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Optimum NPK management over extended cropping periods in south-west Côte d'Ivoire

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Abstract

In the Taï region of south-west Côte d'Ivoire P is the yield-limiting nutrient on (moderately) well drained soils. In order to find the optimum P application rate, a factorial experiment (2N × 4P × 2K) in three replicates was conducted at two sites during six seasons. The factors investigated were N (0 and 50 kg N ha^{-1}), P (0, 12.5, 25 and 50 kg P ha^{-1}) and K (0 and 50 kg K ha^{-1}). N (urea) and K (muriate of potash) applications were split into two equal parts and broadcast. From the third season onwards the N application was raised to 100 kg N ha^{-1}. P (triple superphosphate) was placed near the young plants. Upland rice and maize were used as test crops. The experimental sites were located at the crest (Site VII) and lower slope (Site VIII) of a catena. In the first season after clearing at Site VII highest yields were obtained with 12.5 kg P ha^{-1} and at Site VIII with an aplication of 25 kg P ha^{-1}. At the latter site also N application resulted in a positive response. In an extended cropping period the rice yield level could not be maintained. The efficiency of utilization of absorbed P (EUP) of rice was high in the first season after clearing but decreased in subsequent seasons. This is in contrast to EUP for maize which remained constant with time. Hence, it is concluded that the rice yield decline is caused by other factors than nutrient deficiencies. In all seasons yields were higher at Site VII than at Site VIII. The residual effect of fertilizer-P could reasonably well be described by a simple formula: $RFP_t = (0.9 - RFP_1)^{t-1} \times RFP_1$, where RFP and RFP_1 are the apparent recovery fractions of fertilizer-P in year t and year 1, respectively. In all seasons, except in the first season after clearing, the potential P supply was higher at the crest (Site VII) than at the lower slope (Site VIII). Extending the cropping period proved possible when fertilizers were applied and maize was grown. For both sites fertilizer guidelines could be formulated. Comparison of soil chemical data (pH, organic C, total N and total P) before the start of the experiment and after six seasons did not show changes. At the +P plots the balance of P applied with fertilization and exported P with harvested products was only partly recovered in the total P analysis.

Keywords: apparent fertilizer recovery, Côte d'Ivoire, efficiency of nutrient utilization, potential P supply, optimum P fertilizer rate, maize, residual effect, shifting cultivation, upland rice, soil chemical properties

Introduction

In the shifting cultivation system of the Taï region, south-west Côte d'Ivoire, phosphorus was found to be the yield-limiting nutrient on (moderately) well drained soils. Localized application of 50 kg P ha^{-1} resulted in a yield increase of upland rice of 0.4 to 1.1 t ha^{-1}, while the apparent recovery fraction of fertilizer-P varied from 3.3 to 6.9% (Van Reuler & Janssen, 1989; 1996b). When 50 kg P ha^{-1} was applied, grain production per kg absorbed P varied between 450 and 520 kg ha^{-1}. These efficiency of utilization values are well below 600, which is considered the maximum value for small grains (Van Keulen & Van Heemst, 1982). It was assumed therefore that the same yield increase could be established with lower P application rates.

Trials were set up with different application rates of fertilizer-P, and this paper describes the results of these trials carried out in the Taï region. The trials were continued during six seasons in order to serve the other objectives of the research: to study the dynamics of soil P over extended cropping periods and the fate of residual fertilizer-P, and to verify the hypothesis that gradually also other nutrients than P could become limiting. These objectives were based on the following considerations. On the one hand, it was expected that the pool of available soil P would gradually decrease under extended cropping and hence more fertilizer-P would be needed to maintain yields at the first-season level. On the other hand, fertilizer-P has a residual effect because applied P that is not absorbed remains in the soil in forms that are at least partly available to crops. In case the application is repeated, the total recovery increases due to the residual effect of previously applied P and consequently the apparent recovery fraction of the latest P application is overestimated. In the first season after application of fertilizer-P, the apparent recovery fraction by the crop is usually about 10–15% (Brady, 1984), but recovery fractions of residual P in subsequent seasons decrease. An obvious cause of this is removal of P by the harvested crop. Another cause is the 'aging' of P, ascribed to processes like diffusion into internal pores of soil particles and subsequent sorption onto internal sorption sites (ISMA, 1978). The process of decreasing availability of residual fertilizer-P with time may be described as a transfer of P from the labile to the stable pool. On the basis of long-term field trials and modelling, it was concluded that each year a fraction of 0.2 of the labile pool is transferred to the stable pool (Janssen *et al.*, 1987; Wolf *et al.*, 1987). Janssen & Wolf (1988) showed that for easily soluble fertilizers, the residual effect during four or five years after a single dosis of P can be calculated by a simple equation: $RFP_t = (0.8-RFP_1)^{t-1} \times RFP_1$, where RFP_t and RFP_1 are the apparent recovery fractions in year t and year 1, respectively. When fertilizer-P is applied every year the total effect after n years is the sum of RFP_1, RFP_2, RFP_3, ... and RFP_n. It was tested whether this equation could describe the fate of fertilizer-P in the present study.

