Combined Effects of Legumes with Rock Phosphorus on Rice in West Africa

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ABSTRACT

Rice (*Oryza sativa* L.) demand in West Africa is unmet because of insufficient production. Legume fixed N [biological N fixation (BNF)] may sustainably increase rice productivity in low-input systems. However, P deficiency limits BNF on the acid soils encountered in the region, despite the prevalence of phosphate rock (PR). Pot and field experiments were conducted in Côte d'Ivoire in 1996–1998 to study the impact of combined legume and PR on rice performance. Triple superphosphate and PR were applied at rates of 60 (pot) and at 90 (field) kg P ha^{-1} to rice and the legume *Aeschynomene afraspera* grown for 8 wk and then incorporated before rice transplanting. Legume fixed N was determined by ^{15}N isotope dilution. Under field conditions, addition of PR doubled the biomass of *A. afraspera*. Irrespective of P source, P application increased the amount of BNF-N (three- to eightfold) to 36 mg N plant^{-1} in pots and to 84 kg N ha^{-1} in the field. Nitrogen derived from the air was correlated with legume P uptake (r = 0.97*, where *** = significant at the 0.001 level) and nodulation (r = 0.91**, where ** = significant at the 0.01 level). The synergy of PR and BNF on N and P cycling improved P nutrition and total biomass of subsequent lowland rice under pot conditions. Combining legume green manure (GM) with PR enhanced soil extractable Bray-1 P and may thus play an important role in improving the availability of PR. Under field conditions, due to asynchrony in GM nutrient release and demand, the impact of the combined GM–PR treatment on rice yield was minimal.**

In West Africa, the demand for rice (5% average annual growth rate since 1973) exceeds regional production (WARDA, 1996). Imports of additional rice to fill the gap, which stood at 2.6 million tonnes in 1990–1992, were projected in the year 2000 to approximate 4 million tonnes, which was worth $1 billion in foreign currency (Nwanze, 1998). The increase in local production is expected to come from the region's underutilized 52 million hectares of inland valleys (Windmeijer and Andriesse, 1993). These lowland swamps are located in the humid zone of West Africa and are expected to increasingly absorb the growing pressure on uplands for food crops and particularly for rice production. Increasing lowland rice productivity presupposes cropping intensification and thus increasing removal of nutrients from the soil where little or no external inputs are applied. The depletion in essential plant nutrients of the predominantly sandy Alfisols and Ultisols of the region is seen as a major threat to the sustainability of smallholder production systems (Smaling and Braun, 1996). Diagnostic on-farm experiments in Côte d'Ivoire showed negative nutrient balances under intensified land use, which resulted in significant rice yield decreases (Becker and Johnson, 1999). Alleviation of continued nutrient mining by the West African resource-limited rice producers requires (i) the efficient use of resources internal to the production system (e.g., GM) and (ii) the use of low-cost indigenous amendments (e.g., PR).

Large deposits of PR exist in sub-Saharan Africa (Buresh et al., 1997). Their use in the strongly weathered and P-deficient acidic soils of humid West Africa is agronomically warranted (Mokwunye, 1995) and economically profitable as the unit price of P from the rock can be as little as one-third the price of a unit of P from commercial superphosphate (Nye and Kirk, 1987). Shinde et al. (1978) observed that PR applied to a continuously flooded acidic soil 2 to 3 wk before submergence was able to meet part of the P requirements of rice. Semiaquatic green manure legumes, such as *Aeschynomene afraspera*, reportedly accumulate sufficient N in 45 to 60 d to meet much of the N requirements of lowland rice (Becker et al., 1995). A P application to GM has been shown to enhance legume biomass, N accumulation, and BNF (Becker et al., 1991; Somado, 2000). The P applied to *Sesbania rostrata* more than doubled its N accumulation (Becker et al., 1991). Returning this biomass substantially improved P nutrition and yield of rice. Nitrogen fixation is known to acidify the rhizosphere of legumes and enhance PR dissolution (Anguilar and van Diest, 1981).

With P stimulating legume growth and BNF, it is conceivable that PR application to a flood-tolerant pre-rice GM may stimulate N and P cycles of rice–legume rotations. This hypothesis was tested in pot and field experiments in representative sites of the Côte d'Ivoire humid forest zone of West Africa. The objectives of this study were to (i) estimate the effect of PR application on the contribution of BNF to N accumulation and biomass production of pre-rice GM, (ii) assess the impact of possible interactions between GM and PR on P nutrition of lowland rice, and (iii) evaluate the impact of this same combination on lowland rice yields.

