Influence of rock phosphate on growth and biomass production of pigeonpea (*Cajanus cajan* (l.) millsp.) in different farmers' fields and its residual effect on maize in the derived savanna of Bénin

K. Aihou[1], N. Sanginga[2], B. Vanlauwe[2], J. Diels[3], R. Merckx[4] and O. Van Cleemput[5]

Abstract

One of the options to alleviate soil fertility constraints for sustainable agriculture in West African's savanna is to develop soil nutrient management technologies from an adequate supply and feasible share of organic and inorganic fertilizers. The impact of combined application of organic input (fresh *Cajanus cajan* pruning residues) and inorganic fertilizers (Togo phosphate rock) on maize performance was investigated on 2 sites (Zouzouvou and Eglimé) in the derived savanna benchmark of Bénin, where 2 main geological units can be distinguished, giving rise to distinct soil associations. One (Zouzouvou) is a Rhodic Ferralsol and one (Eglimé) a complex pattern of Acrisols, Lixisols, Luvisols and Leptosols with inclusions of Vertisols and Cambisols. The application of rock phosphate increased the shoot dry weight of *Cajanus cajan* by 29 to 145 % in 5 out of 12 farmers' fields at Zouzouvou and 17 to 53 % in 3 out of 12 farmers' fields at Eglimé. The dry matter of the leaves increased by 13 to 227 % in 6 out of 12 farmers' fields at Zouzouvou, while at Eglimé, in 6 out of 11 fields, it increased by 7 to 31 %. A significant increase was obtained with symbiotic parameters of *Cajanus cajan* such as % AMF, nodule number and nodule fresh weight with rock phosphate application, at both places. Only 40 % of farmers' fields at Zouzouvou had a subsequent maize grain increase (by 17 to 90 %) as a result of the residual effect of combining organic (*Cajanus cajan*) and inorganic input. There was no effect at Eglimé.

Key words: Organic input, inorganic fertilizer, legume, biomass production, subsequent crop, AMF, N fixation, cropping systems.

Influence du phosphate de roche sur la croissance et la production de biomasse du pois d'angole (*Cajanus cajan* (l.) millsp.) dans différents champs de paysans et son effet résiduel sur le maïs dans la savane dérivée du Bénin

Résumé

Une des options pour lever les contraintes de la fertilité des sols pour l'agriculture durable dans la savane en Afrique occidentale est de développer la gestion des nutriments du sol sur la base des technologies d'approvisionnement adéquat et d'apport réalisable d'engrais organiques et inorganiques. L'impact de l'application combinée d'intrants organiques (émondage de résidus frais de *Cajanus cajan*) et des engrais inorganiques (phosphate de roche du Togo) sur la performance du maïs a été étudié sur 2 sites (Zouzouvou et Eglimé). Ces 2 sites servent de repère dans la savane dérivée du Bénin, où 2 unités géologiques principales peuvent être distinguées, donnant lieu à des associations de sol distinctes. Un (Zouzouvou) est un Rhodic Ferralsol et un (Eglimé) un modèle complexe d'Acrisols, de Lixisols, de Luvisols et de Leptosols avec les inclusions de Vertisols et Cambisols. L'application de phosphate de roche a augmenté le poids sec des pousses de *Cajanus cajan* de 29 à 145 % dans 5 des champs de 12 paysans à Zouzouvou et 17 à 53 % dans 3 des champs de 12 paysans à Eglimé. La matière sèche des feuilles est passé de 13 à 227 % dans 6 des champs de 12 paysans à Zouzouvou, tandis qu'à Eglimé,

[1] Institut National des Recherches AGRICOles du Bénin, B.P. 884 RP, Cotonou, Bénin, E-mail : k_aihou@yahoo.fr

[2] Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture (CIAT), PO BOX 30677, Nairobi, Kenya N.sanginga@cgiar.org; B.vanlauwe@cgiar.org.

[3] International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria J.diels@cgiar.org

[4] Laboratory of Soil Fertility and Soil Biology, Faculty of Agricultural and Applied Biological Sciences, K.U. Leuven, Kasteelpark, Arenberg 20, 3001 Heverlee, Belgium

[5] Laboratory of Physical Chemistry, Faculty of Agricultural and Applied Biological Sciences, Gent University, Coupure 653, B-9000 Gent, Belgium. Oswaldvancleemput@ugent.be;

dans 6 des 11 champs, elle est passée de 7 à 31 %. Une augmentation significative a été obtenue avec les paramètres symbiotiques de *Cajanus cajan* comme le pourcentage de AMF, le nombre de nodules et le poids frais des nodules avec l'application de phosphate de roche sur les deux sites. Seulement 40 % des champs des paysans à Zouzouvou avaient une augmentation ultérieure de grains de maïs de 17 à 90 % suite à l'effet résiduel de la combinaison des apports d'intrants organiques (*Cajanus cajan*) et inorganique. Il n'y avait aucun effet à Eglimé.

Mots clés : Intrant organique, engrais inorganique, légumineuses, production de biomasse, récolte ultérieure, AMF, fixation de N, systèmes de cultures.

