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Comparison of the fertilizing effects of ash from burnt secondary vegetation and of mineral fertilizers on upland rice in south-west Côte d'Ivoire

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Abstract

An important reason for burning the slashed vegetation in shifting cultivation systems is the release of nutrients. In an experiment in the Taï region, S.W. Côte d'Ivoire the fertilizing effects of ash and mineral fertilizers were compared. The ash was derived from a 20-year-old secondary forest which was slashed, dried, piled together and burned. The nutritional value of ash was compared with that of N, P, K fertilizers and lime in a field trial consisting of a "fertilizer" portion and an "ash" portion. The experimental design of the fertilizer portion was a 3^4 factorial. The application rates per ha were 0, 50, 100 kg N (urea); 0, 12.5, 25 kg P (triple superphosphate); 0, 50, 100 kg K (KCl); 0, 400, 800 kg $Ca(OH)_2$. The 81 treatment combinations were divided into nine subblocks. To each of these subblocks three experimental units were added. In six of them ash was applied at rates of 0, 4000 and 8000 kg ash ha^{-1}. With 4000 kg ash ha^{-1} 31 kg P, 264 kg K, 915 kg Ca, 150 kg Mg, 10 kg Na, 10 kg Mn, 2.6 kg Zn and 32 kg S were applied. Upland rice (cultivar IDSA 6) was grown as test crop. The grain yields on individual experimental units varied from 1.2 to 3.2 t ha^{-1}. In the 3^4 trial, N and P application significantly affected the yields of grain and straw. P application increased the uptakes of N, P, K, Ca and Mg significantly. N uptake was also significantly increased by N application and liming. There was a significant negative quadratic P effect on grain and straw yield, and uptake of nutrients, indicating that higher application rates did not result in higher yields and uptake of nutrients.

Ash application significantly increased the yields of grain and straw and the uptakes of N, P, K and Mg, but not of Ca. It was concluded from the two trials that the response to ash application was mainly a P effect.

The recovery fractions of P at about the same P applications rates were 7.4% and 11%, in the ash and 3^4 trial, respectively. Hence, the relative effectiveness of ash-P was 0.67 or 67%, and the substitution rate 1.5. This implies that for the uptake of a unit of P about 1.5 times as much ash-P as fertilizer-P should be applied.

The effectiveness of ash as liming material was 0.59 compared to $Ca(OH)_2$, hence 1.7 times as much ash as $Ca(OH)_2$ is needed to establish a same increase in pH. The CaO equivalent of ash proved to be 44% and the $CaCO_3$ equivalent 78%. In the ash trial a higher efficiency of utilization of absorbed P was found than in the 3^4 trial. Several possible causes of this difference are discussed but no conclusive answers could be given.

Introduction

Shifting cultivation is judged to be a sound agricultural system in areas with a low population density (Sanchez, 1976). In many areas, however, the population density has increased and the system is under pressure to change.

In south-west Côte d'Ivoire, shifting cultivation is the traditional land use system of the indigenous population, belonging to the ethnic groups of Oubi and Guéré. Since the mid-1960s the population density has increased enormously through immigration (Dosso et al., 1981). The immigrants are used to planting perennial crops, such as coffee, cocoa or rubber, after food

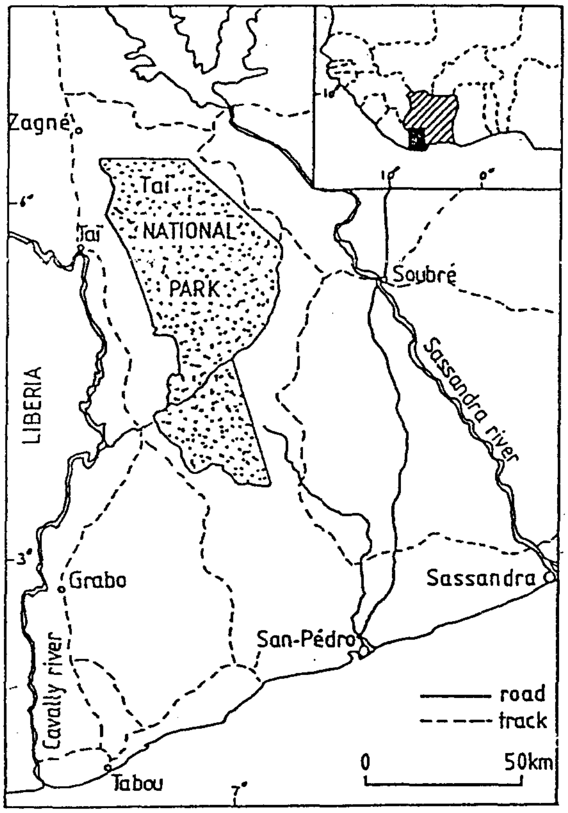

Figure 1. Location of the study area.

crops. Because of the revenues involved, this practice has now been accepted by the Oubi and Guéré.