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Abbreviations: atom%, atom percent; BNF, biological nitrogen fixation; DM, dry matter; GM, legume green manure; %Ndfa, percentage of nitrogen derived from the atmosphere; PR, phosphate rock; TSP, triple superphosphate.

MATERIALS AND METHODS

Experimental Sites

Experiments were conducted between 1996 and 1998 in Côte d'Ivoire at the main research center of the West Africa Rice Development Association (WARDA) at Mbé (screenhouse trials, derived savanna zone, 7°30′ N, 5°6′ W, 280 m altitude) and at a field site in the monomodal forest zone near the town of Danané (7°18′ N, 8°12′ W, 336 m altitude).

Experimental Soil Characteristics

Two acid (pH 4.7–5.2), P-deficient (4 mg kg^{-1} Bray-1) Ultisols (Aquults) were used in the studies. These included (i) a bulk surface sample (0–20 cm) from a lowland field under natural fallow near Danané (Soil 1) that was translocated to Mbé, dried, sieved (<2 mm), and used for pot study and (ii) a lowland soil in a rice field near Danané (Soil 2). No record of previous fertilization in these soils was known. Some important physical and chemical characteristics of the experimental soils are summarized in Table 1.

Eight liter-glazed pots (40 cm diam.) were each filled with 6 kg of dried Soil 1 (Table 1). The soil was saturated with distilled water and manually puddled after application of P and K. A water table of 3 to 5 cm was maintained throughout the growing period.

Trial Design, Establishment, and Treatments

Both experiments were set up as a randomized complete block design with three replications. Two cropping systems and three types of P application were studied to compare the effects of P on GM and rice yields and on N and P cycling. In addition to an unfertilized control (no P), triple superphosphate (TSP in granular form, 19.6% P) and the Tilemsi (Mali) rock P (PR finely ground <0.3 mm, 13.7% P) were used in the experiments. The P sources were applied at rates of 60 (pot) and 90 (field) kg P ha^{-1} either to the pre-rice legume (GM–rice rotation) or to the rice crop. *In the field only*, an additional mineral N–P–K (80:60:100) fertilizer treatment was included, and randomly allocated to targeted plots, to allow for a comparison with the mineral fertilization practice for rice production in Côte d'Ivoire. In this case, N was applied as urea at 80 kg N ha^{-1} in three split doses (i) 10 d after transplanting, (ii) at maximum tillering, and (iii) at flowering. All pots and field plots received an initial uniform dose of 100 kg K ha^{-1} as KCl. All fertilizers were broadcast and manually incorporated in the top 5- to 10-cm soil layer. The fertilizer sources and mode of application were the same in either experiment.

Table 1. Physical and chemical properties of soil used in the pot and field experiments.

	Soils	
Characteristics	**Pot**	**Field**
Soil order	**Ultisol (Uquults)**	**Ultisol (Uquults)**
Texture	**Loam**	**Silt-loam**
pH H_2O (1:2.5)	**5.2**	**4.7**
pH KCl	**4.4**	**3.9**
Organic C, %	**1.10**	**1.3**
Total N, %	**0.08**	**0.14**
Available P (Bray 1), mg kg^{-1}	**4.0**	**4.0**
Exch. Ca, cmol (+) kg^{-1}	**1.26**	**0.70**
CEC, cmol (+) kg^{-1}†	**3.86**	**3.34**
Exch. acidity, cmol (+) kg^{-1}	**0.06**	**0.09**

† CEC, cation exchange capacity.

Determination of Biological Nitrogen Fixation: Nitrogen-15 Fertilizer Application and Labeling Procedure

Soils for both pot and field trials had been enriched with ^{15}N for GM–BNF estimation by the ^{15}N isotope dilution technique. Nitrogen-15–labeled ammonium sulfate [10 atom percent (atom%) excess] was added at 0.1 g ^{15}N kg^{-1} (pot) and 1 kg ^{15}N ha^{-1} (field) of soil 1 yr before the trials to stabilize the ^{15}N isotopic composition of the soil (Pareek et al., 1990). In the field, each 4- by 6-m plot sown to GM contained two microplots of 0.60- by 0.60-m area, which were separated from the field plot by a sheet of galvanized iron frame pushed 30 cm deep into the soil. Microplots were fertilized with ^{15}N-labeled ammonium sulfate.