Introduction

In humid tropical Africa, soil fertility decline is the major biophysical constraint to a sustained use of land. In that ecological region, P and N have been identified as the most limiting plant nutrients (Van der Pol *et al.*, 1993, Tchienkoua *et al.*, 2003). Unlike N, which can be replenished biologically through atmospheric fixation, P is the result of soil's inherent properties and management practices. In southern Bénin, the high population density (130-220 inhabitants.km^{-2}) has resulted in the breakdown of the traditional land use system, the reduction or elimination of traditional fallow periods and the expansion of agriculture into marginal areas have led to declining soil organic matter contents and widespread depletion of soil nutrients. Consequently, crops yields are low, in fact decreasing in many areas, and the long-term sustainability of major farming systems is at risk (Schulz *et al.*, 2003). Without input by fertilizers or others sources of plant nutrients, nutrient budgets are negative, resulting in soil fertility depletion (van der Pol *et al.*, 1993).

Technological solutions based on the use of chemical fertilizers are available and have been applied in some areas. In regions with a high population density coupled with land tenure, such as southern Bénin in the derived savanna where land is scarce, inorganic inputs are needed in adequate amounts to increase crop yields to the levels required to support the growing demand. The results of a recent on-farm survey showed that more than 90 % of the farmers in some villages (Zouzouvou and Eglimé) in southern Bénin used chemical fertilizers. However, up to 81 % of the maize fields received less than half of the recommended rates because of the high fertilizer cost following the removal of subsidies and due to inefficient marketing (Houngnandan *et al.*, 2000). Supplementation of fertilizer inputs with organic matter therefore seems both an environmentally as well as an economically sound strategy.

Cultivation of leguminous crops in rotation with other food crops has been recognized as one of the cost-effective ways by which farmers can maintain soil fertility. The legumes meet some of their N requirement through N_2-fixation, thus sparing some of the soil N to the subsequent crops in addition to the residual N that accrues, due to nodules, senescence and fallen leaves (Osunde *et al.*, 2003). However, the amount of soil nutrients supplied by those systems is by themselves not sufficient to solve the crop productivity problem in a sustainable manner because of sustained nutrient export in harvested products (Sanginga *et al.*, 1997). To arrest and reverse this process of soil degradation, integrated soil fertility management strategies are needed that combine the use of inorganic and organic sources so as to compensate for nutrient uptake in the short term and to increase soil organic matter levels and improve soil physical and chemical properties in the long term.

Judicious combinations of inorganic and organic inputs are therefore essential to raise and maintain crop yields in many areas. However, a previous study (Vanlauwe *et al.*, 2001; 2002) has shown that *in situ* production of sufficient organic inputs for subsequent use to improve soil fertility is constrained. As organic inputs are often scarcer than inorganic fertilizers, it is necessary to develop cropping systems in which organic matter is produced on part of the cropland, separated in time or space. As such, the major challenge resides in producing enough organic matter *in situ* to maintain soil organic matter contents while producing an economic product. The longer growing season in the DS zone allows the growth of at least two crops per year and to produce more organic matter. Here, the strategy is to follow the maize and other food crops of the first season with long-duration legumes, which take full benefit of the residual soil moisture and preferably maintain an effective mulch until the end of the following dry season, and offer some kind of immediate benefit to the farmer (grains or considerable labor saving because of weed suppression). Possible legumes to consider are soybean, long-duration cowpea, long-duration groundnut, *Cajanus cajan* and other legume shrubs.

Phosphorus is critically needed to improve soil fertility for sustainable crop production in large areas of developing countries. In recent years rock phosphate (RP) for direct application has been tested in tropical acid soils as a potential alternative to conventional water-soluble P fertilizers like single super phosphate (SSP) and triple super phosphate (TSP) (Chien and Menon, 1995). Tropical soils are often low in available P, and therefore require substantial inputs of P fertilizers for optimum plant growth and production of food. Due to economic considerations, the cost of applying imported or locally produced water-soluble P fertilizers is often more expensive than utilizing indigenous rock phosphate (Kato *et al.*, 1995). It is therefore necessary to evaluate locally available P sources that are affordable and agronomically effective in enhancing crop production. The direct application of indigenous rock phosphate as a source of P is viewed as an attractive option for building P capital, i.e. the stock of soil P that gradually crop yield increases after tree fallow have been reported. Fertilization with rock phosphate is often needed to improve the N benefits from tree fallows (Graham and Vance, 2003).

Cajanus cajan, a legume crop cultivated as intercrop or in rotation with cereals or other crop species, is a multipurpose shrub and could be used as source of organic matter in combination with rock phosphate to improve soil fertility and the subsequent crop yield. The purpose of this study was to assess the potential of *Cajanus cajan* to enhance the availability of P from low reactivity rock phosphate and to evaluate maize grain yield with a range of soils on farm conditions supplies plant available P to crops for about 5-10 years (Sanchez and Palm, 1996).

Material and methods

Site description

The experiment was conducted on 24 farmers' fields in the derived savanna (DS) benchmark area of the 'Ecoregional Programme for the Humid and Sub-Humid Tropics in Sub-Saharan Africa' (EPHTA, 1996). The DS ecoregion is defined as the area with a length of growing period (LGP) between 210 and 270 days. Two research locations were chosen, Zouzouvou and Eglimé, to represent the main geological units in the benchmark area.

The first location, Zouzouvou (1°41'E; 6°53'N), is represented by the 'terre de barre' soils, which is a red soil, characterized by a clay content (kaolinitic) increasing with depth. The soils are formed on Oligocene/sea-terrace (parental material is sedimentary origin-continental terminal). They are highly weathered, up to 10 m deep and well drained, rich in sesquioxide (mainly kaolinitic), and characterized by small textural changes within the soil profile. The soil of the location is sandy over sandy clay loam, and classified as a Rhodic Ferralsol (FAO, 1991).