In 1972 the Taï National Park (340,000 ha) was established (Fig. 1). As a result, the forested area outside the Park boundaries available for clearing for agricultural purposes diminished rapidly, and the Park itself became endangered. For the protection of the Park, it became necessary to intensify agricultural production in the surrounding areas. A research programme to study the possibilities of agricultural intensification was set up by the Wageningen Agricultural University. The programme included investigations of nutrient fluxes in the traditional system of food crop production.

It was found that burning the slashed vegetation doubled yields of upland rice compared to the yields on non-burnt fields, i.e. an increase of about 0.7 ton per ha, in the first season after clearing. This increase could be ascribed to the addition of P with the ash (Van Reuler and Janssen, 1993b). Nevertheless, P still remained the yield-limiting nutrient on burnt fields at well drained sites (Van Reuler and Janssen, 1989, 1993b).

The objective of the present experiment was to compare the fertilizing effects of ash and mineral fertilizers on the yields and nutrient uptakes of upland rice. The effect on soil pH was also studied.

The fertilizing value of a certain nutrient source can be judged by comparing it with the fertilizing value of a reference nutrient source. For that purpose a so-called relative effectiveness (RE) has been defined, being the ratio of the instantaneous slopes of the application – yield or application – uptake response curve, found for the source being tested and the reference nutrient source (Barrow, 1985). The inverse of the RE, known as substitution rate or substitution value, indicates how many nutrient units of the source under examination are needed for bringing about the same response as one nutrient unit in the reference fertilizer. Both expressions are used in this paper.

Materials and methods

Study area

The study site was located at approximately 1 km north of the village of Taï (Fig. 1). Mean annual rainfall amounts to 1885 mm with a standard deviation of 338 mm (Collinet et al., 1984). A pronounced dry season occurs from November to March. The natural vegetation can be classified as lowland evergreen seasonal forest (Vooren, 1985) in the UNESCO classification (UNESCO, 1973).

The field experiment was carried out on the lower part of a catena representative of the region (Fritsch, 1980, Van Kekem, 1986, De Rouw et al., 1990). Soils in this physiographic position are classified as Dystric Regosols (FAO, 1988) and as Typic Troporthents (Soil Survey Staff, 1990). The topsoil (0–20 cm) data presented in Table 1 show that the inherent soil fertility was low.

The field had been cultivated for one season one year and six years before the present trial started. The almost one-year-old secondary vegetation was slashed and removed from the field. It was not burned to avoid interference with the experimental treatments.

Experimental design

The nutritional value of ash was compared with that of N, P, K fertilizers and lime in a field trial consisting of a "fertilizer part" and an "ash part". The experimental design of the fertilizer part trial was a 3^4 factorial. In

Table 1. Soil analytical data (0–20 cm) of the experimental site

sand%	80	Exch. cations[c]	
silt	9	Ca mmol+ kg^{-1}	9.9
clay	10	Mg	3.5
		K	1.2
pH-H_2O[a]	5.18	Na	0.1
		Al	6.0
Org. C g kg^{-1}	1.2	Mn	0.4
Org. N	0.08		
		ECEC mmol+ kg^{-1}	21.0
Total P mg kg^{-1}	88		
P-Dabin[b]	10.0		
P-Olsen	3.3		

[a] average of 108 samples, other data are the average of 27 samples
[b] modified Olsen extraction (0.5 M $NaHCO_3$+0.5 M NH_4, pH 8.5)
[c] $BaCl_2$ extraction

order to reduce uncontrollable variance the block size was reduced from 81 to nine subblocks by confounding three-factor interactions (Cochran and Cox, 1957). To each of these nine subblocks three experimental units were added, bringing the total number to 9 * 12 = 108 units. An experimental unit measured 4 × 5 m.

The application rates in the factorial experiment were 0, 50 and 100 kg N ha^{-1} applied as urea (46% N), 0, 12.5 and 25 kg P ha^{-1} applied as triple superphosphate (20% P), 0, 50 and 100 kg K applied as potassium chloride (50% K), and 0, 400 and 800 kg $Ca(OH)_2$ ha^{-1} (according to product information the liming material contained 96.5% $Ca(OH)_2$ and the CaO equivalent was guaranteed to be 74%).

In six of the nine subblocks the ash trial was conducted. The application levels were 0, 4,000 and 8,000 kg ash ha^{-1}. Such high rates, far above normal, were used to be sure that the effect of ash could show up. The amounts of nutrients applied with the ash are presented in Table 2. The ash was derived from a 20-year-old secondary vegetation described by Van Reuler and Janssen (1993a). For the present experiment a piece of 30 × 30 m of the forest was slashed, dried, piled and burnt very intensively. In this way about 2 t ash ha^{-1} was produced.

