the standard soil analysis package of the former ORSTOM laboratory at Adiopodoumé, Côte d'Ivoire (Gouzy, 1973a).

The recovery of applied fertilizer-P by the crop depends on properties of the fertilizer itself, on soil and crop characteristics, and on weather conditions. Fertilizer-P may react with many soil constituents, among which oxides of iron and aluminum and clay minerals are the most important ones. As a result, fertilizer-P may become unavailable to plants for a shorter or longer time (phosphorus fixation). Sanchez & Uehara (1980) report that for soils with a relatively similar mineralogy soil texture is an important parameter for P fixation. According to Juo & Fox (1977), the major West African soils (Luvisols and Acrisols) have a low to medium P-sorption capacity, when compared to Ferralsols and Andisols from South America and Hawaii. They also concluded that P-sorption is related mainly to the extent of reactive surfaces of soil particles.

Materials and methods

Experimental area

The study area lies between the Taï National Park and the Cavally river which forms the boundary with Liberia (Figure 1). This Park is the last extensive area (340,000 ha) of undisturbed forest in West Africa. In the period 1978 to 1982 the average annual rainfall amounted to 1885 mm with a standard deviation of 338 mm (Collinet *et al.*, 1984).

The uplands of the Taï region are characterized by a catena which can be subdivided into crest, upper slope, middle slope, lower slope and valley bottom. The soils of the crest, upper and middle slope are well drained (Acrisols and Ferralsols). The soils of the lower slope are moderately well and imperfectly drained (Ferralsols and Gleysols), while the soils of the valley bottom are poorly drained (Gleysols). This catena is representative of about 300,000 ha.

The area where we conducted our fertilizer field trials ranges from 20 km north to 10 km south of the village of Taï. Six locations were selected in 1987 (Sites I–VI) and two in 1988 (Sites VII and VIII). In Table 1, the physiographic position of the experimental sites and the age of the fallow vegetation present before clearing are shown. In all following tables, the arrangement of the data is according to this physiographic position of the sites.