The second location, Eglimé (1°40'E; 7°05'N), is located in the 'savane arborée'. Eglimé soils are Basement Complex soils, showing marked soil variability over short distances. These soils consist mainly of granite and gneiss, which gave rise to a complex association of Acrisols, Lixisols, Luvisols and Leptosols with inclusions of

Vertisols and Cambisols (Faure and Volkoff, 1998). In the basement rocks area, the saprolite is often found at shallow depth and the clay fraction contains kaolinite and swelling (2:1) clays in varying proportions depending on parent rock and drainage conditions (Volkoff, 1976; Volkoff and William, 1976).

Soil sampling

In 1998, in each of 24 farmers' fields, trials were laid out containing three plots of 8 m by 8 m. Before implementation of the field trials, soil was sampled from each plot at 0-10 cm and 10-30 cm (one diagonal across the plots, 10 cores per plot). Afterwards, equal amounts of soil sampled from each of the 8 plots in a field were mixed to form one composite sample per field. All samples were air-dried and sieved to pass 4 mm. Selected physical and chemical characteristics were measured according to IITA analytical procedures (IITA, 1982) and are shown in Table 1.

Table 1. Means of selected physical and chemical soil parameters from 12 farmers' fields at Zouzouvou and 12 farmers' fields at Eglimé

Parameters	Farmers' fields at Zouzouvou		Farmers' fields at Eglimé	
	0-10 cm	10-30 cm	0-10 cm	10-30 cm
Sand ($g.kg^{-1}$)	830 (679-884)	780 (610-854)	740 (602-853)	750 (582-882)
Silt ($g.kg^{-1}$)	60 (27-119)	49 (18-99)	150 (90-196)	137 (86-224)
Clay ($g.kg^{-1}$)	110 (290-229)	171 (113-291)	110 (28-221)	113 (30-229)
Total C (%)	0.79 (0.57-1.05)	0.54 (0.38-0.75)	1.06 (0.67-1.93)	0.70 (0.45-1.31)
Total N (%)	0.06 (0.04-0.09)	0.05 (0.03-0.07)	0.08 (0.05-0.13)	0.05 (0.03-0.09)
P Olsen ($mg.kg^{-1}$)	8.01 (1.38-22.21)	4.20 (1.40-11.20)	13.30 (8.65-22.21)	4.7 (2.10-7.10)
Ca ($cmol.kg^{-1}$)	2.80 (1.70-4.70)	2.35 (1.20-4.00)	6.78 (2.60-14.10)	5.76 (2.00-13.20)
CEC ($cmol.kg^{-1}$)	4.02 (2.60-6.90)	3.27 (1.83-5.80)	8.99 (3.5-18.30)	7.61 (2.70-17.00)
ECEC ($cmol.kg^{-1}$)	4.61 (3.40-6.80)	3.80 (2.60-6.00)	9.38 (3.80-18.40)	8.18 (3.70-17.20)
pH (H_2O)	6.70 (6.17-7.11)	6.69 (6.29-7.14)	6.69 (5.95-7.21)	6.56 (6.15-6.94)
pH (Kcl)	5.14 (4.21-6.39)	4.86 (4.07-6.14)	5.34 (4.18-6.38)	4.81 (3.00-22.90)

Values between brackets are ranges (minimum and maximum)

Some differences in physical properties were observed between the two locations. The Zouzouvou soils had more sand than the Eglimé soils. The average percentage of silt was higher in Eglimé than in Zouzouvou. Pronounced differences in chemical properties were observed between the two locations. Total carbon, total nitrogen, Olsen P, calcium and ECEC were higher at Eglimé than at Zouzouvou. However, an importantly high variability was noticed among these characteristics, e.g., Olsen P in the top layer ranged from 1.38 to 22.21 $mg.kg^{-1}$ of soil at Zouzouvou and from 8.65 to 22.21 $mg.kg^{-1}$ soil at Eglimé. A similar variation was observed for the other soil parameters. Values of these soil properties were generally higher for the 0-10 cm than for the 10–30 cm soil layer (Table 1). All data showed an extremely high variability among the different fields.

Treatments

The experimental design was a researcher-managed replicated trial in 24 farmers' fields (12 in Zouzouvou and 12 in Eglimé). In each field, three treatments were established: (1) the control; (2) was planted by the local perennial *Cajanus cajan* without application of Togo rock phosphate and (3) was planted by the local perennial *Cajanus cajan* with application of Togo rock phosphate (90 kg P_2O_5 ha^{-1}). The control was treated similarly as a farmer's field without *Cajanus cajan* fallow and without rock phosphate application.

In April 1998, the local perennial *Cajanus cajan* was planted in rows: 1.6 m between the rows and 0.15 m within the rows. In February 1999, *Cajanus cajan* pods were harvested. However, they contained a lot of empty pods because of the attack by insects and diseases. The *Cajanus cajan* biomass was measured and the leaves were applied to the soil surface in April 1999, just before maize planting. At that time, the farmers at Zouzouvou and at Eglimé for social reasons destroyed respectively two fields and one field, ending up with 10 fields in Zouzouvou and 11 in Eglimé. In 1999, no mineral N input was applied to maize. At harvest, maize grain and stover yield was measured.