The remaining experimental units in the other three subblocks were used for another purpose, not dealt with in this paper.

Crop cultivation

Upland rice (*Oryza sativa*, cultivar IDSA 6) was grown between April and August 1989. The rice was sown in the traditional way with a planting stick or machete. The average density of plant holes was 100,000 holes ha^{-1} with five to ten seeds in each hole. Ash, mineral fertilizers and lime were broadcast one day after planting. The field was fenced to limit damage by rodents. During the growing season, the field was weeded when necessary, leaving the weed remains as surface mulch. During the ripening stage, the rice field was guarded against bird damage. After 130 days the rice was harvested, net plot size being 3 × 4 m. Grain and straw samples of all treatments and some panicle samples were collected for chemical analysis. All above-ground crop residues were removed from the field. The yield data refer to grain with a moisture content of 14%.

Interpretation of yield and nutrient uptake data

The relation between nutrient application and grain yield can be split into the relation between nutrient application and nutrient uptake and the relation between nutrient uptake and grain yield. This so-called three-quadrant method was introduced by De Wit (1953) and applied by, among others, Van Keulen and Van Heemst (1982) and Van Keulen (1982). The apparent fertilizer recovery fraction (RF) is the fraction of a nutrient applied by fertilizer that is absorbed by the crop.

Table 2. Nutrients applied with the ash; all data in kg ha^{-1}

Ash rate	N	P	K	Ca	Mg	Na	Mn	Zn	S
4,000	0	31	264	915	150	10	10	2.6	32
8,000	1	62	528	1830	300	19	20	5.1	63

The efficiency of utilization (EU) is defined as grain yield per unit of nutrient absorbed. The EU is an indication of the availability of the particular nutrient in relation to other growth factors. According to Van Keulen and Van Heemst (1982), grain yield of small cereals maximally increases by 70 kg per kg N absorbed, by 600 kg per kg P and by 55 to 100 kg per kg K absorbed. Janssen et al. (1990) report for maize maximum values of 70 kg per kg N, 600 per kg P and 120 kg per kg K absorbed. Minimum values, indicating accumulation in the crop are 30, 200 and 30 kg grain per kg N, P and K, respectively.

Soil, plant and ash samples

Before planting, per subblock three composite soil samples (0–20 cm), totalling 27 samples were collected. The samples were analyzed according to Houba et al. (1989). In addition, composite soil samples for pH-H_2O (1:2.5) measurement were taken at 0–5 cm, 5–10 cm and 10–20 cm depth in each experimental unit, and at 40–50 cm depth in some units. This sampling was repeated 144 days after ash and $Ca(OH)_2$ application.

Moisture contents of plant samples were determined by 24-h drying at 70 ^{0}C. Thereafter samples were ground. Grain samples were also dried at 105 ^{0}C. The yield data refer to grain with a moisture content of 14%. Plant and ash samples were analyzed according to Walinga et al. (1989).

Statistical analysis

For quantitative statistical analysis the SAS programme was used (SAS Institute Inc., 1989). In the regression model for the 3^4 experiment N, P, K, and L, their quadratic terms and two-factor interactions were included. The model for the ash trial consisted of ash and ash * ash. The General Linear Model (GLM) procedure was used to estimate the regression coefficients for each term. The quadratic terms and two-factor interactions were deleted from the model one by one until the ones remaining in the model were significant at P < 0.1. At each step, the variable showing the smallest contribution to the model was deleted. The response to nutrient or ash application can be predicted by multiplying the relevant regression coefficient by the application rate (0, 1 or 2). The R-squared value provides a measure of how much of the variability in the observed data can be explained by the model.

Results and discussion

Yields and nutrient uptake data

Grain yields on individual experimental units varied from 1.2 t ha^{-1} to 3.2 t ha^{-1}. Main treatments average values of grain yields, straw yields and uptakes of N, P, K, Ca and Mg (uptake refers to the quantities of nutrients in all above-ground plant parts, grain, straw and panicle) are presented in Table 3, and the results of the statistical analysis of the 3^4 and the ash trial, in Table 4 and Table 5, respectively. About 37 and 41% of total variation in grain and straw yield, respectively, was explained by the statistical models in the 3^4 trial, although N and P significantly affected grain and straw yields. Highest values of total R^2 were obtained for nutrient uptakes, with the maximum of 73% for P uptake (Table 4). N, K, Ca and Mg uptakes significantly increased as well as a result of P application, all again pointing to P as being the primary growth-limiting nutrient. The significant negative quadratic P effect indicate that at higher application rates yield and nutrient uptakes will not increase. Highest yields were obtained at P1 (12.5 kg P ha^{-1}), but highest P uptake at P2 (25 kg P ha^{-1}). N as well as P significantly stimulated N, K and Ca uptake.