It is to be expected that other nutrients than P become limiting over extended cropping when only P is applied. The hypothesis that in the Taï region also other nutrients may be limiting was supported by the results of an experiment comparing the fertilizing effects of ash from burnt vegetation with the effects of mineral fertilizers (Van Reuler & Janssen, 1996a). It was found that per kg P absorbed from ash more grain was produced than per kg P absorbed from triple superphosphate (TSP). The difference suggests that other nutrients contained in the ash but not in TSP had improved the efficiency of utilization of absorbed P. Hence, it was decided to study the effects of other nutrients (N, K, S, Mg and a mixture of trace elements) on yield and on the relationships between P uptake and yield as well. Liming was not included, as it had been shown that it did not affect yields (Van Reuler & Janssen 1989; 1996b).

Materials and methods

Experimental area

The environmental conditions of the experimental area and of the soil properties of the two sites were described elsewhere (Van Reuler & Janssen, 1996b). The trials were conducted at Sites VII and VIII of that study. The sites were cleared of 20-year-old (Site VII) and one-year-old (Site VIII) secondary vegetation, respectively. The vegetation was slashed, dried and burnt in the traditional way. The experiment was carried out in three replications. The experimental units had a size of 4 × 5 m. Fields were fenced against damage by rodents and, at maturing stage, guarded against bird (rice) and monkey (maize) damage.

Field trials

Two crops per year were grown, in the sequences shown in Table 1. Upland rice (*Oryza sativa* L.) was planted by means of a planting stick or machete. The average density was 100,000 plant holes ha^{-1} with 6 to 10 grains in each hole. The cultivar was IDSA 6 with a growth period of 125 days, except in Season 88-2 at Site VIII when cultivar IDSA 10 with a growth period of 100 days was planted. Maize (*Zea mays* L., Pioneer 3274) with a growth period of 105 days was planted in rows (60 × 30 cm) resulting in 55,555 plants ha^{-1}. Maize was sprayed with an insecticide (Decis) against stalk borers. A detergent was added to increase the efficiency. In all seasons fields were weeded twice leaving the weeds as surface mulch. At harvest all crop residues were removed from the fields.

The factors investigated in the factorial experiment (2N × 4P × 2K) were N (0 and 50 kg N ha^{-1}), P (0, 12.5, 25 and 50 kg P ha^{-1}) and K (0 and 50 kg K ha^{-1}). N (urea) and K (muriate of potash) applications were split into two equal parts and broadcast

Table 1. Crop sequences at the two sites.

	Season						
Site	88-1	88-2	89-1	89-2	90-1	90-2	91-1
VII	rice	maize	rice	maize	rice	–	maize
VIII	rice	rice	rice	maize	rice	–	maize

at one week and at about seven weeks after planting. P (triple superphosphate) was placed one week after planting at approximately 8 cm from the plants at a depth of maximally 10 cm. From 89-1 onwards, the N rate was increased to 100 kg N ha^{-1} at both sites.

In Season 91-1 sulphur, magnesium and a mixture of trace elements were included in the trial. The trials at both sites were combined into one experiment with a partially balanced incomplete block design (4P × 2^5 (N, K, S, Mg, trace elements) in three replications divided over two locations. S was applied as phosphogypsum at a rate of 30 kg S ha^{-1}, and Mg as $MgCl_2$ at a rate of 30 kg Mg ha^{-1}. The mixture of trace elements contained Cu (1.8 kg Cu ha^{-1} as $CuSO_4.5H_2O$), Mn (4.0 kg Mn ha^{-1} as $MnSO_4.H_2O$), Zn (8.0 kg Zn ha^{-1} as $ZnCl_2$), Mo (0.46 kg Mo ha^{-1} as $(NH_4)_6Mo_7O_{24}.4H_2O$ and B (1.1 kg B ha^{-1} as H_3BO_3. The mixture was sprayed about 54 days after sowing.