Aeschynomene afraspera was grown as an N_2–fixing legume for 8 wk before incorporation. A nonfixing reference rice plant (Pareek et al., 1990) was also grown for the same period of time. At harvest, legume shoots were cut at ground level from the whole pot or from an area of 12 m^2 (field), and dry weight was determined after oven-drying at 70°C for 3 d. Nodule number and weight of 6 (pot) or 15 (field) randomly selected plants were determined and oven-dried. Above- and belowground plant parts were used for total N and ^{15}N analysis.

Shoots of the legume aboveground biomass were chopped (<1 cm in pot and 10–15 cm in field) and manually incorporated into the upper 10 cm of soil. For the rice-cropping phase of experiments, the ^{15}N-labeled and the unenriched legume biomass (either P-fertilized or not) was manually incorporated into their respective enriched and unlabeled pots/microplots. After legume aboveground biomass (in the case of rice–GM rotation) was incorporated (7 d in pot and 14 in field), 21-d-old WARDA-improved rice seedlings (WITA 1) were transplanted into the water-saturated lowland soil. Table 2 summarizes the amounts of GM residues incorporated before the rice crop.

Plant and Soil Sampling and Analyses

Rice was harvested at maturity from a 12-m^2 area (field) or from whole pots. Rice straw was oven-dried (70°C for 3 d) and grain weight recorded, and its moisture content was measured using a multigrain moisture tester. Grain yield was then adjusted for 14% moisture.

Soil samples were collected at the initiation of the trials and at the harvest of the rice plants, and their analyses were performed in three replicates using composites of 3 (pot) and 10 (field) random samples. Parameters analyzed included particle size (Gee and Bauder, 1986), pH (soil/KCl solution ratio of 1:2.5), cation exchange capacity (Chapman, 1965), sum of bases (Jackson, 1967), organic C (Okalebo et al., 1993), total Kjeldahl N, available Bray-1 P, and exchangeable acidity (Okalebo et al., 1993). Subsamples of legumes and rice were

Table 2. Amounts of *Aeschynomene afraspera* aboveground biomass dry matter (DM) and N and P recycled to soil before rice transplanting under flooded conditions in the pot and field experiments.

	Pot			Field		
P sources	**DM**	**N**	**P**	**DM**	**N**	**P**
		g pot^{-1}			**kg ha^{-1}**	
0 P	**45.1**	**0.82**	**0.05**	**1832**	**71**	**2.9**
PR†	**87.6**	**1.40**	**0.11**	**5374**	**220**	**17.6**
TSP‡	**125.9**	**2.23**	**0.32**	**7628**	**289**	**23.3**
$LSD_{0.05}$	**15.8**	**0.32**	**0.08**	**947**	**100**	**5.2**

† PR, phosphate rock.

‡ TSP, triple superphosphate.

analyzed for Kjeldahl N content and total P (Okalebo et al., 1993). Total N and ^{15}N analysis were done using an elemental N analyzer (Carlo Erba NA 1500) connected to a Finnigan MAT 251 mass spectrometer.

Computation

The proportion of plant N derived from the atmosphere (%Ndfa) was calculated using the ^{15}N isotope dilution equation (Fried and Middleboe, 1977):

$$\%\text{Ndfa} = 1 - (\text{Nfix}/\text{Nref}) \times 100 \qquad [1]$$

where Nfix is the ^{15}N atom% excess of the N-fixing plant and Nref the ^{15}N atom% excess of the nonfixing reference plant.

The amount of total N fixed from the atmosphere was estimated using the equation:

$$\text{N (fixed)} = (\%\text{Ndfa}/100) \times \text{TNY} \qquad [2]$$

where TNY is total N yield (kg ha^{-1}).

The total N yield was calculated using the following equation:

$$\text{TNY} = (\text{LSN}/100) \times \text{DM} \qquad [3]$$

where LSN is legume shoot N concentration (%) and DM is dry matter yield (kg ha^{-1}) of legume.

The rice N derived from the legume residues [percentage of apparent N recovery (%ANR)] was computed as:

$$\%\text{ANR} = (N_t - N_0) \times 100/N_a \qquad [4]$$

where N_t is rice N uptake in manured plots, N_0 is rice N uptake in unmanured plots, and N_a is GM N applied.

Statistical Analysis

Data were subjected to ANOVA and Pearson's linear correlation using the SAS General Linear Model (GLM) (SAS Inst., 1996). To take account of the bias caused by the inclusion of the additional N–P–K treatments in the field experiment, the GLM type III error was used to calculate the mean square error. Treatment single degree-of-freedom contrasts were used to compare individual treatments.