Ash significantly increased grain and straw yields and nutrients uptakes, except, surprisingly enough, Ca uptake. Also here the highest R^2 was found for P uptake, allowing the conclusion that response to ash was mainly a response to P.

In view of the large yield difference between Ash1 and Ash2 in the ash trial, it is possible that higher rates

Table 3. Grain yield, straw yield and total nutrient uptake of the main and of some selected treatments of the 3^4 and ash trials

Treatment	Yield ($t\ ha^{-1}$)		Total uptake ($kg\ ha^{-1}$)				
	Grain	Straw	N	P	K	Ca	Mg
Control[a]	1.61	1.99	43.2	2.6	29.9	5.1	3.9
Ash1	2.38	2.89	56.3	4.8	50.6	7.0	6.4
Ash2	2.79	3.41	67.1	6.9	66.4	7.7	7.8
N0	1.89	2.51	46.2	4.4	38.6	6.3	5.2
N1	2.10	2.78	57.4	4.6	44.3	7.5	6.1
N2	2.02	2.96	65.0	4.6	49.0	8.2	6.6
P0	1.83	2.41	51.9	3.0	38.8	6.1	5.0
P1	2.12	2.91	59.8	4.8	46.3	8.0	6.5
P2	2.05	2.94	56.7	5.8	46.7	7.9	6.4
K0	1.97	2.51	54.6	4.3	41.6	6.9	5.6
K1	2.05	2.86	58.9	4.9	46.1	7.9	6.3
K2	1.99	2.89	54.8	4.4	44.2	7.2	6.0
L0	1.92	2.64	52.7	4.4	41.7	6.6	5.5
L1	2.05	2.84	56.5	4.6	44.5	7.7	6.2
L2	2.03	2.77	58.9	4.6	45.7	7.6	6.2
-N+P+K+L	1.96	2.89	49.0	5.4	42.7	7.1	5.7
-N−P+K+L	1.57	1.94	36.0	2.3	25.9	4.4	3.5
-N+P−K+L	2.17	2.49	50.8	5.6	45.5	6.2	6.0
-N+P+K−L	1.86	2.95	52.1	7.4	47.3	8.0	6.1

[a] average of 7 experimental units, one from the 3^4 trial and six from the ash trial

Table 4. Estimated regression coefficients for N, P, K and lime and significant terms in equations describing the yields and nutrient uptakes in the 3^4 trial. The variance explained by the models is indicated by R^2 (%)

Parameter	Yield ($t\ ha^{-1}$)		Total nutrient uptake ($kg\ ha^{-1}$)				
	Grain	Straw	N	P	K	Ca	Mg
N	0.36**	0.23***	9.4***	0.04	5.22***	0.95***	0.16
P	0.48***	0.74***	13.7***	2.30***	3.94***	2.93**	2.18***
K	0.01	0.19***	8.5 ·	0.96**	1.31	0.13	0.13
L	0.06	0.07	2.8*	0.14	1.97	0.51	-0.21
N*N	-0.15**						
N*L							0.59**
P*P	-0.19***	-0.23**	-5.5**	-0.45**		-1.00*	-0.78*
K*K			-4.3*	-0.47**			
R^2	37	41	54	73	39	26	41

*, **, *** significant at $P < 0.1$, $P < 0.05$ and $P < 0.01$

Table 5. Estimated regression coefficients for ash in equations describing the yields and nutrient uptakes in the ash trial. The variance explained by the models is indicated by R^2 (%)

Parameter	Yield ($t\ ha^{-1}$)		Total nutrient uptake ($kg\ ha^{-1}$)				
	Grain	Straw	N	P	K	Ca	Mg
Ash	0.57***	0.65*	11.1***	2.11***	17.1***	1.14	1.96**
R^2	85	66	64	87	82	23	53