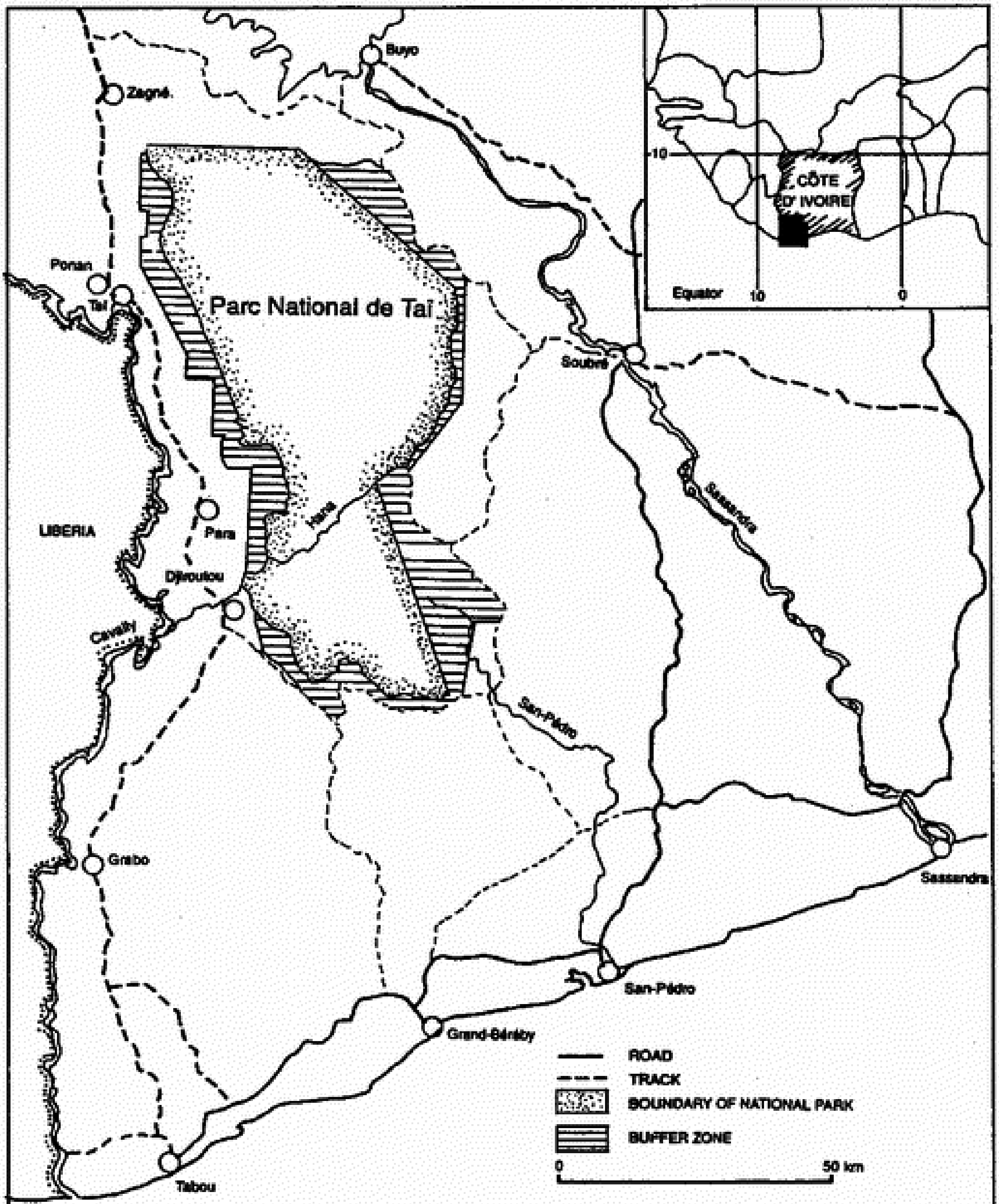

Figure 1. Location of the study area.

Soil and plant analysis

Topsoil samples (0–20 cm) were collected after the slashed vegetation had been burnt. They were analyzed according to the procedures described by Gouzy (1973a). First, the gravel content (> 2 mm) and the fine-earth fraction (< 2 mm) were deter-

Table 1. Experimental sites in order of their position at the catena, and age of the vegetation before clearing.

Experimental site	Position at catena	Age of regrowth years
VII	crest - upper slope	25
IV	upper slope	23
I	upper - middle slope	*
III	middle slope	34
II	lower slope	*
VIII	lower slope	1
VI	lower slope - valley bottom	1
V	valley bottom - lower slope	23

* primary forest

mined, and next, pH-KCl (1:2.5) and pH-H_2O (1:2.5), organic C and organic N, CEC and exchangeable cations (1 M NH_4OAc, pH 7), P-Dabin, and total P were determined. P-Dabin (0.5 M $NaHCO_3$ and 0.5 M NH_4F, pH 8.2) is a modified P-Olsen method (Dabin, 1967).

Since in (very) gravelly soils the volume of soil plants can exploit for water and nutrients is smaller than in gravel-free soils, we considered it more appropriate to express the analytical data, with exception of pH, per unit of volume of total soil, i.e. the fine earth plus gravel, than per unit of mass of the fine earth (Van Reuler & Janssen, subm.). For that purpose, the data per unit of mass of fine earth fraction must be multiplied by a factor MF, where

MF = [(100 – gravel content) × volumic mass]/100 (kg dm^{-3}).

Volumic mass (VM) was calculated on the basis of the following relation established for the Taï region (Van Reuler & Janssen, subm.)

VM (kg dm^{-3}) = 1.43 + 0.008 × gravel content (%); R^2 = 0.74

At harvest, plant samples were collected. The 1987 plant samples were analyzed by ORSTOM (Gouzy, 1973b) and the 1988 samples in Wageningen (Houba *et al.*, 1985).

Field trials

Table 2 presents some soil analytical data, being the mean values of 12 and 16 composite soil samples (at Sites I–V and VI–VIII, respectively). The samples were collected immediately after the burn. On the basis of the gravel data, the multiplication factors (MF) were established for the conversion of the soil chemical data into (m)g dm^{-3}.

The experimental sites were cleared by the respective farmers applying the traditional slash-and-burn practice. After the burn, unburnt wood was removed by hand as much as possible. As a result, the area that could be planted was 5–20% larger than on farmers' fields. In both years, the fields were fenced.

The test crop, upland rice (*Oryza sativa*, cultivar IDSA 6), was grown during the main growing season (March to August). It was sown in the traditional way with a planting stick or a machete. The average density of planting holes was 100,000 ha^{-1}

Table 2. Analytical data of the topsoil (0–20 cm) of the experimental sites. Gravel content is expressed as fraction of the total soil, other chemical properties as a fraction of the fine earth (< 2 mm).