Soil and plant analysis

At both sites 16 composite soil samples (0–20 cm), each composed of 4 subsamples, were collected before the start of the trials. After six seasons each experimental unit was sampled. The samples were air-dried, thereafter the gravel content (> 2 mm) was determined and, next, the fine earth (< 2 mm) analyzed, according to Walinga *et al.* (1989).

At harvest grain samples of all treatments and, to a limited extent, straw- and panicle samples were collected for analysis. Plant samples were dried at 70 °C for 24 h, ground and analyzed as described in Van Reuler & Janssen (1993). Separate grain samples were also dried at 105 °C, to allow calculation of grain yields at 14% moisture content.

Statistical analysis

Statistical analysis was carried out with the General Linear Model (GLM) procedure of the SAS statistical programme (Anonymous, 1989). The differences between treatments were tested by t-test for all pairwise comparisons ($P < 0.05$). The data of the two fields were combined to test whether there was a location effect. In 91-1, all experimental units having received the trace element mixture had to be excluded (see below). Consequently, the number of experimental units per site was reduced from 48 to 24. This would have resulted in a confounding of some treatments, but that could be avoided by combining the three P application rates into one (henceforth indicated as +P). This procedure was justified by the fact that there were no significant differences among P rates.

Results

Grain yields and P uptakes of the main treatments obtained at the two sites are presented in Tables 2 and 3.

Table 2. Grain yield (t ha^{-1}) and P uptake (kg ha^{-1}) of upland rice and maize at Site VII. Values within a column, for each of the nutrients, followed by the same letter are not significantly different ($P < 0.05$).

	Rice			Maize		
	88-1	89-1	90-1	88-2	89-2	91-1
Grain yield						
Control	2.55	1.57	–	1.85	1.46	2.64
N0	3.08 a	2.14 a	–	2.51 b	2.14 b	3.33 b
N1	3.33 a	2.27 a	–	3.69 a	3.97 a	4.13 a
P0	2.86 b	1.60 b	–	2.17 b	2.07 c	2.91 b
P1	3.42 a	2.40 a	–	3.33 a	3.06 b	
P2	3.35 a	2.50 a	–	3.46 a	3.58 a	4.55*a
P3	3.19 ab	2.33 a	–	3.45 a	3.52 ab	
K0	3.06 a	2.19 a	–	2.95 a	2.81 b	3.55 a
K1	3.34 a	2.22 a	–	3.25 a	3.30 a	3.91 a
–S						3.82 a
+S						3.64 a
–Mg						3.67 a
+Mg						3.80 a
P uptake						
Control	4.89	3.50	–	3.73	3.26	6.34
N0	6.48 a	6.46 a	–	7.24 b	5.49 b	9.37 a
N1	6.70 a	6.78 a	–	8.85 a	8.96 a	10.51 a
P0	5.01 b	3.95 c	–	5.03 c	4.15 c	6.66 b
P1	6.13 b	6.80 b	–	8.17 b	6.66 b	
P2	7.56 a	7.52 ab	–	8.82 b	8.50 a	13.22*a
P3	7.67 a	8.22 a	–	10.15 a	9.59 a	
K0	6.18 a	6.66 a	–	7.27 b	6.51 b	8.92 a
K1	7.00 a	6.59 a	–	8.81 a	7.94 a	10.96 a
–S						10.54 a
+S						9.35 a
–Mg						9.58 a
+Mg						10.30 a

* average of +P treatment combinations

Rice

In Season 90-1, drought and termite damage reduced yields and nutrient uptakes. The reduction was severe at the well drained gravelly Site VII, but less at the moderately well drained non-gravelly Site VIII. The gravelly soils of the Taï region have a low water-holding capacity which makes them susceptible to drought. Therefore the results of this season are not reported.

Table 3. Grain yield (t ha^{-1}) and P uptake (kg ha^{-1})of upland rice and maize at Site VIII. Values within a column, for each of the nutrients, followed by the same letter are not significantly different ($P \times 0.05$).