*, **, *** significant at $P < 0.1$, $P < 0.05$ and $P < 0.01$

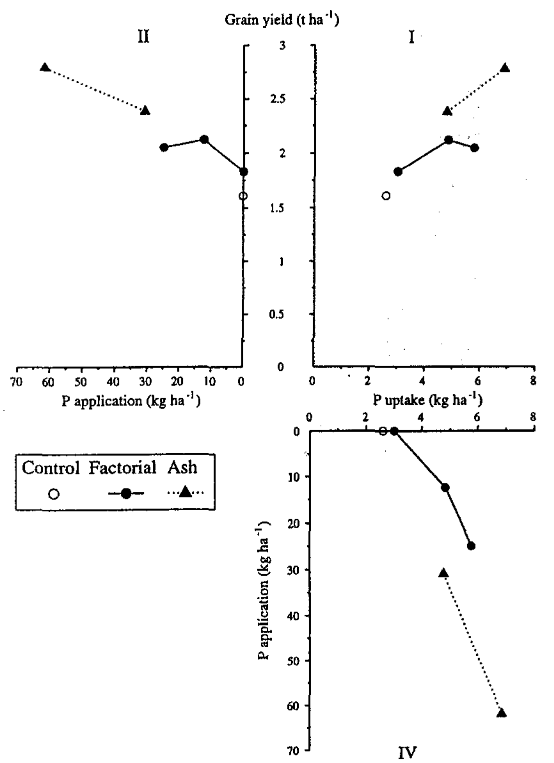

Figure 2. The relations between P application, P uptake and rice grain yield in the 3^4 (main P treatments) and ash trials.

of ash could have resulted in yields higher tha 2.8 t ha^{-1}.

Relations between nutrient application and nutrient uptake; fertilizing and liming value of ash

Phosphorus.
Fig. 2 shows the relations between P application, P uptake and yield in a three-quadrant diagram. The slope of the line in Quadrant IV represents the apparent recovery fraction (RF). RF was 14.5% between P0 and P1, and 7.6% between P1 and P2. The calculation of the recovery of ash-P is more complicated, because ash contains other nutrients besides P. Theoretically, equal quantities of these other nutrients should have been applied at all ash levels including Ash0, but it is impossible to achieve this in practice. Besides P, also K and Ca were applied with ash. Therefore, as approximation to the P uptake at Ash0, the average P uptake of the -N-P+K+L treatment combinations (N0P0K1L1, N0P0K2L1, N0P0K1L2, N0P0K2L2) of the 3^4 trial should be used (Table 3), considering the K and Ca supplies with these treatments as the best possible approximations of those at Ash1 and Ash2. However, the average P uptake on the -N-P+K+L plots (2.3 kg) does not differ significantly from the average P uptake (2.6 kg) on the seven control plots. Therefore for the P uptake of Ash0 the average of both treatment combinations was used, i.e. 2.5 kg P ha^{-1}. The recovery of ash-P was 7.4% between Ash0 and Ash1, and 6.7% between Ash1 and Ash2. Thus, the P-recovery from ash seems much lower than that from TSP, but the comparison is hampered by the fact that with ash more P was applied than with TSP. At Ash1 and P2 (in the 3^4 trial), about equal quantities of P (31 and 25 kg) were applied and the P-recovery fractions were 7.4 and 11.0%, respectively. Hence, the relative effectiveness of ash-P is estimated to be 7.4/11.0 = about 0.67 or 67%, and the substitution rate 11.0/7.4 = 1.50. This implies that for a same uptake of P, about 1.5 times more ash-P than TSP-P should be applied.

Potassium.
As approximation for the K uptake at Ash0, the average K uptake of the -N+P-K+L treatment combinations (N0P1K0L1, N0P2K02L1, N0P1K0L2, N0P2K0L2) of the 3^4 trial was used, considering the P and Ca supplies of these treatments as the best possible approximations of those at Ash1 and Ash2 (Table 3). The K uptake thus found was 45.5 kg ha^{-1}, being significantly higher than the average uptake (29.3 kg) in the control plots. The recovery of ash-K would be strongly overestimated when the control plots were to be used as reference. The recovery of ash-K was 1.9% between Ash0 and Ash1, and 6.0% between Ash1 and

Ash2. The relative effectiveness of ash-K is difficult to assess for two reasons. One reason is that the application of KCl in the 3^4 trial did not result in a significant increase in K uptake, and the other is that far more K was applied with ash than with KCl. From the uptake data in Table 3, the recovery fraction of K from KCl may be estimated at 9.0% between K0 and K1, and at 2.6% between K0 and K2. Hence, the relative effectiveness of ash-K would lie somewhere between 1.9/9.0 =0.21 and 6.0/2.6 = 2.29. This range is so wide that such an answer cannot be considered as conclusive. The most concrete statement that can be made is that there is no reason to assume that ash-K is less available to the crop than KCl-K. Since under the prevailing conditions of high rainfall and low soil-ECEC K-leaching is a serious risk, such a reduced solubility may be looked upon as an asset. Exchangeable K is about 1.2 mmol kg^{-1} and ECEC 21 mmol(+) kg^{-1} (Table 1) and, hence, the relative K saturation is about 6%. In the 3^4 trial, maximum K uptake was obtained at K1, i.e. at an K application of 50 kg ha^{-1}. If the added K is retained as exchangeable K in the topsoil of 3 million kg, the added 50 kg of K would increase exchangeable K by 0.43 mmol K kg^{-1}. The relative K saturation would then rise from about 6 to about 8%. It is questionable whether the soil can maintain such a high value. The data of Table 3 suggest that the soil itself can supply about 40 kg K per ha per season, which is roughly 30% of exchangeable soil K. Assuming that the same recovery value holds for fertilizer-K that is retained as exchangeable K, and taking into account that 9% of fertilizer-K was recovered by the crop, it follows that 9/30 = 0.3 or 30% of the applied K was present as exchangeable K in the topsoil. The remainder of applied K may have moved to deeper soil layers and/or may have been incorporated into soil minerals, thus becoming unavailable to the crop.