	Experimental site							
	VII	IV	I	III	II	VIII	VI	V
Gravel %	14	20	32	4	2	1	1	1
Sand	75.6	74.1	70.9	69.2	67.8	81.3	76.9	67.3
Silt	5.9	7.5	7.2	6.6	6.1	6.1	10.3	8.1
Clay	17.9	14.9	18.3	21.2	22.8	11.8	10.5	21.4
pH-H_2O	6.1	4.9	4.0	4.1	4.0	5.6	4.3	4.4
pH-KCl	5.5	4.5	3.8	4.0	3.9	5.0	4.0	4.1
Org. C g kg^{-1}	12.9	11.5	16.1	8.9	11.4	9.8	8.6	10.2
Org. N	1.3	1.2	1.4	0.9	1.2	0.9	0.8	1.2
Total P mg kg^{-1}	161	129	72	138	91	113	80	134
P-Dabin	6.0	13.1	16.7	10.1	10.4	6.8	17.1	22.6
CEC mmol(+) kg^{-1}	54.2	48.9	75.7	46.6	57.0	40.5	34.4	56.5
Exch. cations								
Ca mmol(+) kg^{-1}	16.7	15.3	8.7	6.4	7.0	10.0	8.1	8.2
Mg	7.1	7.3	5.3	3.3	4.0	4.8	4.4	5.7
K	2.5	2.6	2.2	2.2	1.4	1.3	1.1	2.3

with five to ten seeds per hole. When necessary, the fields were weeded by hand, leaving the weed remains as a surface mulch. During the maturing stage the fields were guarded against bird damage. The rice was harvested after approximately 120 days. The yield data refer to grains with a moisture content of 14%. The dimensions of the experimental units were 4 × 5 m. Within these plots 3 × 4 m were harvested in order to avoid boundary effects.

In 1987 (Sites I–VI), the experimental design was a 2^4 factorial in three replicates, with N, P, K and lime as factors. Application rates were 0 and 50 kg N ha^{-1} applied as urea (46% N), 0 and 50 kg P ha^{-1} applied as triple superphosphate (20% P), 0 and 50 kg K ha^{-1} applied as potassium chloride (50% K), and 0 and 400 kg $Ca(OH)_2$ ha^{-1}. Liming was practised before sowing. N and K fertilizers were broadcast, and applied in two equal portions, at 10 and 50 days after sowing. P was placed in holes of 1 cm diameter at a depth of less than 12 cm and at a distance of about 7 cm from the plants, at the time of the first application of N and K.

In 1988 (Sites VII and VIII), the experimental design was a factorial comprising 2 N × 4 P × 2 K levels, in three replicates. Method and time of application, fertilizer types, and sizes of experimental units were the same as in 1987. For N and K the application rates were again 0 and 50 kg ha^{-1}, whereas P was applied at four levels, 0 (P0), 12.5 (P1), 25 (P2) and 50 (P3) kg P ha^{-1}.

At harvest, grain samples were collected for chemical analysis, and also a limited number of panicle and straw samples. Plant samples were dried (24 h) at 70 °C, and grain samples also at 105 °C. Thereafter samples were ground and analyzed. P contents were calculated for grain, straw and panicles as the product of dry matter and P mass fractions and total P uptake was calculated by adding these contents. Also the relations between P in grains and total P uptake were established. This relation was used to calculate total P uptake for the plots of which only grain samples had been analyzed. The recovery fraction of fertilizer-P was calculated as the ratio of fertilizer-P absorbed and fertilizer-P applied. The value for fertilizer-P absorbed was found as the difference in uptake between fertilized and non-fertilized plots. Efficiency of utilization (EU) was calculated as the ratio of grain yield to total uptake.

Results

Yield

Rice yields on individual experimental units varied from 0.7 to 5 t ha^{-1}. Table 3 presents the average grain yields of the control and the various P treatments in relation to the application of N, K and lime.

Table 3. Grain yield (t ha^{-1}) and coefficient of variation (%) in grain yield of upland rice of some selected fertilizer treatments.

		Experimental site							
Treatment		VII	IV	I	III	II	VIII	VI	V
Control		2.55	2.50	1.48	2.57	1.55	2.56	3.14	3.11
P0	N0	2.82	2.61	1.63	2.35	1.56	2.43	2.99	3.82
	N1	3.04	2.79	1.66	2.09	1.75	2.81	3.19	3.91
	K0	2.64	2.71	1.71	2.32	1.56	2.79	3.25	3.67
	K1	3.25	2.69	1.57	2.15	1.78	2.45	2.93	4.06
	L0		2.79	1.64	2.39	1.84		3.14	3.71
	L1		2.60	1.65	2.10	1.47		3.04	4.03
P1	N0	3.39					2.55		
	N1	3.60					3.56		
	K0	3.32					3.12		
	K1	3.68					2.99		
P2	N0	3.02					2.98		
	N1	3.68					3.60		
	K0	3.29					3.16		
	K1	3.41					3.43		
P3	N0	3.08	3.82	2.67	2.71	1.97	3.12	3.32	3.70
	N1	3.29	3.79	2.63	2.46	2.09	3.86	3.61	4.07
	K0	3.01	3.73	2.48	2.60	2.17	3.55	3.49	3.83
	K1	3.37	3.88	2.83	2.57	1.88	3.44	3.43	3.94
	L0		3.87	2.44	2.57	1.77		3.50	4.04
	L1		3.74	2.88	2.60	2.28		3.42	3.73
C.V.		14.9	16.3	34.9	15.8	25.2	11.9	15.0	18.6