	Rice				Maize	
	88-1	88-2	89-1	90-1	89-2	91-1
Grain yield						
Control	2.56	0.76	1.70	–	1.55	1.62
N0	2.77 b	0.98 b	1.94 b	–	1.94 b	1.97 a
N1	3.46 a	1.40 a	2.25 a	–	3.30 a	2.48 a
P0	2.62 c	0.85 b	1.68 c	–	1.83 b	1.73 b
P1	3.05 b	1.21 a	2.05 b	–	2.85 a	
P2	3.29 ab	1.25 a	2.22 ab	–	2.66 a	2.75*a
P3	3.49 a	1.46 a	2.42 a	–	3.13 a	
K0	3.15 a	1.15 a	2.26 a	–	2.30 b	2.01 a
K1	3.08 a	1.24 a	1.92 b	–	2.93 a	2.44 a
–S						2.40 a
+S						2.06 a
–Mg						2.25 a
+Mg						2.20 a
P uptake						
Control	4.91	1.59	4.17	–	2.57	2.82
N0	5.17 b	3.66 b	6.18 b	–	4.81 b	3.96 a
N1	6.47 a	4.61 a	7.82 a	–	7.28 a	5.49 a
P0	4.42 b	1.99 c	4.51 c	–	3.17 c	2.41 b
P1	5.59 b	3.84 b	6.75 b	–	5.89 b	
P2	6.30 ab	4.48 b	7.57 ab	–	6.65 b	7.03*a
P3	6.99 a	6.22 a	9.18 a	–	8.47 a	
K0	5.91 a	3.93 a	7.61 b	–	5.56 a	4.56 a
K1	5.74 a	4.34 a	6.39 a	–	6.53 a	4.88 a
–S						4.80 a
+S						4.64 a
–Mg						5.30 a
+Mg						4.15 a

* average of +P treatment combinations

In Seasons 88-1 and 89-1, yields were significantly higher at Site VII than at Site VIII, reflecting differences in inherent soil fertility. Rice yields were mainly limited by P at Site VII, and by N as well as by P at Site VIII. At Site VII yields did not significantly differ among the three application rates of P ha^{-1}. At Site VIII highest yields were obtained with 50 kg P ha^{-1}, except in Season 88-2 where no significant differences were observed among the three levels of P. In all three seasons also a positive response to N application was found.

At both sites the P uptake increased with increasing P application rates. At Site VIII a positive response to N application was found as well.

Maize

At Site VII during three and at Site VIII during two seasons maize was grown. Yields of maize too were significantly higher at Site VII than at Site VIII. Maize responded more strongly to nutrient application, in terms of both yield and P uptake, than upland rice.

In four out of the five cases that maize was grown, yields did not increase further when more than 12.5 kg P ha^{-1} was applied. In contrast to yields the P uptake increased at higher application rates. At both sites the highest uptakes were found when 50 kg P ha^{-1} was applied.

At Site VII in all three seasons a significant N effect was found. At Site VIII the response to N application was significant in season 89-2 only.

In Season 91-1 no differences among different P application rates were found and the P treatments were combined into one +P rate in order to avoid confounding with other treatments. Statistical analysis of the combined results of the Sites VII and VIII showed significant Location, N, P effects and N × P interaction ($P \times 0.01$) and the K treatment was significant at $P \times 0.10$. No interaction between location and treatments was significant.

In 91-1 the response to trace elements was studied as well. After spraying the mixture of trace elements, however, leaves died within 48 h, and all experimental units having been sprayed had to be excluded. A greenhouse experiment where maize was sprayed with each of the compounds of the trace element mixture separately, revealed that leaves died only when sprayed with $ZnCl_2$. Leaves also died when sprayed with $ZnSO_4$, thus indicating that Zn was responsible.

Apparent recovery fraction of applied N and P

The apparent recovery fractions of applied N (RFN) and P (RFP) are presented in Table 4. The RFN is calculated for the P+ and the RFP for the N+ treatments. At Site VII the RFN of maize is higher than of rice, while at Site VIII values are similar for both crops. At both sites the highest RFP values are found for the P1 treatments, except in Season 88-1. The RFP values increase for both crops with time. P application was repeated each season and the RFP encompasses the residual effect.

Discussion

Efficiency of utilization of absorbed nutrients

In Figure 1 the efficiencies of utilization of absorbed P (EUP) for rice and maize of N+ treatments are presented. These figures also show the maximum dilution (YPD) and accumulation (YPA) of absorbed P, as established for maize by Janssen *et al.*

Table 4. Recovery (%) of applied N (+P treatments) and P (+N treatments) at the two sites in the different seasons.

	Site VII						Site VIII					
	rice			maize			rice				maize	
	88-1	89-1	90-1	88-2	89-2	91-1[a]	88-1	88-2	89-1	90-1	89-2	91-1[a]
N[b]	23.2	15.9	–	62.3	35.6	45.0	34.6	40.6	30.5	–	23.6	36.2
P1	10.4	21.8	–	29.3	27.1	59.2	7.0	16.6	19.3	–	25.0	36.9
P2	14.2	15.4	–	14.2	21.3	34.8	8.4	10.1	9.8	–	16.7	20.3
P3	6.8	8.0	–	11.1	15.7	12.0	7.1	10.1	9.3	–	12.3	11.7