RESULTS AND DISCUSSION

Legume Response to Phosphorus Application

Dry matter (DM) accumulation of *A. afraspera* responded strongly ($P < 0.001$) to P application. Under pot conditions, DM increased by twofold (PR) and threefold (TSP) over the control. In the field, the increase was more than 5 t ha^{-1} (PR) and 7 t ha^{-1} (TSP) compared with the no-P treatment (Table 2).

By way of a substantial stimulation of nodulation (the number and the weight of nodules; Table 3), GM-N accumulation after 8 wk substantially increased. In the pot study, N accumulation ranged from 24 mg N plant^{-1} in the unfertilized control to 58 (PR) and 123 (TSP) mg N plant^{-1}. In the field, GM-N accumulation exceeded that of the unfertilized control by 150 kg N ha^{-1} (PR) and 218 kg N ha^{-1} (TSP) (Fig. 1). The difference between TSP and PR was not significant (Table 2 and Fig. 1).

Similarly, P application, irrespective of P source, increased %Ndfa by *A. afraspera*. Under pot conditions, %Ndfa ranged from 56 (no P) to 63 (PR) and 71% (TSP). The amounts of N derived from BNF were 13 (no P), 36 (PR), and 87 (TSP) mg plant^{-1} N derived from the atmosphere (Fig. 2). In the field, P application increased %Ndfa 2.6-fold (PR) and threefold (TSP) over the control (Fig. 2). Amounts of fixed N ranged from 10 kg ha^{-1} in the unfertilized plots to 84 and 122 kg ha^{-1} in the PR and TSP treatments, respectively (Fig. 1).

These results showed that P deficiency limited the legume crop performance. As in previous studies (Becker et al., 1991), alleviating this deficiency with PR increased nodulation, N$_2$ fixation, and the accumulation of biomass, N, and P in *A. afraspera* grown in P-deficient acid soil under continuously flooded conditions. Shinde

Table 3. Nodulation parameters in *Aeschynomene afraspera* as affected by P sources under flooded conditions in the pot and field experiments.

P sources	Pot		Field	
	Total nodule number	Dry weight total nodules	Total nodule number	Dry weight total nodules
	No plant^{-1}	mg plant^{-1}	no. plant^{-1}	mg plant^{-1}
0 P	22	33	4	4
PR†	41	65	24	39
TSP‡	55	90	38	51
LSD$_{0.05}$	18	13	18	34

† PR, phosphate rock.

‡ TSP, triple superphosphate.

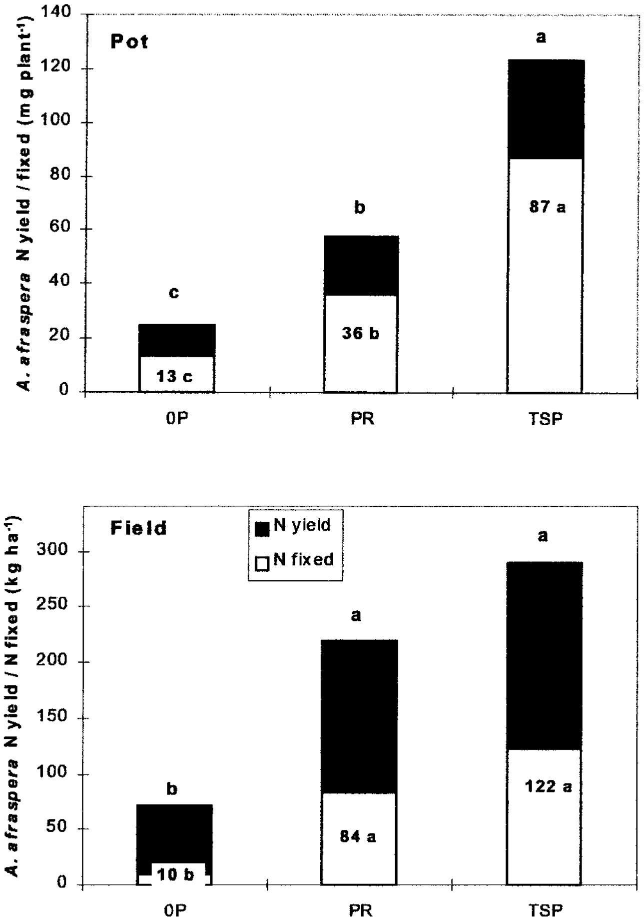

Fig. 1. Legume N yield and amounts of N fixed (^{15}N isotope dilution method) as affected by P sources under flooded conditions in the pot and field experiments. Bars with the same letters are not significantly different (LSD, $P < 0.05$). PR, phosphate rock; TSP, triple superphosphate.

et al. (1978) observed that poorly soluble PR applied to an acidic soil 2 to 3 wk before submergence solubilized sufficiently to meet P requirements for rice plant growth. Enhanced DM and N accumulation with P application has also been shown for the semiaquatic N-fixing legume *Sesbania rostrata* (Becker et al., 1991).