At all sites, except the imperfectly drained site V, a significant, positive response to P was found. At the other 1987 sites, the response to 50 kg P ha^{-1} varied from 0.4 to 1.1 t ha^{-1}. At the 1988 sites (VII and VIII), an application of 12.5 kg P ha^{-1} resulted in a yield increase of 0.5 and 0.4 t ha^{-1}, respectively. Yields increased further when 25 or 50 kg P ha^{-1} was applied at Site VIII, but not at Site VII.

A significant, positive response to N was found only at Site VIII, whereas at Site III the response to N was significantly negative. The other treatments had no significant effects on yields.

The coefficient of variation (C.V.) of yield was high, especially on the sites cleared of primary forest (I and II) (Table 3). The harvest index (H.I.), calculated as the ratio of grain mass dried at 70 °C to total above-ground dry mass, varied a little among sites. Site V had the lowest value (0.38), and Site VI the highest (0.46). The average value of all plots was 0.42. H.I. was unaffected by fertilizer treatments.

P uptake

In Table 4, the average total P uptake of the above-ground plant parts of the control and the various P treatments in relation to the application of N, K and lime are pre-

Table 4. P uptake (kg ha^{-1}) by above-ground plant parts and coefficient of variation (%) in P uptake of upland rice of some selected fertilizer treatments.

Treatment		Experimental site VII	IV	I	III	II	VIII	VI	V
Control		4.89	3.93	2.14	4.20	2.53	4.91	5.16	8.51
P0	N0	5.38	4.28	2.44	4.18	2.60	4.00	5.64	10.14
	N1	5.48	4.51	2.54	3.49	2.77	4.84	5.48	8.74
	K0	5.01	4.34	2.63	4.07	2.53	4.80	5.79	8.92
	K1	5.83	4.45	2.14	3.66	2.89	4.04	5.33	9.97
	L0		4.54	2.35	4.02	3.10		5.43	9.11
	L1		4.25	2.43	3.73	2.27		5.69	9.77
P1	N0	6.32					5.45		
	N1	6.20					5.72		
	K0	5.91					6.20		
	K1	6.69					4.97		
P2	N0	6.95					6.05		
	N1	8.17					6.94		
	K0	7.64					5.39		
	K1	7.48					7.49		
P3	N0	7.29	8.10	5.08	5.69	4.11	5.58	8.01	10.31
	N1	8.05	7.95	5.11	5.25	4.43	8.39	7.64	10.84
	K0	6.61	7.85	4.74	5.54	4.71	7.51	7.83	10.35
	K1	8.73	8.20	5.48	5.40	3.83	6.46	7.81	10.85
	L0		8.27	4.77	5.46	3.90		7.87	10.97
	L1		7.78	5.45	5.48	4.65		7.77	10.17
C.V.		21.8	20.7	39.1	16.6	29.5	24.1	15.5	16.1

sented. P uptake of P0-treatments varied from 1.1 to 13.0 kg P ha^{-1} on individual experimental units. The highest uptake was found at Site V located on the lower part of the catena. At all sites, P application significantly increased P uptake (Table 4). N application resulted in a significant increase in P uptake at Site VIII, and in a significant decrease at Site III. The other treatments had no significant effects on P uptake.

The coefficient of variation (C.V.) for total P uptake was even higher than for yield, again with the highest values on the sites cleared of primary forest (Sites I and II) (Table 4).

At Sites VII and VIII P uptake was higher at P3 (50 kg P ha^{-1}) than at lower P rates. The recovery fractions of fertilizer-P, as calculated from the data of Table 4, were higher at P1 and P2 than at P3. The maximum value was 9.4% for P1 at Site VIII. The recovery fractions for P3 varied from 0.3% at Site V to 6.9% at Site IV.