[a] P recovery data biased due to confounding

[b] from Season 89-1 onwards the N application rate was increased from 50 to 100 kg N ha^{-1}

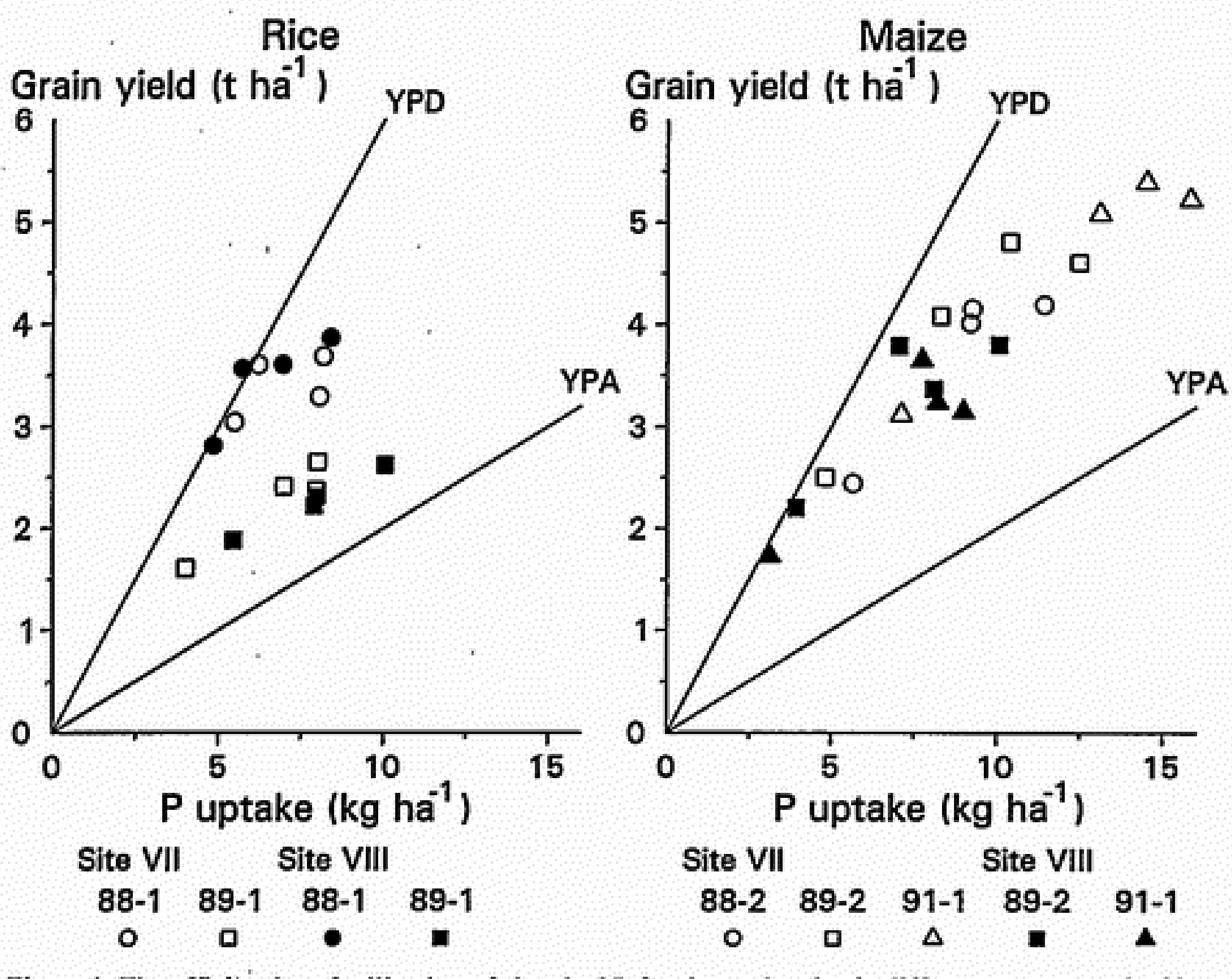

Figure 1. The efficiencies of utilization of absorbed P for rice and maize in different seasons at the Sites VII and VIII. YPD and YPA indicate the maximum dilution and maximum accumulation of absorbed P, respectively.

(1990). The EUP of rice was near its maximum value of 600 at both sites in Season 88-1 but decreased substantially afterwards. Because P uptake did not decrease, it is concluded that P was still available, but could not efficiently be used.

The EUP for maize did not decrease with time, in contrast to that of rice.

The EUP's were equal for rice and maize at comparable amounts of absorbed P. However, maize could absorb more P than rice and at higher amounts absorbed the EUP of maize decreased.