Likewise, the nodulation and %Ndfa response to P application agrees with previous findings (Cadisch et al., 1993). Improved P supply not only stimulated legume growth but also increased nodule number and weight and nitrogenase activity (Israel, 1987). Results obtained do support the view of Becker et al. (1991) that application of P to the stem-nodulating legume *A. afraspera* significantly improved the %Ndfa per se.

The %Ndfa measured in the field, however, using the ^{15}N isotope dilution method was lower than values reported for the same legume species by Becker and Ladha (1996) using the same measurement technique. The reported study was conducted in wetland fields in the Philippines. Wide variability in N accumulation by legumes has been reported across different environments and within the same site with different soil and climatic conditions (Becker et al., 1995). This may explain the discrepancy between the %Ndfa obtained in the present experiments and that of the studies conducted in the Philippines.

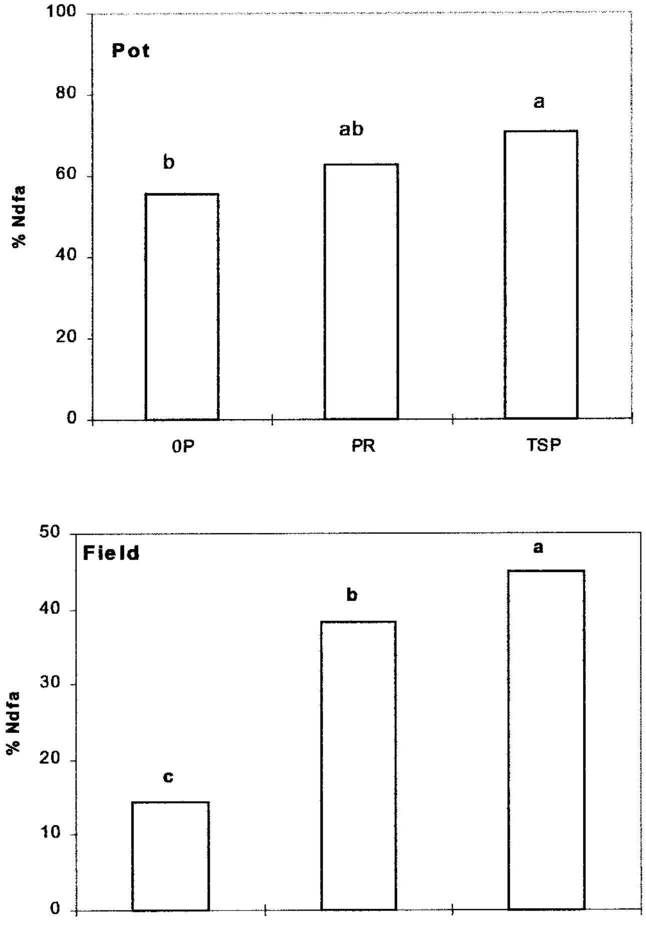

Fig. 2. Effects of P sources on percentage of N derived from the atmosphere (%Ndfa) by *A. afraspera* as measured by the ^{15}N isotope dilution method under flooded conditions in the pot and field experiments. Bars with the same letters are not significantly different (LSD, $P < 0.05$). PR, phosphate rock; TSP, triple superphosphate.

A strong linear correlation was found between the amount of N_2 fixed and P uptake ($r = 0.97$, $P < 0.001$), total nodule number ($r = 0.90$, $P < 0.001$), and legume dry weight ($r = 0.91$, $P < 0.01$). Cassman et al. (1993) reported similar relationships and suggested a synergy between legume-fixed N and P supply. This synergy was suggested to be exploited to maximize yields of crops grown in rotation with N-fixing legumes (Kirk et al., 1998).

Rice Response to Added Phosphorus and Legume-Fixed Nitrogen

Addition of fertilizer P significantly increased rice grain yield in the pot study (Table 4). Averaged over GM treatments, grain yield increases were 1.6- (PR) and twofold (TSP) above the no-P treatment. Single degree-of-freedom contrast analysis indicated no difference between the two P sources. Mean grain yield averaged over fertilizer P sources was significantly ($P < 0.05$) greater following GM than following bare fallow. The PR presumably released adequate amounts of plant-available P under the acid-flooded soil conditions prevailing in the pots. De Swart and van Diest (1987) also observed that in acid soil, solubilization of Tilemsi PR proceeds rapidly enough to supply sufficient P to young *Pueraria javanica* plants.