Plant sampling and harvesting of Cajanus cajan

Plant sampling was done across location in each field and on the two treatments where *Cajanus cajan* was planted. For each field, at 16 weeks after planting, three plants of *Cajanus cajan* per treatment were collected randomly for the estimation of N fixation, based on the sap solute procedure, as developed by Peoples *et al.* (1989). The roots of three plants of *Cajanus cajan* were collected in a plastic bag and placed on ice in a cooler for transportation to the laboratory where the roots were washed on a 1-mm mesh sieve and stored at 4 °C. The nodules were removed, counted, and weighed. Later, the roots were cut into pieces of 10 to 20 mm length and 0.25 g was cleaned in KOH and stained with trypan blue in lactoglycerin at room temperature (Phillips and Hayman, 1970). The stained roots were examined for colonization by arbuscular mycorrhizal fungi (AMF) by the gridline intersect method using a dissecting microscope at x 100 (Giovanneti and Moose, 1980).

Results

Shoot dry weight of Cajanus cajan, 16 weeks after planting

With rock phosphate application, the mean shoot dry weight, 16 weeks after planting was lower at both locations compared to the mean shoot dry weight without rock phosphate application. It ranged between 48 to 1037 g per three plants at Zouzouvou and between 172 to 1454 g per three plants at Eglimé (Table 2). At Zouzouvou, the shoot dry weight was on average significantly related to soil C ($r=0.54$, $P<0.01$, $n=12$), soil P (0.48, $P<0.01$, $n=12$), and pH ($r=0.46$, $P<0.05$, $n=12$). At Eglime, the shoot dry weight (g per 3 plants) was not related to any soil characteristic (Table 5).

At Zouzouvou, considering the response to P application, two groups of farmers' fields could be identified when looking at the shoot dry weight production 16 weeks after planting. In one group, for 5 out of 12 farmers' fields, the shoot dry weight increased by 29 to 145 % with rock phosphate application compared to the control. In the second group, for 7 out 12 farmers' fields, the shoot dry weight was lower than the control. At Eglimé, also two groups of farmers' fields were identified. In one group, for 3 out of 12 farmers' fields, the shoot dry weight increased by 17 to 53 % with rock phosphate application compared to the controls. While in the second group, for 9 out of 12 farmers' fields, the shoot dry weight was lower than the control or did not show a significant increase (Table 5). As such, it was observed that more negative than positive responses were found to application of rock phosphate.

Symbiotic parameters of Cajanus cajan, 16 weeks after planting

The percentage N fixed varied between 41 and 50% per three plants at Zouzouvou, while at Eglimé, it varied between 35 and 46 % per three plants. In both locations, there was no significant effect of P application on the % N fixed (Table 2). The arbuscular mycorrhiza fungi (% AMF) varied between 10 to 39 % at both locations and with P application. The mean AMF at Zouzouvou increased by 53 % compared to the control without P application, while at Eglimé, it increased by 20 % (Table 2). At Zouzouvou, the number of nodules per three plants varied between 9 and 39 in both locations and was on average positively related to nodule fresh weight ($r=0.69$, $P<0.01$, $n=12$)

and inversely related to soil C (r=-0.42, P<0.05, n=12). At Eglimé, on the other hand, the number of nodules per three plants was positively related to only the nodule fresh weight (r=0.97, P<0.01, n=12). The nodule fresh weight (g per three plants) varied between 0.0 to 0.3 g per three plants in both locations and with P application. A significant increase of symbiotic parameters (arbuscular mycorrhizal fungi, number of nodules, nodules fresh weight was observed upon P application.

Table 2. Means shoot dry weight (sdwt), percentage nitrogen fixed (% NF), percentage arbuscular mycorrhizal fungi (% AMF), nodule number (ndn0) and nodule fresh weight (ndfw) of *Cajanus cajan* (L.) Millsp. 16 weeks after planting as affected by the addition of rock phosphate at 0 kg P2O5 ha-1 and 90 kg P2O5 ha-1 in 12 farmers' fields at Zouzouvou and 12 at Eglimé

Parameters	Farmers' fields at Zouzouvou				Farmers' fields at Eglimé			
	0 kg P_2O_5 ha^{-1}		90 kg P_2O_5 ha^{-1}		0 kg P_2O_5 ha^{-1}		90 kg P_2O_5 ha^{-1}	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
sdwt (g/3 plants)	427 (125-633)	176	384 (48-1037)	337	723 (172-1442)	339	663 (247-1454)	357
% NF (/3 plants)	46 (43-50)	2.85	45 (41-48)	2.12	43 (35-46)	3.02	42 (38-46)	3.08
% AMF (/3 plants)	17 (10-25)	4.5	26 (15-34)	6.42	25 (17-36)	5.90	30 (20-39)	6.97
ndn0 (/3 plants)	16 (11-24)	4.10	25 (17-34)	6.52	20 (9-25)	4.52	31 (22-39)	6.40
ndfw (g/3 plants)	0.08 (0.2-0.3)	0.09	0.13 (0.0-0.3)	0.08	0.09 (0.0-0.1)	0.04	0.20 (0.1-0.3)	0.08

Values between brackets are ranges (minimum and maximum) **SD**: Standard Deviation