In another experiment in the Taï region (Van Reuler & Janssen, submitted), it was found that the EUP for maize decreased with time as well. The two studies differ in the way the fields were cleared. In the present study the slashed vegetation was burnt and with the ash nutrients, among others substantial amounts of K, are added. In the other experiment the slashed vegetation was removed from the fields. Another difference is that in the present experiment NPK treatment combinations were included, while in the former only NP treatment combinations occurred. Therefore it is suggested that K may have had an effect on the EUP. The positive effect of ash on EUP was also most likely caused by K (Van Reuler & Janssen, 1996a).

It is often found that yields decline when rice is grown continuously. The decline is thought to be caused by soil pathogens, nutrient depletion, soil structure deterioration or accumulation of toxic substances (Gupta & O'Toole, 1986). From the fact that maize can maintain its EUP and rice not, it is concluded that the decline in EUP is caused by factors to which rice is susceptible and maize not.

Residual effect of fertilizer-P

The apparent recovery fraction (RFP) was calculated by the equation of Janssen & De Wolf (1988):

$RFP_t = (0.8 - RFP_1)^{t-1} \times RFP_1$, where RFP_t and RFP_1 are the apparent recovery fractions in year t and year 1, respectively. According to Janssen & Wolf (1988) each year 20% of the labile fraction is transferred to the stable pool. In this study two crops per year were grown, therefore t expressed in seasons instead of in years. Per season approximately 10% of the labile fraction is transferred to the stable pool, and hence the factor 0.8 was changed into 0.9. Because upland rice and maize differ in their capacity to absorb fertilizer-P, RFP_1 obtained for rice could not be used for maize. The first time that maize was grown was Season 1988-2, on Site VII. The recovery in this season consisted of a first season recovery and a residual response to P that was applied to rice in 1988-1. Hence, the measured recovery of maize in 1988-2 (RFP_{1+2}) can be described by:

$$RFP_{1+2} = RFP_{1\,maize} + RFP_{1\,maize} \times (0.9 - RFP_{1\,rice})$$

$RFP_{1\,maize}$ was derived from this equation, and turned out to be 16.3%. This value was also used for Site VIII.

In Figure 2 the calculated and measured recovery fractions are compared for the N1P1 treatments at both sites. In two out of seven comparisons the calculated RFP values are much higher than the measured ones for which no explanation is available.

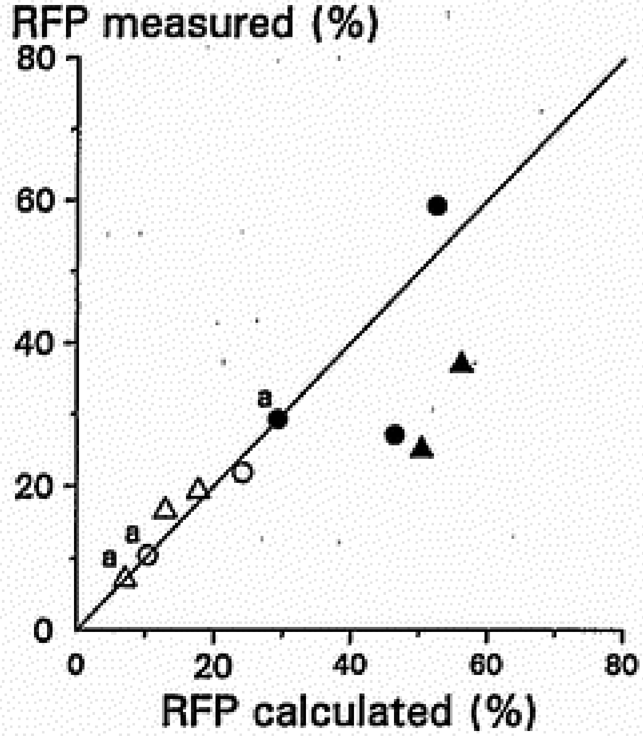

Figure 2. Comparison of the calculated and measured apparent recovery fractions of fertilizer-P (RFP).
Site VII rice ○ maize ● Site VIII rice △ maize ▲
a - values used for the calculation

Potential soil P supply

P uptake in the N1P0 treatments is used as indicator of the potential soil P supply. Based on the EUP it can be assumed that only in the first season after clearing rice growth was limited by P only, and hence only that rice season could be used for the estimation of the maximum amounts of P absorbed. Because for maize EUP did not decrease with time, all maize seasons could be used. Thus in Figure 3, the first season supply is from rice and those in subsequent seasons from maize. In all seasons, except 88-1, the potential P supply at Site VII was higher than at Site VIII. At Site