Nitrogen concentration in the GM residues used in the experiment varied between 15.9 and 18.2 g kg^{-1} (data not shown). The effect of GM on rice yield was positive only after addition of P (Table 4). Incorporation of unfertilized GM residues gave grain yield comparable to that obtained in the control treatment (no P and no GM-N added). This implies that P was the limiting factor in the water-saturated soil condition prevailing in the

Table 4. Grain and total biomass yields of lowland rice as affected by P fertilization and green manuring (GM) with *Aeschynomene afraspera* under flooded conditions in the pot experiment.

	Grain yield		Total biomass	
P fertilizer sources	Without GM	With GM	Without GM	With GM
	g pot^{-1}			
No P fertilizer applied	9.3	12.0	20.9	24.3
Phosphate rock (PR)	14.7	20.0	28.3	41.4
Triple superphosphate (TSP)	16.2	28.4	33.7	56.9
Single degree-of-freedom contrast of means given above				
	F significance			
None vs. applied P (PR+TSP)	**		***	
TSP vs. PR	ns†		ns	
No-GM vs. unfertilized GM	ns		ns	
(TSP+GM) vs. TSP alone	*		*	
(PR+GM) vs. PR alone	ns		*	
GM main effect mean	10.1		19.9	
P main effect mean	15.6		30.3	
LSD$_{0.05}$ (GM main effects)	4.7		8.2	
LSD$_{0.05}$ (P main effects)	5.7		10.0	
LSD$_{0.05}$ (P × GM interaction)	ns		ns	

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† ns, not significant at the 0.05 probability level.

Table 5. Total N and P uptake of lowland rice in response to P fertilization and green manuring (GM) with *Aeschynomene afraspera* under flooded conditions in the pot experiment.

P fertilizer sources	N uptake Without GM	N uptake With GM	P uptake Without GM	P uptake With GM
	mg pot^{-1}			
No P fertilizer applied	**161**	**223**	**30**	**26**
Phosphate rock (PR)	**225**	**368**	**46**	**59**
Triple superphosphate (TSP)	**251**	**521**	**81**	**148**
Single degree-of-freedom contrast of means given above				
	F significance			
None vs. applied P (TSP+PR)	***		**	
TSP vs. PR	**		**	
No-GM vs. unfertilized GM	**ns†**		**ns**	
(TSP+GM) vs. TSP alone	***		**	
(PR+GM) vs. PR alone	**		**ns‡**	
GM main effect mean	**238**		**42**	
P main effect mean	**259**		**115**	
LSD$_{0.05}$ (GM main effects)	**45**		**22**	
LSD$_{0.05}$ (P main effects)	**56**		**27**	
LSD$_{0.05}$ (P × GM interaction)	**ns**		**ns**	

** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† ns, not significaznt at the 0.05 probability level.
‡ not significant at the 0.10 probability level.

Table 6. Effects of P fertilization and green manuring (GM) with *Aeschynomene afraspera* on soil P and N contents at rice maturity under flooded conditions in the pot experiment.

Treatments	Soil N content	Soil Bray-1 P content
	%	mg kg^{-1} soil
GM alone	**0.11**	**1.64**
PR (phosphate rock) alone	**0.09**	**1.70**
GM + PR	**0.11**	**2.08**
TSP (triple superphosphate) alone	**0.09**	**2.98**
GM + TSP	**0.11**	**4.63**
Control (no P and no-GM)	**0.08**	**1.62**
Single degree-of-freedom contrast of means given above		
	F significance	
None vs. applied P (TSP+PR)	**ns†**	***
TSP vs. PR	**ns**	***
No-GM vs. unfertilized GM	**ns**	**ns**
(TSP+GM) vs. TSP	**ns**	**
(PR+GM) vs. PR	**ns**	*
GM main effect mean	**0.035**	**1.25**
P main effect mean	**0.007**	**2.90**
LSD$_{0.05}$ (GM main effects)	**0.015**	**na‡**
LSD$_{0.05}$ (P main effects)	**ns**	**na**
LSD$_{0.05}$ (P × GM interaction)	**ns**	**0.60**

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† ns, not significant at the 0.05 probability level.
‡ na, not applicable (P × GM is significant).

pots. Thus, the potential of GM to supply N to the subsequent rice crop is fully realized only when P, regardless of the P source, is applied. This finding may have an important practical value in P-deficient acidic soils of the West African humid forest zone when an attempt is made to alleviate soil N deficiencies through GM.