Calcium and liming. In the 3^4 trial as well as the ash trial Ca uptake did not increase significantly upon liming and ash application, respectively. Therefore calculations of the recovery fractions of Ca are not meaningful. The purpose of application of $Ca(OH)_2$ was to increase pH. Assessment of the effectiveness of ash in comparison with $Ca(OH)_2$ should therefore refer to their effects on pH.

Fig. 3 shows the effect of $Ca(OH)_2$ and ash application on pH-H_2O (0–20 cm) at the end of the growing season. The ratio of the slope of the ash line between Ash0 and Ash1 to the slope of the $Ca(OH)_2$ line between L0 and L2 amounts to 0.59. This implies

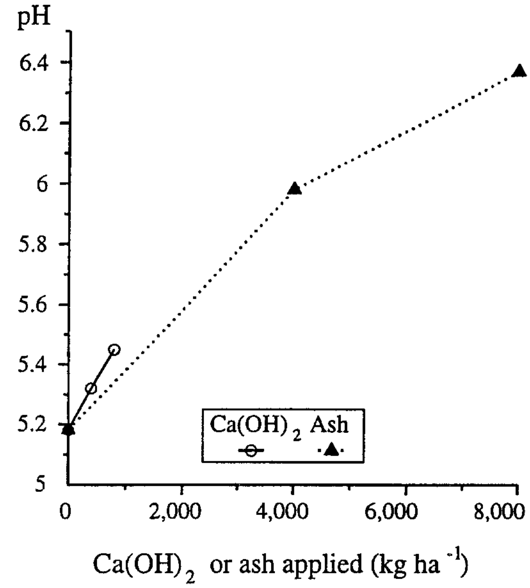

Figure 3. Effect of $Ca(OH)_2$ and ash application on pH.

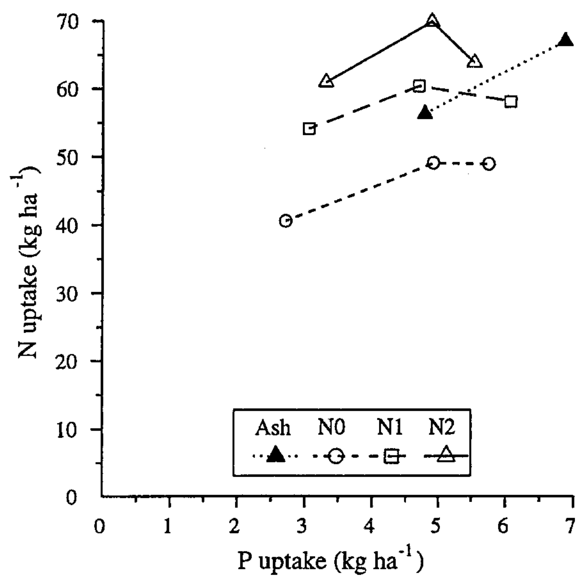

Figure 4. Relation between N and P uptake in the ash and for the three N levels of the 3^4 trial.

that for a same pH increase, the quantity of ash to be applied is 1.7 times as large as the quantity of $Ca(OH)_2$.

The effectiveness of liming materials is generally expressed in terms of CaO or $CaCO_3$ equivalent. The CaO equivalent of the applied $Ca(OH)_2$ was 74%, and hence the $CaCO_3$ equivalent was 74 * 100/56 = 132%. Consequently, the CaO equivalent of the ash may be estimated at 0.59 * 74 = 44% , and the $CaCO_3$ equivalent at 0.59 * 132 = 78%.

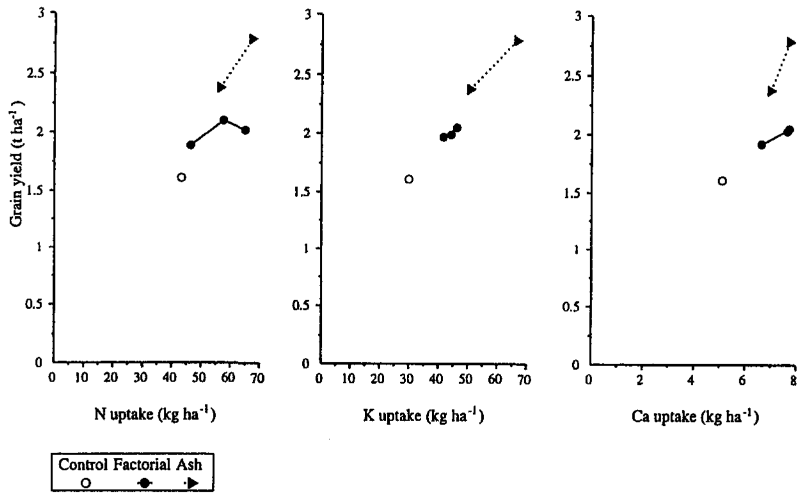

Figure 5. Relation between grain yield and uptakes of N, K and Ca. Uptakes are averaged per application rate of N, K and lime.