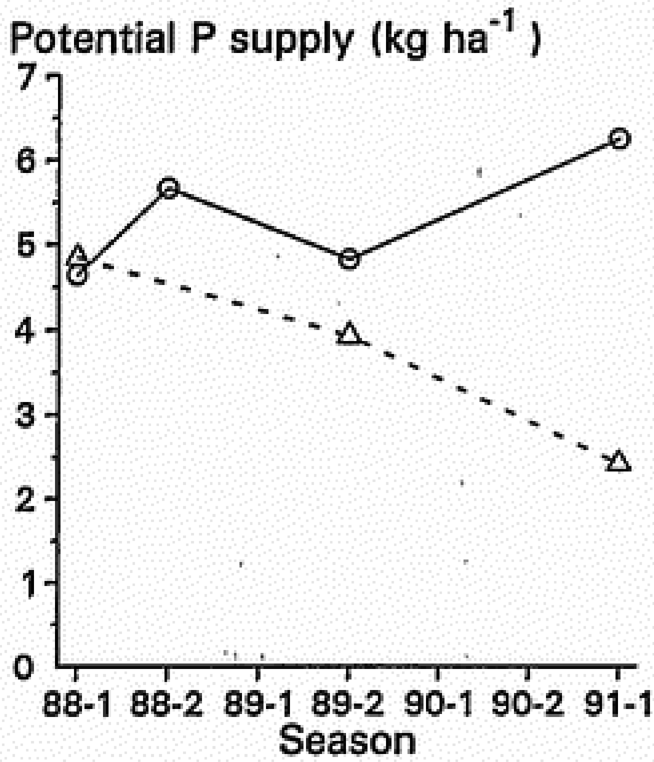

Figure 3. Potential soil P supply of the Sites VII and VIII.
Site VII —○— Site VIII ·····△·····

VIII in Season 89-2 the potential P supply was lower than in Season 88-1. There is a continued decrease at Site VIII while at Site VII in Season 91-1 higher amounts were absorbed than in the preceding seasons. Two factors may have contributed to the increase of the potential P supply at Site VII in Season 91-1. Firstly, the growth conditions in the first season were better than in the second season due to higher radiation (Collinet *et al.*, 1984). Secondly, the fallow Season 90-2 may have had a positive effect on the potential P supply in the following growing season. At Site VIII these effects could not avoid a further decrease in potential P supply. The differences between the two sites are thought mainly to be caused by differences in soil properties and by the position on the slope. At lower position on the slope (Site VIII), the risk of runoff and erosion may be higher. Also in another study along a catena it was found that soil fertility decreased at a higher rate of soils on the lower slope than of soils on the upper slope (Van Reuler & Janssen, submitted).

Soil chemical properties

In Table 5 the soil chemical properties before the start of the experiment in 88-1 and after the last harvest in 91-1 are presented. No differences between the two sampling dates in pH, organic C, total N and total P (–P plots) were found. In many studies (Brams, 1971; Sanchez *et al.*, 1983; Mueller-Harvey *et al.*, 1985, 1989) a decrease in organic matter content during extended cultivation was found. In this study the organic C content shows an increase instead of a decrease. The same trend was found in another study in the Taï region (Van Reuler & Janssen, submitted).

In the plots sampled in 91-1 the cumulative application was 150 kg P ha^{-1}, and about 50 kg P ha^{-1} was exported. The expected differences in total P between Season 89-1 and 91-1 are 100 kg P ha^{-1} or 35 mg P kg^{-1} soil. At Site VII this balance was almost completely recovered in the topsoil and at Site VIII only partly. Although the variability of the total P data is a major disturbing factor, runoff at the lower part of the slope may also have played a role.

Table 5. Soil chemical properties before the start of the experiments (88-1) and after the last harvest (91-1).

	Site VII			Site VIII		
	88-1	91-1		88-1	91-1	
		–P	+P		–P	+P
pH	6.2	6.7	6.3	5.6	5.4	5.2
Org C (g kg^{-1})	11.7	17.3	16.0	9.8	13.7	13.0
total (N g kg^{-1})	0.12	0.11	0.10	0.08	0.08	0.08
total P (mg kg^{-1})	152	150	179	110	101	115

Conclusions

The crop performance on the gravelly well drained soils (Site VII) of the crest-upper slope of a catena was in each season better than the performance on the non-gravelly moderately well drained soils on the lower slope (Site VIII). A drawback of the gravelly soils is the low water-holding capacity, but this can be overcome by a well distributed rainfall.