Total dry matter biomass of Cajanus cajan after one year of fallow

At Zouzouvou, the mean dry matter of the leaves increased by 18 % with rock phosphate application. It ranged between 2.1 to 9.1 t ha^{-1}. While at Eglimé, it increased by only 2 %. It ranged between 3.7 to 8.5 t ha^{-1}. The dry matter of the leaves increased by 13 to 227 % in 6 out of 10 farmers' fields at Zouzouvou with rock phosphate application. At Eglimé, the dry matter of the leaves increased by 7 to 31 % in 6 out of 11 fields. The dry matter mean of the wood at Zouzouvou increased by 17 %, while at Eglimé, it decreased by 6 % with the rock phosphate application. It ranged between 0.7 to 6.9 t ha^{-1} at Zouzouvou and between 2.5 to 9.1 t ha^{-1} at Eglimé. The mean total dry matter increased by 17 % with the rock phosphate application. While at Eglimé, it decreased by 2 % (Table 3).

Table 3. Mean of dry matter of the leaves (dml), dry matter of the wood (dmw), total dry matter biomass (tdmb) (t ha-1) of Cajanus cajan (L.) Millsp. after one year of fallow as affected by the addition of rock phosphate at 0 kg P2O5 ha-1 and 90 kg P2O5 ha-1 in 10 farmers' fields at Zouzouvou and 11 at Eglimé

Parameters	Farmers' fields at Zouzouvou				Farmers' fields at Eglimé			
	0 kg P_2O_5 ha^{-1}		90 kg P_2O_5 ha^{-1}		0 kg P_2O_5 ha^{-1}		90 kg P_2O_5 ha^{-1}	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
dml	4.88 (2.3-7.9)	1.99	5.74 (2.1-9.1)	2.14	5.79 (3.9-8.5)	1.55	5.89 (3.7-7.11)	1.92
dmw	3.11 (0.7-6.9)	1.82	3.63 (1.1-5.8)	1.51	4.43 (4.3-9.1)	1.96	4.17 (2.5-6.5)	1.28
tdmb	7.99 (3.2-13.4)	3.58	9.37 (3.2-14.9)	3.42	10.22 (6.7-17.5)	3.36	10.06 (7.0-17.2)	3.21

Values between brackets are ranges (minimum and maximum) **SD**: Standard Deviation

On average the dry matter of the leaves was more related to the dry matter of the wood (r=0.75, P<0.01, n=11), the dry total dry matter biomass (r=0.95, P<0.01, n=11); while at Eglimé, it was related to the dry matter of the wood (r=0.72, P<0.01, n=11) and the total dry matter of the biomass (r=0.93, P<0.01, n=11). At Zouzouvou, the total dry matter of the biomass was related to the dry matter of the leaves (r=0.95, P<0.01, n=10), the dry matter of the wood (r=0.92, P<0.01, n=10), the soil C (r=0.51, P<0.05, n=10) and soil P (r=0.50, P<0.05, n=10). While at Eglimé, it was more related to the dry matter of the leaves (r=0.93, P<0.01, n=10) and wood (r=0.92, P<0.01, n=10) (Table 6).

Maize dry matter yield

At Zouzouvou, the mean maize grain yield obtained from the treatment of residual fallow of *Cajanus cajan* without rock phosphate was higher than the control (88 %) and the treatment of residual fallow of *Cajanus cajan* with rock phosphate (3 %). A similar trend was observed with the stover yield. The maize grain yield ranged between 34 to 2565 kg ha^{-1}, while the stover yield ranged between 566 to 2891 kg ha^{-1} (Table 4).

At Eglimé, a similar observation was made. The treatment of residual fallow of *Cajanus cajan* without rock phosphate was higher than the control (97 %) and the treatment of residual fallow of Cajanus cajan with rock phosphate (21 %). The maize grain yield ranged between 238 to 2391 kg ha^{-1}, while the stover yield ranged between 712 to 3853 kg ha^{-1}. A very large variability in farmers' fields was observed (Table 4). The residual effect of rock phosphate combined with *Cajanus cajan* biomass produced in situ, did not affect the maize grain yield, except in five of the 10 fields at Zouzouvou, where the maize grain yield increased by 17 to 90 %. At Eglimé, in only two of the 11 fields hardly any effect of rock phosphate was observed.

Table 4. Mean maize grain and stover dry matter yield (kg ha-1) as affected by the combined residual effects of dry matter leaves of *Cajanus cajan* L. Millsp. and addition of rock phosphate at 0 and 90 kg P2O5 kg ha-1 (rCcRP) in 12 farmers' fields at Zouzouvou and 12 at Eglimé

Treatments	Farmers' fields at Zouzouvou				Farmers' fields at Eglimé			
	Grain yield	SE	Stover yield	SE	Grain yield	SE	Stover yield	SE
Control	750 (34-1990)	205.65	1449 (566-1969)	152.51	756 (238-2035)	198.34	1431 (712-2462)	237.43
rCcRP0	1412 (191-2565)	205.65	1980 (867-2891)	152.51	1487 (311-2271)	193.26	2179 (811-3853)	237.43
rCcRP90	1374 (172-2405)	205.65	1995 (1238-2476)	152.51	1233 (259-2391)	193.26	2015 (828-3183)	237.43

Values between brackets are ranges (minimum and maximum) SE: Standard error

Table 6. Correlation coefficient between dry matter leaves (dml), dry matter wood (dmw), total dry matter biomass (tdmb) and selected soils characteristics (0-10 cm) with Cajanus cajan L. Millsp. grown after one year of fallow in 10 farmers' fields at Zouzouvou and 11 at Eglimé