Discussion

The control yields were much higher than the 0.8 to 1.0 t ha^{-1} which are obtained by local farmers (De Rouw, 1991a). The main reasons for this difference are the better management (e.g. weeding and protection against damage by animals) at the experimental fields, and the larger net area planted to rice, as a consequence of the removal of unburnt wood (Van Reuler & Janssen, 1989). The highest control yields were obtained at Sites V and VI, both located on the lower slope.

The values for the coefficients of variation of both grain yield and P uptake seem to increase with the age of the vegetation that was cleared. Reasons may be the het-

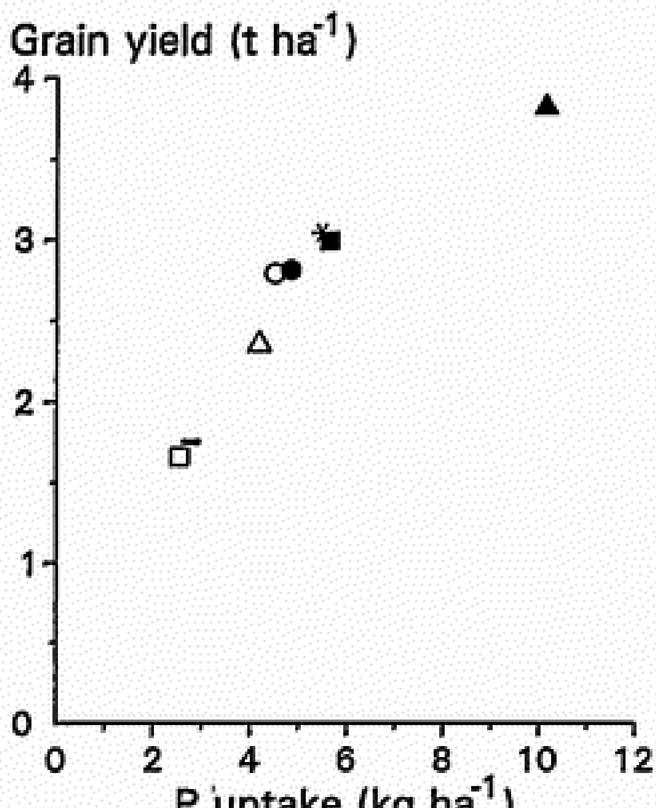

Figure 2. Relation between grain yield (t ha^{-1}) and P uptake (kg ha^{-1}) at the various sites (✱ = VII, ○ = IV, □ = I, △ = III, — = II, ● = VIII, ■ = VI, ▲ = V).