Rice accumulated comparable amounts of N from either TSP or PR-treated plots without GM (Table 5). With the GM, PR increased N uptake 143 mg N pot^{-1} above sole PR treatment, whereas TSP increased N uptake 270 mg N pot^{-1} above the sole TSP treatment. Incorporation of unfertilized GM improved rice N uptake by only 62 mg pot^{-1} (not significantly different from no P and no GM control).

Rice P uptake followed the same pattern as N uptake. Contrasts indicated that rice P uptake with TSP + GM was significantly greater than with TSP alone. Inclusion of GM into the lowland rice–GM rotation improved phosphate nutrition of rice in the PR + GM treatment by as much as 16.9 mg P pot^{-1} (Table 4). These results agree with observations by Kamh et al. (1999) that in pot experiments with an acid P-deficient soil, P nutrition of wheat was significantly improved by a highly P-efficient white lupin (*Lupinus albus* L.) legume grown in mixed culture. However, beyond the improved P nutrition of rice, presumably as a result of additional mobilization of PR by the pre-rice legume, a positive rotational effect of GM on soil properties in the manured treatments cannot be ruled out.

Applying PR to GM also increased extractable Bray-l P in the soil 1.2-fold compared with PR applied alone (Table 6). In the case of TSP, this enhancement of soil P was even more ($P < 0.01$). Also, soil N content showed a significant effect of GM but no significant interaction with P application. The stem-nodulating legume *A. afraspera* thus improved the efficiency of the applied PR, as indicated by the enhanced soil extractable Bray-l P and improved P nutrition of the subsequent rice crop grown in the PR + GM plots (Tables 5 and 6). This mechanism would explain the 22% increase in plant-available P brought into solution when PR was combined with the preceding legume compared with sole application of PR.

In the field, rice yields were 1 t ha^{-1} (PR) and 2 t ha^{-1} (TSP) more than the no-P control without GM, but when averaged across GM treatments, P main-effect rice yields were not significant (Table 7). A combination

Table 7. Grain and total biomass yields as affected by P fertilization and green manuring (GM) with *Aeschynomene afraspera* under lowland field conditions in Danané.†

P fertlizer sources	Grain yield Without GM	Grain yield With GM	Total biomass Without GM	Total biomass With GM
	kg ha^{-1}			
No P fertilizer applied	**2555**	**4397**	**4461**	**7412**
Phosphate rock (PR)	**3551**	**3957**	**5831**	**6046**
Triple superphosphate (TSP)	**4570**	**4608**	**7440**	**7685**
N–P–K (80:60:100)	**4197**		**7514**	
Single degree-of-freedom contrast of means given above				
	F significance			
None vs. applied P (TSP+PR)	**ns‡**		**ns**	
TSP vs. PR	**ns**		**ns**	
(TSP+GM) vs. TSP alone	**ns**		**ns**	
(PR+GM) vs. PR alone	**ns**		**ns**	
(TSP+GM) vs. N–P–K (80:60:100)	**ns**		**ns**	
(PR+GM) vs. N–P–K (80:60:100)	**ns**		**ns**	
GM main effect mean	**1143**		**1602**	
P main effect mean	**1778**		**3079**	
LSD$_{0.05}$ (GM main effects)	**ns**		**ns**	
LSD$_{0.05}$ (P main effects)	**ns**		**ns**	
LSD$_{0.05}$ (P × GM interaction)	**ns**		**ns**	

† ANOVA was performed excluding N–P–K treatments to avoid that their effects bias the significance of P and GM main effects on grain and total biomass yields. On the other hand, single degree-of-freedom contrasts analysis included N–P–K treatments.
‡ ns, not significant at the 0.05 probability level.

of GM with P fertilizers increased grain yield more than the sole application of P, but treatment contrast analysis showed the increase to be nonsignificant. The application of the imported inorganic fertilizer (N–P–K) at the recommended rate did not prove superior to combined PR + GM or TSP + GM. Neither the rice yields nor the rice N uptake was significantly different when P was applied to GM or directly to rice, and P uptake was significantly affected by P fertilizer only (Table 8).