Locations	Farmers' fields at Zouzouvou						Farmers' fields at Eglimé					
Parameters	dml	dmw	tdmb	% C	P	pH_{water}	dml	dmw	tdmb	% C	P	pH_{water}
dml	-	0.75**	0.95**	ns	ns	ns	-	0.72**	0.93**	ns	ns	ns
dmw	0.75**	-	0.92**	0.60**	0.63**	ns	0.72**	-	0.92**	ns	ns	ns
tdmb	0.95**	0.92**	-	0.51*	0.50*	ns	0.93**	0.92**	-	ns	ns	ns
% C	ns	0.60**	0.51*	-	0.44*	0.44*	ns	ns	ns	-	ns	ns
P	ns	0.63**	0.50*	0.44*	-	ns	ns	ns	ns	ns	-	ns
pH_{water}	ns	ns	ns	0.44*	ns	-	ns	ns	ns	ns	ns	-

***** significant at p <0.05 ****** significant at p <0.01 **ns**: not significant

Table 5. Correlation coefficient between shoot dry weight (sdwt (g/3plants), percentage nitrogen fixed (% NF), percentage arbuscular mycorrhizal fungi (% AMF/3 plants), number of nodules (ndn0/3 plants), nodule fresh weight (ndfw/ (3 plants), and selected soil characteristics (0-10 cm) with Cajanus cajan L. Millsp. grown for 16 weeks after planting in 12 farmers' fields at Zouzouvou and 12 at Eglimé

Parameters	Farmers' fields at Zouzouvou								Farmers' fields at Eglimé							
	sdwt	% NF	% AMF	ndn0	ndfw	C	P	pH	sdwt	% NF	% AMF	ndn0	ndfw	C	P	pH
Sdwt	-	ns	ns	ns	ns	0.54**	0.48**	0.46*	-	ns	ns	ns	ns	ns	ns	ns
%NF	ns	-	ns	ns	ns	ns	-0.42*	ns	ns	-	ns	ns	ns	ns	ns	ns
%AMF	ns	ns	-	ns	ns	ns	ns	ns	ns	ns	-	ns	ns	ns	ns	ns
Ndn0	ns	ns	ns	-	0.69**	-0.42*	ns	ns	ns	ns	ns	-	0.97**	ns	ns	ns
Ndfw	ns	ns	ns	0.69**	-	-0.42*	ns	ns	ns	ns	ns	0.97**	-	ns	ns	ns
C	0.54**	ns	ns	-0.42*	-0.42*	-	0.44*	0.44*	ns	ns	ns	ns	ns	-	ns	ns
P	0.48**	-0.42*	ns	ns	ns	0.44*	-	ns	ns	ns	ns	ns	ns	ns	-	ns
pH	0.46**	ns	ns	ns	ns	0.44	ns	-	0.49*	ns	ns	ns	ns	ns	ns	-

***** significant at $p<0.05$ ****** significant at $p<0.01$ **ns**: nonsignificant

Discussion

Annual herbaceous or grain legumes are often advocated as sources of organic matter because of their potential ability to fix N_2 from the atmosphere, and because their biomass usually has a relatively high biochemical quality and consequently N release characteristics. Grain legumes, such as cowpea (*Vigna unguiculata*), are traditionally part of the existing cropping systems in the DS benchmark. Recently, farmers in southern Bénin have shown interest in *Cajanus cajan*, because of its economic importance and soil fertility restoration. *Cajanus cajan* produced between 2 t and 10 t biomass ha^{-1} and accumulated between 50 and 200 kg N ha^{-1} in the above-ground biomass. On average, 50 % of this N was observed to be derived from N_2 fixation, but this depended on the history and location of the farmers' fields. The observed very large variation in biomass production and N accumulation indicates that legumes do not perform equally well at all locations and should not be considered as a panacea to soil fertility regeneration. Houngnandan *et al.* (2000) also observed a large variation in the symbiotic characteristics and growth of Mucuna pruriens in the same villages.

In the DS benchmark area, legumes have been shown to significantly enhance the grain yield of a subsequent maize crop, compared to yields obtained in a maize-maize or natural fallow-maize cropping sequence. Versteeg *et al.* (1998) observed that maize yields after Mucuna were 33 % higher than yields after maize on 15 farmers' fields at the Adja Plateau in Southern Bénin. On severely depleted soils, yielding only 480 kg maize grains ha^{-1}, yields were increased to 1140 kg ha^{-1} on 19 farmers' fields on the Adja plateau. Increases in maize grain yield by 88 % at Zouzouvou and by 97 % at Eglimé, following Cajanus cajan, as compared to maize following maize have been observed in our studies. Diels *et al.* (1999) (Unpublished data) showed a 28 % increase in maize yield relative to the control after application of 90 kg N ha^{-1} as cowpea residue on the same farmers' field plots. Although maize following an herbaceous legume such as Mucuna can significantly benefit from the previous presence of this legume, the land is kept out of production for at least one growing season and in this case Mucuna is not an economical product such as edible grain. This is hardly acceptable by the farmers' community in a region where the population pressure on land is very high, as in the Mono province of the Bénin Republic. In contrast to Mucuna, *Cajanus cajan* is harvestable and has an economical value (grain). The cropping system in which it is grown allows the farmers to get the maximum benefits from their land.