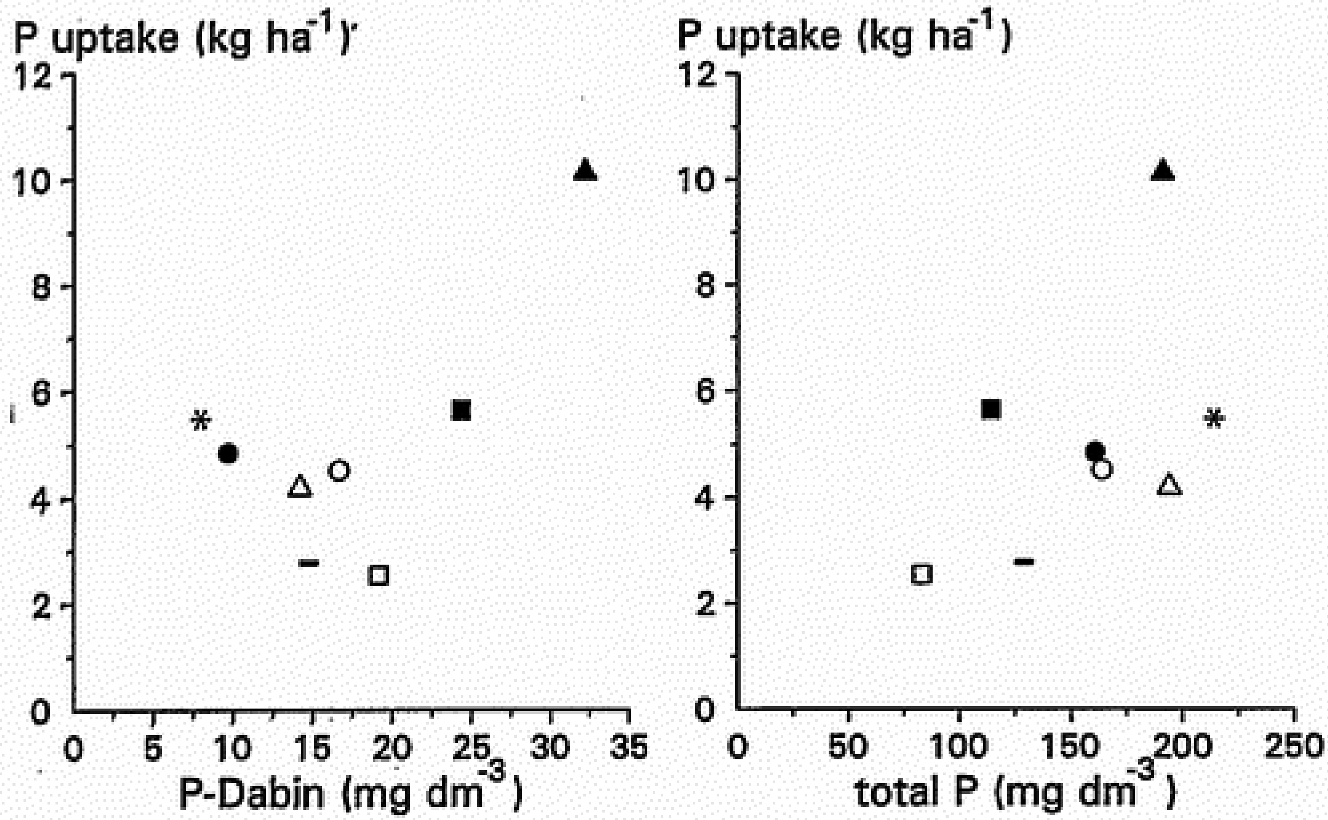

Figure 3. Relation between P uptake (kg ha^{-1}) and P-Dabin content and total P content (mg dm^{-3}) at the various sites (* = VII, ○ = IV, □ = I, △ = III, — = II, ● = VIII, ■ = VI, ▲ = V).

erogeneity in fallow or forest vegetation, the heterogeneous ash distribution resulting from poor burning of slashed big trees due to incomplete drying and presence of remaining roots.

On the well drained soils of the crest, upper and middle slope, P obviously was the main limiting nutrient (Table 3). Apart from the yield responses to P application, this is reflected in the high values of efficiency of utilization. In Figure 2 the relation between grain yield and P uptake is presented. For uptake, the higher value of the uptakes of the N1P0 and N0P0 treatments was used. These values were considered the best possible estimates of the potential P supply of the soils. At all sites, except Site V, approximately 600 kg of grain are produced per kg absorbed P. This is the maximum value found by Van Keulen & Van Heemst (1982) and Janssen *et al.* (1990), and it indicates that P is the main yield limiting factor. At Site V the EU values for N and K are 37 and 42, respectively. Maximum values reported are 70 for N and 100–120 for K (Van Keulen & Van Heemst, 1982; Janssen et al., 1990). Therefore it can be concluded that neither N nor K did limit the yield at Site V. The maximum yield obtained at experimental stations for the used rice cultivar is 5.2 t ha^{-1}, and the yields at Site V were rather close to this value (Poisson & Doumbia, 1987).

In Figure 3, the uptake of P from the soil alone has been plotted against P-Dabin and total P, respectively. For uptake, again the higher value of the uptakes of the N1P0 and N0P0 treatments was used. Figure 3 shows a fairly good relation for five sites. Two sites, both with a relatively high pH (Sites VII and VIII) have a relatively high P uptake, and Site I, with a low pH has a relatively low P uptake. There is a clear relation between P uptake and total P for six sites. Sites V and VI have a higher

Table 5. Correlation matrix for soil properties related to soil P supply and/or recovery of fertilizer-P.

	P-Dabin	Total P	pH	Silt	Clay	Silt + Clay	Drainage class
P-Dabin	1.000						
Total P	−0.344	1.000					
pH	−0.602	0.615	1.000				
Silt	0.722**	−0.407	−0.385	1.000			
Clay	0.107	0.233	−0.394	−0.454	1.000		
Silt + Clay	0.375	0.114	−0.575	−0.149	0.949**	1.000	
Drainage class[a]	0.762**	−0.147	−0.253	0.833**	−0.189	0.086	1.000

[a] Sites VII, IV, I, III, II and VIII class I; Sites VI and V class 2
** $P < 0.05$; *** $P < 0.001$

P uptake. These sites differ in two aspects from the other sites, namely (i) their values for P-Dabin are above 17 mg kg^{-1}, and (ii) they are situated on the lower slope, and hence they are not well drained (imperfectly for Site V and moderately well for Site VI). From these observations it may be concluded that besides P-Dabin, which is the index for available P, at least total P and pH affect P uptake, and perhaps drainage conditions too. Unfortunately, we had not more than eight experimental sites, and because P-Dabin and drainage class are correlated (Table 5), it remains difficult to establish the influence of the individual factors in a satisfactory way.