Nitrogen.
Although the ash used contained practically no N, it proved to have a significant positive effect on N uptake. The extra N absorbed must have been supplied by the soil. The efficiency of utilization of N (EUN), i.e. the ratio of yield to N uptake, was always closer to 30 than to 70 as can be derived from Table 3, indicating that N was never growth limiting (Janssen et al., 1990). The uptake of N was related to crop growth which in turn depended mainly on P availability. Fig. 4 shows the relations between N uptake and P uptake. The line for ash lies closer to the line for N1 rather than N0 at higher ash rates, suggesting that in the ash plots the supply of N was about the same as in the N1 plots of the 3^4 trial. In the 3^4 trial liming increased the N uptake significantly ($P < 0.1$). The significant effect of ash on N uptake may be caused by a combined effect of P and Ca applied with ash. This extra uptake may have been derived from increased N mineralization in the ash plots, possibly as a result of the increase in pH in these plots. In the N0 treatment, however, there proved to be no relation between pH and amount of N taken up.

Apparently the soil can supply at least 65 kg N ha^{-1} in one growing season. Available N not actually taken up may simply remain in the soil solution, but is usually subjected to processes like leaching, volatilization, denitrification and immobilization. These processes were not measured in Taï. The recovery of fertilizer N was only about 20% and it is likely that leaching played a dominant role in N-losses.

Relations between nutrient uptake and yield; additional ash effect

From the relation between P uptake and grain yield (Quadrant I in Fig. 2), it follows that high values, even above 600 for efficiency of utilization (EU) of P, were found on minus-P plots, and that in the ash trial absorbed P was more efficiently used than in the 3^4 trial. Similar conclusions can be drawn from Fig. 5, showing the uptake-yield relations for N, K and Ca. In all cases the lines for ash lie above those of the 3^4 trial and the question arises as to which factors, nutrient(s) or others, the better EU's of the crop for P in plots with ash can be ascribed. An obvious hypothesis is that the presence in ash of nutrients other than the ones under study improves the EU.

A greenhouse experiment with the double-pot technique revealed (G.J.F. van Ewijk, personal communication) that ash supplied, in the first place, K and S to the plants, and furthermore small amounts of N, P, Zn and Cu, but no Mg, Fe, B and Mn. These results suggest that the additional beneficial effects of ash could have been caused by S, Zn or Cu. This hypothesis was tested in a field experiment on sites which had been cultivated for six seasons (Van Reuler and Janssen, (1996)). Application of S as $CaSO_4$ did not have any positive effect on yield, thus making it unlikely that the additional effect was caused by the sulphur in the ash. Unfortunately, no conclusions could be drawn about the effects of micronutrients because in a similar test for micronutrients the crop was damaged by the foliar application of a solution of these nutrients. On compa-

Table 6. Comparison of yields (t ha^{-1}), nutrient uptake (kg ha^{-1}) and the ratio of K uptake to Ca uptake in the Ash and 3^4 trial for fixed values (**bold**) of N, P, K and Ca uptakes, respectively

Trial	Grain yield t ha^{-1}	Uptake of nutrients kg ha^{-1}					K/Ca
		N	P	K	Ca	Mg	
Ash	2.52	**60**	5.5	56.0	7.2	6.9	7.8
3^4	2.07	**60**	4.6	45.9	7.7	6.3	5.9
Ash/3^4	1.22		1.2	1.2	0.9	1.1	1.3
Ash	2.42	57.4	**5**	52.3	7.1	6.6	7.4
3^4	2.11	59.2	**5**	46.4	8.0	6.5	5.8
Ash/3^4	1.15	1.0		1.1	0.9	1.0	1.3
Ash	2.24	52.5	4.0	**45**	6.7	5.9	6.7
3^4	2.03	58.2	4.8	**45**	7.7	6.2	5.8
Ash/3^4	1.10	0.9	0.9		0.9	1.0	1.2
Ash	2.42	57.3	5.0	52.1	**7**	6.6	7.4
3^4	1.97	54.1	4.4	42.7	**7**	5.7	6.1
Ash/3^4	1.23	1.1	1.1	1.2		1.1	1.2

rable soils with a sandy texture in Ghana, Zn deficiency was common. Unfortunately the length of the cultivation period at this site was not reported (Kang and Juo, 1984). Because the cropping history of the present site in Taï was relatively short, Zn deficiency is not yet to be expected.