However, because the N accumulation from N_2 fixation was rather low, it is unlikely that maize N nutrition can be completely covered by the preceding grain legume. Moreover, maize yields need to double in the next 20 years to at least 1500 kg ha^{-1} from the currently low yields of 750 kg ha^{-1} (Koudokpon *et al.,* 1994) to support the projected demand for cereals, as estimated by Pinstrup-Andersen *et al.* (1997). The additional application of mineral fertilizer will be essential to obtain yield increases of this order of magnitude in the absence of abundantly available land. Vissoh *et al.* (1998) similarly concluded that additions of external inputs are required to achieve sustainability of a Mucuna-maize rotation in the Mono province of the Bénin Republic. This is likely to be also the case for *Cajanus cajan* cropping systems.

Indigenous finely ground rock phosphate for direct application has been tested on some tropical soils because it requires only a low capital investment and low product costs. However, direct application of rock phosphate with low reactivity often does not give satisfactory results (Kpomblekou *et al*., 1991). The addition of rock phosphate led to significant site- and species-dependent changes in the tripartite legume-rhizobium-mycorrhizal fungi. Firstly, the addition of rock phosphate increased the AMF infection of the *Cajanus cajan* roots to a similar extent in all fields. As rock phosphate did not change the AMF infection rate of the maize roots, this increase must also be related to processes taking place in the rhizosphere of the studied legumes. Kamh *et al.* (1999) found that *Lupinus albus* depleted the stable P fraction in the rhizosphere where citrate and other organic anions were produced. Abbott *et al.* (1984) demonstrated that high levels of P fertilizer decreased the proportion of root length of subterranean clover colonized by AMF fungi. Bolan *et al.* (1984) observed that insufficient P could restrict mycorrhizal development. The availability of P derived from rock phosphate may be enhanced in the rhizosphere of legumes, thus stimulating the colonization of roots by AMF. Most likely, the release of P from rock phosphate was not substantial enough to suppress AMF colonization, contrary to what can be observed after addition of soluble P fertilizers.

Although addition of rock phosphate stimulated nodulation and/or AMF infection, this enhanced soil microbiological activity was not always translated in an improved N and P accumulation in the aboveground biomass. It is possible that root diseases, caused e.g. by nematodes, may have reduced biomass production in view of the negative correlation between biomass production and nematode content. Earlier work in the same benchmark zone revealed that herbaceous legumes were affected by 17 genera of fungi, 2 genera of bacteria and 21 genera of nematodes (S Killani, personal communication). In this work, Lablab roots contained significantly more nematodes compared to Mucuna roots, which was previously observed by Ibewiro (1998). Legumes are generally highly dependent on mycorrhiza for P uptake due to their coarse root systems. The inoculation of *Cajanus cajan* with arbuscular mycorrhizal fungi (AMF) combined with appropriate diseases control can thus improve and enhance the utilization of rock phosphate and maximize crop yields.

Conclusion

Studies of P cycling and availability have posed a challenge to agronomists for many years because P exists in soils and sediments in many different physico-chemical forms, and it is involved in myriads of biological processes. Long-term studies involving important factors like rock phosphate sources, soil properties, management practices, crop species, symbiotic parameters (AMF) and mainly rainfall pattern in farmers' fields could be done to design better technologies to overcome phosphorus deficiencies. However, for the short term, studies must be undertaken on the minimal amount of soluble P fertilizers (complementary effect or starter effect) to be combined with rock phosphate (investment and replenishment), symbiotic parameters and different *Cajanus cajan* species to improve *Cajanus cajan* biomass produced *in situ* and subsequent maize yield with minimal amount of N-fertilizers.

References

Abbott L.K., Robson A.D. and De Boer G., 1984. The effect of phosphorus on the formation of hyphae in soil by the vesicular arbuscular mycorrhizal fungus, Glomus fasciculatum. New Phytologist 97, 437–446.

Bolan N.S., Robson A.D. and Barrow N.J., 1984. Increasing phosphorus supply can increase the infection of plant roots by vesicular-arbuscular mycorrhizal fungi. Soil Biology & Biochemistry 16, 419-420.

Chien S.H. and Menon R.G., 1995. Factors affecting the agronomic effectiveness of phosphate rock for direct application. Fertilizer Research 41, 227-234.

EPHTA, 1996. Mechanism for sustainability and partnership in agriculture. International Institute of Tropical Agriculture, Ibadan, Nigeria, 29 pp.

FAO, 1991. World Soil Resources: An Explanatory Note on the FAO World Soil Resources Map at 1:25 000 000 Scale. Food and Agriculture Organization of the United Nations, Rome, Italy, pp 58.

Faure P. and Volkoff B., 1998. Some factors affecting regional differentiation of the Soils in the Republic of Bénin (West Africa). Catena, 32, 281–306.

Giovanneti M. and Mosse B., 1980. An evaluation of methods for measuring vesicular arbuscular infection in roots. New Phytology, 84, 489–500.

Graham P.H. and Vance C.P., 2003. Legumes: Importance and constraints to greater use. Plant Physiology, 131, 872-877.

Houngnandan P., Sanginga N., Woomer P., Vanlauwe B., and Van Cleemput O., 2000. *Mucuna pruriens* to symbiotic nitrogen fixation by rhizobia following inoculation in farmers' fields in the derived savanna of Bénin. Biology Fertility Soils 30, 558–565.