Multiple linear regression yielded the equations presented in Table 6. The coefficient of determination is higher when soil data are expressed on a volume basis than on the basis of mass of fine earth. The positive effect of the pH on P uptake seems to contradict the fact that liming had no significant effect on P uptake, but several reasons can be put forward to explain why these findings are not conflicting. Soils differing in pH by nature are different in more aspects than pH only, because soil pH is the result of a large number of soil properties and processes. These do not or at least not immediately change upon liming. Other reasons for the lack of a liming effect in the present trials may be that not more than 400 kg $Ca(OH)_2$ ha^{-1} were applied and that the lime was not worked into the soil.

Generally the recovery fractions of fertilizer-P are not higher than 10–15% due to P sorption processes and the slow rate of movement of this nutrient to plant roots in the soil (Brady, 1984). In this study these values were only approximated at the Sites VII and VIII for the P1 treatments, 6.8 and 9.4%, respectively. At higher P application rates the P uptake did not increase at the same rate and consequently the recovery fractions decreased.

No clear relation was found between the recovery fraction of applied fertilizer-P and soil P, either P-Dabin or total P. The content of fine soil particles proved of much more importance, in accordance with Juo & Fox (1977). Table 6 presents the results of multiple linear regression analysis, including or not including soil P characteristics. Inclusion of pH did not further increase the coefficient of determination. Again the coefficients of determination are higher when soil data are expressed on a volume basis than when expressed on the basis of mass of fine earth.

Table 6. Regression equations for P uptake and recovery of fertilizer-P.

A. Soil properties expressed per unit of mass of the fine-earth fraction

UP	= 1.097 +	0.034*TPmfe		$R^2 = 0.20$	(1)
UP	= −2.236 +	0.216*PDmfe		$R^2 = 0.27$	(2)
UP	= −5.281 +	0.319*PDmfe +	0.054*TPmfe	$R^2 = 0.72$	(3)
UP	= −10.893 +	0.403*PDmfe +	0.038*TPmfe + 1.360*pH	$R^2 = 0.81$	(4)
RFP	= 15.611 −	0.454*SCmfe		$R^2 = 0.71$	(5)
RFP	= 15.627 −	0.395*SCmfe −	0.113*PDmfe	$R^2 = 0.79$	(6)
RFP	= 16.835 −	0.368*SCmfe −	0.145*PDmfe − 0.013*TPmfe	$R^2 = 0.81$	(7)
RFP	= 17.344 −	0.377*SCmfe −	0.147*PDmfe − 0.012*TPmfe − 0.086*pH	$R^2 = 0.81$	(8)

B. Soil properties expressed per unit of volume of the total soil

UP	= 0.651 +	0.028*TPvs		$R^2 = 0.28$	(9)
UP	= 1.755 +	0.188*PDvs		$R^2 = 0.40$	(10)
UP	= −4.711 +	0.232*PDvs +	0.037*TPvs	$R^2 = 0.85$	(11)
UP	= −10.941 +	0.301*PDvs +	0.024*TPvs + 1.483*pH	$R^2 = 0.97$	(12)
RFP	= 14.952 −	0.032*SCvs		$R^2 = 0.83$	(13)
RFP	= 15.071 −	0.027*SCvs −	0.095*PDvs	$R^2 = 0.93$	(14)
RFP	= 15.461 −	0.026*SCvs −	0.105*PDvs − 0.004*TPvs	$R^2 = 0.94$	(15)
RFP	= 17.601 −	0.028*SCvs −	0.112*PDvs − 0.374*pH	$R^2 = 0.94$	(16)
RFP	= −18.020 −	0.029*SCvs −	0.112*PDvs − 0.456*pH + 0.002*TPvs	$R^2 = 0.94$	(17)

UP = P uptake in kg ha^{-1}
RFP = recovery of fertilizer-P in %
PDmfe = P-Dabin in mg P kg^{-1} of fine earth
TPmfe = total P in mg P kg^{-1} of fine earth
SCmfe = silt + clay in % of fine earth
PDvs = P-Dabin in mg P dm^{-3} of total soil
TPvs = total P in mg P dm^{-3} of total soil
SCvs = silt + clay in g dm^{-3} of total soil

The found relations are schematically shown in Figure 4. Figure 4A presents the relations between P uptake and P-Dabin for various values of total P and pH, and Figure 4B those between fertilizer-P recovery and silt-plus-clay content for various values of P-Dabin.