In this experiment it was shown that cropping can be extended successfully when N and P fertilizers are applied, and maize is grown. The rice yield level, however, could not be maintained at the first-season level. The decrease in yields is thus not caused by a decrease in soil available P. The efficiency of utilization (EUP) of absorbed P for rice decreased with time, while the EUP for maize remained constant. It was concluded that rice yield decline was caused by extraneous factors to which rice is susceptible and maize not. Therefore in an extended cropping system upland rice can be grown only once or twice.

The apparent recovery of fertilizer P increased over time, as a result of the residual effect of previously added fertilizer P. The residual effect could rather satisfactory be described by the equation developed by Janssen & Wolf (1988).

Other nutrients than P that proved to become limiting were N and sometimes K, but not S or Mg.

On the basis of these results, and taking into account the results obtained in other studies (Slaats,1995; Van Reuler & Janssen, submitted), guidelines for fertilizer application and the length of the cropping period can be formulated (Table 6).

Table 6. Fertilizer guidelines for food crops over an extended cropping period at the well drained soils of the crest, upper and middle slopes and the moderately well drained soils of the lower slope.

	Well drained soils		Moderately well drained soils	
	Season		Season	
	1	subsequent[a]	1	subsequent[b]
	rice	maize	rice	maize
Target yield t ha^{-1}	3	4	2.5	3
All crop residues removed				
N kg ha^{-1}	–	100	62.5	75
P	10	10	25	10
K	–	50[c]	–	50[c]
All crop residues left				
N kg ha^{-1}	–	70	62.5	55
P	10	7	25	7
K	–	–	–	–

[a] 6 to 8 seasons
[b] 4 to 6 seasons
[c] from the third season onwards

It is proposed to grow upland rice in the first season after clearing and maize in subsequent seasons. In the first season after clearing the soils supplies enough N for crops grown.

The P application rate is based on an average EUP for rice of 500, indicating that per 3 t grain 6 kg P ha^{-1} is absorbed. Burning the slashed vegetation adds about 10 kg P ha^{-1} to the soil (Van Reuler & Janssen, 1993). The soil P, including the ash-P, can supply at least 5 kg P ha^{-1}. With a recovery fraction of fertilizer-P is 10% an application of 10 kg P ha^{-1} will be sufficient for obtaining the target yield.

In subsequent season maize is grown with a target yield of 4 t ha^{-1}. The average EUP is 400 for maize, indicating that 10 kg P ha^{-1} is absorbed. Maize can absorb more P from soil and fertilizer. Therefore a seasonal application of 10 kg P ha^{-1}, combined with the residual effect of applications in preceding seasons, will be sufficient to compensate for the depletion of soil P.

From the second season onwards it will be necessary to apply fertilizer-N. The rate is based on an average EUN of 50, indicating that 80 kg N ha^{-1} is absorbed. In order to compensate for this removal by the crop and for losses out of the soil-plant system application of 100 kg fertilizer-N ha^{-1} is recommended.

The response to K application was erratic. In the first two seasons after clearing the soil K supply is sufficient. In subsequent seasons an application of 50 kg K ha^{-1} is recommended.

The recommendation differs slightly for soils at the lower slope. In the first season after clearing the target rice grain yield for the moderately well drained soils is 2.5 t ha^{-1}. Due to the lower rice target yield the N application can be reduced to 62.5 kg N ha^{-1}. It is recommended from the first season after clearing onwards. For maize with a target yield of 3 t ha^{-1} the rate needs to be increased to 75 kg N ha^{-1}. At these sites, 25 kg P ha^{-1} is recommended in the first season after clearing, which can be reduced to 10 kg P ha^{-1} in the following seasons. The K application remains the same as for the well drained soils.

These recommendations are based on experiments in which all crop residues were removed from the field. In case all residues are left behind on the field the application rates can be reduced substantially.

About 70% of the absorbed N is exported from the fields with grain, i.e. 56 kg N ha^{-1} and the N application rate can thus be reduced to 70 kg N ha^{-1} for the well drained soils and to 55 kg ha^{-1} for the moderately well drained soils. Also about 70% of absorbed P is exported with grain, i.e. 7 kg P ha^{-1}, and the P application rates can be reduced accordingly. The export of K with grain is less than 10 kg K ha^{-1}. This amount can easily be supplied by the soil, and no fertilizer K is needed.

At this moment no data are available for further discernment between the two growning seasons.

With the recommended fertilizer applications the cropping period can at least be extended up to four years for soils at the crest/upper slope and up to three years for soils of the lower slope.

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