Ibewiro B., 1998. Nitrogen availability and soil organic matter transformations under herbaceous legume cover cropping in *Imperata cylindrica* infested tropical savanna. PhD Thesis, Katholieke Universiteit, Leuven, Belgium, 181 p.

IITA (International Institute of Tropical Agriculture), 1982. Automated and semi-automated methods for soil and plant analysis. Manual series n°7 33 p. IITA, Ibadan, Nigeria.

Kamh M., Horst W.J., Amer F., Mostafa H. and Maier P., 1999. Mobilisation of soil and fertiliser phosphate by cover crops. Plant and Soil 211, 19–27.

Kato N., Zapata F. and Axmann H., 1995. Evaluation of the agronomic effectiveness of natural and partially acidulated phosphate rocks in several soils using 32P isotopic dilution techniques. Fertilizer Research 41, 235-242.

Koudokpon V., Brouwers J., Versteeg M.N. and Budelman A., 1994. Priority setting in research for sustainable land use: The case of the Adja Plateau, Bénin. Agroforestry System 26, 101-122.

Kpomblekou K., Chien S.H., Henao J. and Hill W.A., 1991. Greenhouse Evaluation of Phosphate Fertilizers produced from Phosphate Rock. Commun. In Soil Science Plant Anal. 22, 63-73.

Osunde A.O., Bala A., Gwan M.S., Tsado P.A., Sanginga N. and Okogun J.A., 2003. Residual benefits of promiscuous soybean to maize (*Zea mays* L.) grown on farmers' s fields around Minna in the southern Guinea savanna zone of Nigeria. Agriculture, Ecosystems and Environment 100, 209-230.

Peoples M.B., Faizah A.W., Berkasem B. and Herridge D.F., 1989. Methods for evaluating nitrogen fixation by nodulated legumes in the field. Australian Centre for International Agriculture Research Canberra. Monograph N°11. VII. 76 p.

Phillips J.M. and Hayman D.S., 1970. Improved procedure for cleaning roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Transactions of the British Mycology Society 55, 158–161.

Pinstrup-Andersen P., Pandya-Lorch R. and Rosegrant M. W., 1997. The World Food Situation: Recent Developments, Emerging Issues, and Long-term Prospects. 2020 Vision. Food Policy Report. International Food Policy Research Institute, Washington D C, USA. 36 p.

Sanchez P.A. and Palm C.A., 1996. Nutrient cycling and agroforestry in Africa. Unasylva 185, pp 24-28.

Sanginga N., Dashiel K., Okogun J.A. and Thottappilly G., 1997. Nitrogen fixation and nitrogen contribution in promiscuous soybean in southern Guinea savanna of Nigeria. Plant and Soil 195, 257–266.

Schulz S., Tian G., Oyemole B. and Bako S., 2003. Rice mill waste as organic manure on a degraded Alfisol. Agriculture, Ecosystems and Environment 100, 221-230.

Tchienkoua Zech W., 2003. Chemical and spectral characterization of soil phosphorus under three land uses from an Andic Palehumult in West Cameroon. Agriculture, Ecosystems and Environment 100, 193-200.

Vanlauwe B., Aihou K., Houngnandan P., Diels J., Sanginga N. and Merckx R., 2001. Nitrogen management in 'adequate' input maize-based agriculture in the derived savanna benchmark zone of Bénin Republic. Plant and Soil 228: 61-71.

Vanlauwe B., Diels J., Lyasse O., Aihou K., Iwuafor E.N.O., Sanginga N. and Merckx R., 2002. Fertility status of soils of the derived savanna and northern guinea savanna and response to major plant nutrients, as influenced by soil type and land use management. Nutrient Cycling in Agroecosystems 62, 139-150.

Van der Pol F., Gogan A.C. and Dagbénonbakin G., 1993. L'épuisement des sols et sa valeur économique dans le département du Mono, RAMR, Cotonou, Bénin, 48 p.

Versteeg M.N., Amadji F., Eteka A., Gogan A. and Koudokpon V., 1998. Farmers' adoptability of Mucuna fallowing and agroforestry technologies in the coastal savanna of Bénin. Agricultural System 56, 269–287.

Vissoh P., Manyong V.M., Carsky R.J., Osei-Bonsu P. and Galiba M., 1998. Experiences with Mucuna in West-Africa. In Cover crops in West Africa contributing to sustainable agriculture. In: Buckles, D., Eteka, A., Osiname,O., Galiba, M. and Galiano, G., Eds. International Development Research. p. 1-31. Centre, Ottawa, Canada.

Volkoff B., 1976. Carte pédologique de Reconnaissance de la République Populaire du Bénin à 1/20000 Feuille d'Abomey (2) Notice explicative N°66(2. ORSTOM, 40 p.

Volkoff B. and William P., 1976. Carte Pédologique de Reconnaissance de la République Populaire du Bénin à 1/20000 Feuille de Porto-Novo (1. Notice explicative N° (66) (1) ORSTOM, 39 p.

Acknowledgements

The authors gratefully acknowledge the Belgian administration for Development Cooperation (ABOS) who sponsored this work in the framework on the collaborative project between KU Leuven and IITA on 'Process-based studies of soil organic matter dynamics in relation to the sustainability of agricultural systems in the tropics'.