Conclusions

This study confirmed the findings of earlier studies that P is the main limiting nutrient during the first cropping season in the shifting cultivation system of the Taï area.

The supply of P by the soils is dependent on P-Dabin (indicating soil available P), total P, pH, and possibly also on the drainage conditions (position on the slope).

The recovery of fertilizer-P is related mainly to silt-plus-clay content, and to some extent also to soil P.

In the Taï region, where gravel makes up a substantial part of the soil material, the

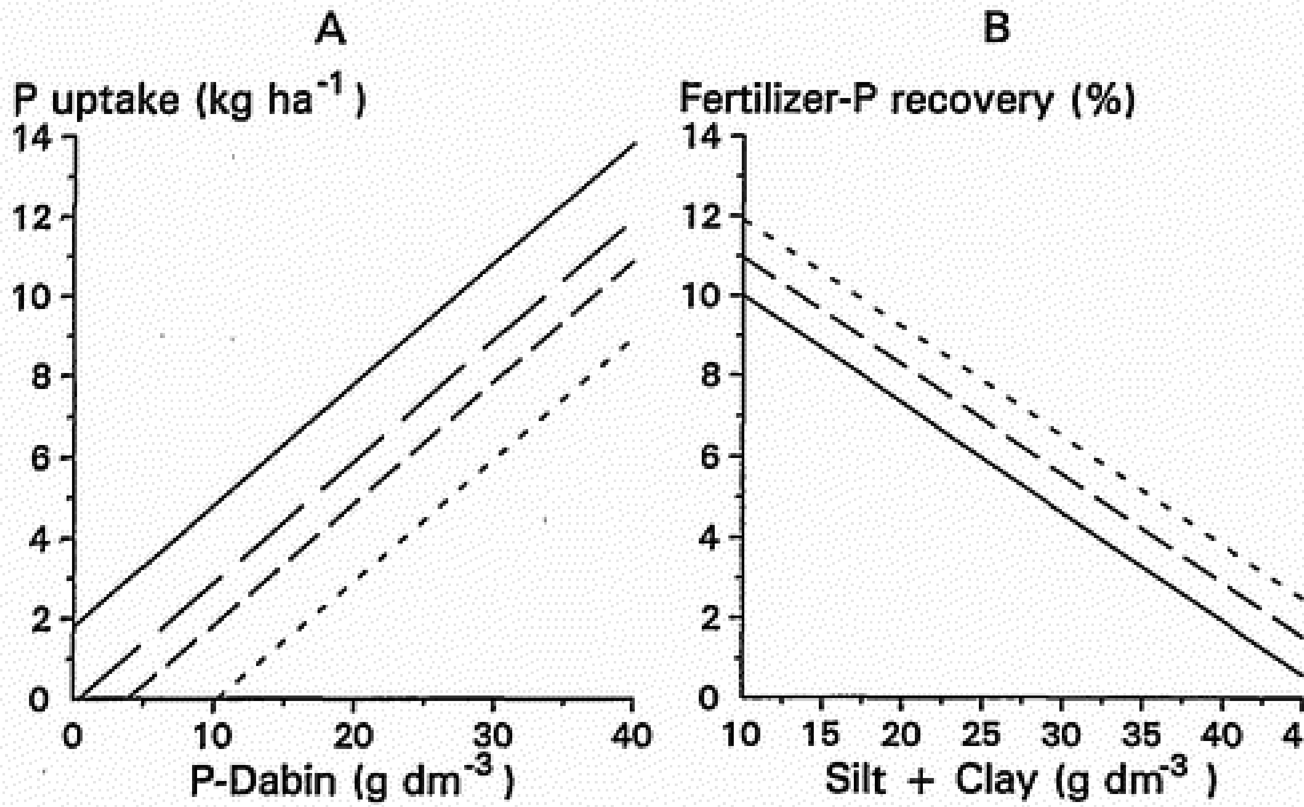

Figure 4A. Relation between P uptake and P-Dabin content as influenced by total P content and pH according to Equation 12 (Table 6).

total P (mg dm^{-3})	pH
160	6 ———
80	6 - - - - - - -
160	4 - - - - - - - - -
80	4 ....

Figure 4B. Relation between P uptake and silt-plus-clay content as influenced by total P-Dabin content according to Equation 14 (Table 6).

P-Dabin (mg dm^{-3})

5 ....
15 - - - - - - - - -
25 ———

values of soil properties should be expressed on a volume basis rather than on a mass basis.

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