Soil pH was strongly raised by ash application (Fig. 3), but the difference in pH is not a very plausible cause to explain the difference in EUs between the plots with and without ash. Reasons are that no response to liming was observed in the 3^4 trial (Tables 3 and 4), and that in general in our previous studies the growth of upland rice was not influenced by pH changes (Van Reuler and Janssen, 1989, 1993b).

Table 6 presents the uptakes of the other nutrients for reference values of the uptake of N, P, K, and Ca, respectively. The yields and uptakes were calculated by interpolation of the data of Table 3. The reference uptake values were chosen in the overlap of the uptake ranges of the ash and the 3^4 trial. There was, however, no overlap in the case of K, its uptake always being lower in the 3^4 trial than in the ash trial. Therefore, a value between the uptake ranges of the two trials was taken as reference value of K uptake.

Table 6 shows that the uptake of K was higher and the uptake of Ca lower in the ash trial than in the 3^4 trial. Hence, the largest difference between the ash and the 3^4 trial is the uptake ratio of K and Ca. The value of K/Ca increases with increasing ash application, being 6.0 on average in the 3^4 trial, 7.2 at Ash1 and 8.6 at Ash2. The ratio K/Ca in ash is 0.3 (Table 2). Apparently ash-K is better available to the crop than ash-Ca. Whether the difference in K/Ca is the cause of the better nutrient utilization and higher yields in the ash trial than in the 3^4 fertilizer trial is not clear. In general, K facilitates water uptake by roots and at the same time reduces transpiration losses (e.g. Beringer and Trolldenier, 1978), and increases the resistance of plants to pathogens and insects. However, the K content in the 3^4 trial does not point to K deficiency. It cannot be excluded that not K/Ca itself, but another nutrient being correlated with K/Ca, was the main cause of the difference in utilization efficiency between the fields with and without ash. It is not likely that Mg is the other nutrient, as the uptake data (Tables 3 and 6) show that differences in Mg uptake between the 3^4 fertilizer trial and the ash trial were of minor importance.

The nature of the vegetation that is burnt and the temperature during the burning influence the chemical composition of the ash produced. Ash produced in a different way or from a different vegetation may have other fertilizing and liming values than the 67% for the relative effectiveness of ash-P, and 73% for the $CaCO_3$ equivalent of ash we found. In this trial, ash was produced in a pile, and the burning was much more intensive than it usually is on farmers' fields. Our ash did not contain N. N is entirely lost at temperatures over 350–400 °C (Andriesse and Schelhaas, 1987), and therefore we may assume that the temperature in the pile had been at least 350 °C.

Our results may also have been affected by the very high application rates of ash, being 4 and 8 ton ha^{-1}, while the normal rate in Taï is about 2.5 ton ha^{-1} (Van Reuler and Janssen, 1993a). As a result, the amounts of P, K and Ca applied through the ash were much higher than those in the 3^4 fertilizer trial, and this difference may have affected the validity of the comparison.

Conclusions

In a 3^4 fertilizer trial the yield of upland rice was increased significantly by application of N ($P < 0.05$) and P ($P < 0.01$). Highest yields were obtained with 50 kg N ha^{-1} and 12.5 kg P ha^{-1}. N application and liming also increased the N uptake, while P application increased the uptake of N, P, K, Ca and Mg.

Also ash application increased the yield and uptake of N, P, K and Mg. The response to ash was mainly a P effect. The apparent recovery fractions of 25 kg fertilizer-P and 31 kg ash-P were 11.0% and 7.4%, respectively. Consequently, the relative effectiveness of ash-P was 0.67 and the substition rate 1.5. The high N uptake in the ash trial is probably a combined effect of P and Ca applied with the ash.

The efficiency of utilization of absorbed ash-P was higher than of absorbed fertilizer-P. The effect might have been related to the high K content, or to the high K/Ca ratio in ash, but other factors may have been involved as well. Further experiments regarding the effect of micronutrients (Zn and Cu) on the efficiency of utilization of absorbed P are required.

Ash was compared with $Ca(OH)_2$ in their effects on pH. It was found that 1.7 times as much ash as $Ca(OH)_2$ need to be applied for establishing the same pH increase.

In this trial ash had direct effects as P fertilizer and as liming material, and an indirect effect consisting of an improvement of utilization of absorbed nutrients. It is obvious that ash may behave as K fertilizer, and there are indications that it may act as S fertilizer too, but the prevailing soil conditions made it impossible to evaluate these qualities.

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