The general absence of added benefits on rice performance in the field experiment may be explained by several mechanisms. The P-fertilized GM residues may have triggered release of nutrients too quickly. Previous studies (Medhi and De Datta, 1997a) demonstrated a rapid release of nutrients, especially N within 2 to 3 wk after GM incorporation in tropical flooded soils. They stressed the need for immediate transplanting after GM incorporation to maximize the subsequent rice crop yields. In the present study, the 14-d delay in rice transplanting in the lowland field coupled with large applications of N-rich GM residues in the PR + GM plots (220 kg N ha^{-1}) might have resulted in asynchrony between GM nutrient release and the actual rice crop nutrient requirement. This may be the reason why rice, grown in rotation with the unfertilized GM, which contributed lower N (71 kg N ha^{-1}), gave comparable or slightly higher yields than did either PR + GM, TSP + GM, or the inorganic urea-N treatments. The 14-d interval between GM incorporation and rice transplanting in the lowland was designed for complete dissipation of the toxic products of the decomposing legume residues. Herrera et al. (1997) suggested a delay of 5 to 7 d, which proved insufficient under pot conditions reported above.

Table 8. Total P and N uptake of rice as affected by P fertilization and green manuring (GM) with *Aeschynomene afraspera* under lowland field conditions in Danané.†

	N uptake		P uptake	
P fertilizer sources	Without GM	With GM	Without GM	With GM
	kg ha^{-1}			
No P fertilizer applied	40.7	68.2	3.2	7.0
Phosphate rock (PR)	47.2	59.1	8.3	9.5
Triple superphosphate (TSP)	64.0	72.7	13.8	14.3
N–P–K (80:60:100)	63.8		11.7	
Single degree-of-freedom contrast of means given above				
	F significance			
None vs. applied P (TSP+PR)	ns‡		***	
TSP vs. PR	ns		***	
(TSP+GM) vs. TSP alone	ns		ns	
(PR+GM) vs. PR alone	ns		ns	
(TSP+GM) vs. N–P–K (80:60:100)	ns		ns	
(PR+GM) vs. N–P–K (80:60:100)	ns		ns	
GM main effect mean	24.1		2.8	
P main effect mean	25.4		11.9	
LSD$_{0.05}$ (GM main effects)	12.8		ns	
LSD$_{0.05}$ (P main effects)	ns		2.7	
LSD$_{0.05}$ (P × GM interaction)	ns		ns	

*** Significant at the 0.001 probability level.

† ANOVA was performed excluding N–P–K treatments to avoid that their effects bias the significance of P and GM main effects on total N and P uptake. On the other hand, single degree-of-freedom contrasts analysis included N–P–K treatments.

‡ ns, not significant at the 0.05 probability level.

Rice grown in rotation with *A. afraspera* in the field recovered as much as 41% GM-N from the unfertilized legume crop (Table 8). This proportion however, was significantly ($p < 0.05$) lower (29%) for the inorganic urea-N fertilizer. Higher recoveries of 30 to 50% at GM-N levels of 60 to 90 kg ha^{-1} have been reported in lowland soils (Diekmann et al., 1993). The equation used in our study to compute legume N recovery is not strictly valid because the control is rather artificial. These plots do not have nutrients extracted by a GM crop. A better method to calculate legume N recovery is to compare plots where GM has been removed with plots where GM has been incorporated. The former treatment (i.e., GM removed) was not tested in the present study, which may underestimate the legume N recovery obtained in our study. The differences in GM-N recoveries may also be due to the differences in the amount applied and the quality (e.g., C/N ratio) of incorporated GM residues.

Vulnerability of urea-N to volatilization loss has been also documented (Medhi and De Datta, 1997a) and might explain the higher apparent N recovery in the unfertilized GM than in the urea fertilizer treatment in the lowland field.

Any positive effect of additional P brought about by the mobilization of PR by the pre-rice legume would likely be lost by the poor synchronization of GM-N release and rice N uptake due to the large GM-N application (220 kg N ha^{-1}). Medhi and De Datta (1997b) reported added benefit on rice yields when GM at a rate of 80 kg N ha^{-1} was combined with PR compared with sole application of PR. Further, additional P in the PR + GM might have also been released from microbial P in soil (Bhardwaj and Datt, 1995).

CONCLUSION

In both the pot and field experiments, significant responses of legume performance (biomass, nodulation, N accumulation, and %Ndfa) to PR application were observed.

The results confirmed the GM potential of *A. afraspera* grown as a short-duration pre-rice GM in acid wetland soils of West Africa but only if fertilized with P. In this regard, Tilemsi (Mali) PR appears to be as efficient a P source as imported water-soluble TSP. The synergy between PR application and legume BNF enhanced soil P availability, rice P uptake, and grain yield of lowland rice grown in rotation with a GM. Hence, application of PR is likely to drive the N and P cycles in legume-based rice production systems. However, further confirmation of these conclusions from field sites is necessary.

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