

LEGUME AND MINERAL FERTILIZER DERIVED NUTRIENT USE EFFICIENCIES BY MAIZE IN A GUINEA SAVANNAH OF COTE D'IVOIRE

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ABSTRACT

This paper deals with reclamation of marginal savannah lands in central Côte d'Ivoire. It aimed at assessing legume-derived nutrient use efficiencies (NUE) by maize and quantifying the importance of these legumes as nutrient source relative to inorganic fertilizers. Experimentations included eight treatments in a RCB design (n=3): four herbaceous legume-maize successions and four continuous maize cropping with urea (U, 46% N, 50 kg ha⁻¹), triple superphosphate (TSP, 45% P, 30 kg ha⁻¹), urea+triple superphosphate (U+TSP) and a control. The NUE was estimated through Apparent Recovery (AR). In addition, the N- and P-fertilizer replacement indices (N-FRI and P-FRI) by legumes, which express their importance as source of N and P for maize relative to inorganic fertilizers, were estimated. The AR of N_{legume} and P_{legume} by maize varied from 16.6 to 29.1 % and from 29 to 62 %, respectively while those of N_{urea} and P_{TSP} were only 12 and 4.3 % on U and TSP plots, respectively. Values of legume N-FRIs and P-FRIs suggest that the legumes' impact on maize yield corresponded to that of the application of 131 to 195 kg urea ha⁻¹ and 27.5 to 96 kg TSP ha⁻¹, respectively. Compared to U and TSP, legume-derived nutrients were more efficiently used by maize, particularly nutrients from *P. phaseoloides*.

Keywords : Agroecology ; Crop nutrition ; Ferralsols ; Legumes ; Marginal land reclamation ; Nutrient sources

RESUME

RECUPERATION COMPAREE DES ELEMENTS NUTRITIFS ISSUS DES LEGUMINEUSES ET DES ENGRAIS INORGANIQUES PAR LE MAÏS DANS UNE SAVANE GUINEENNE DE CÔTE D'IVOIRE

Cette étude traite de la valorisation agronomique des terres marginales dans la zone de contact forêt-savane de Côte d'Ivoire. Elle a pour objectif d'évaluer l'efficacité avec laquelle les nutriments apportés par les légumineuses sont récupérés par le maïs et, partant, l'importance de ces légumineuses comme source de nutriments relativement aux engrais inorganiques. Un dispositif en blocs aléatoires avec trois répétitions a été utilisé, intégrant huit traitements: quatre successions légumineuse-maïs et quatre cultures continues de maïs dont trois avec engrais inorganiques et un sans engrais (témoin). L'efficacité d'utilisation de N et P par le maïs a été estimée par les taux de recouvrement (TRN, TRP) et l'importance des légumineuses comme source de nutriments, par leurs indices de remplacement de l'urée (IR-U) et du Superphosphate triple (IR-SPT). Les TR de N_{legume} et P_{legume} variaient de 16,6 à 29,1 % et de 29 à 62 % respectivement, sur précédents légumineuse alors que ceux de N_{urée} and P_{SPT} ne valaient que 12 et 4,3 % respectivement. Les IRs obtenus indiquent que l'impact des légumineuses sur les rendements de maïs équivaut à celui d'une application

virtuelle de 131 à 195 kg d'urée (46 %) ha^{-1} et 27,5 à 96 kg de SPT (45 %) ha^{-1} . Les nutriments issus des légumineuses ont été mieux assimilés par le maïs, avec en tête *Pueraria phaseoloides*.

Mots-clés : Agroécologie ; Ferralsols ; Légumineuses ; Nutrition minérale ; Source de nutriments ; Valorisation des terres marginales.

INTRODUCTION

Smallholder farmers from West Africa forest-transition zones are faced with inherently poor soil fertility, nitrogen and phosphorus being critically deficient (Okpara *et al.*, 2005). In this agroecological zone, savannah lands exhibit more pronounced fertility problems compared to forest islands and *Chromolaena odorata*-dominated fallows (Koné *et al.*, 2012a), thereby remaining marginalized. In this context, reclaiming savannah lands may be a promising option for alleviating land shortage and improving livelihoods. However, the use of inorganic fertilizers in small-holding farming systems in general is limited in sub-Saharan Africa, because farmers lack the financial wherewithal. Anyhow, these fertilizers are prone to leaching particularly in sandy soils. As an alternative, legume cultivation was incorporated in farming systems (Fofana *et al.*, 2005 ; Okpara *et al.*, 2005 ; Bilgo *et al.*, 2007). However, the impact of legume cultivation on soil fertility and crop productivity is highly influenced by soil conditions (Koné *et al.*, 2008a, Ojiem *et al.*, 2014; Kurwakumire *et al.*, 2014). Also, for crops to significantly benefit from a legume species, these should efficiently use nutrients supplied by that legume (Mat Hassan *et al.*, 2012). This is an essential step for targeting legume species appropriate to a given agroecological zone and sustaining crop production (Chikowo *et al.*, 2010).

Actually, organic farming is an appropriate option to overcome productivity problems of low-activity clay soils (Fuentes *et al.*, 2012). Increasing N and P inputs coupled with efficient use by crops are critical for improved productivity of the farms. Plant residues are known to increase plant available P through soil P mobilization (Guo *et al.*, 2009; Verma *et al.*, 2013). Notably, legume are effective in improving N and P availability in soil through symbioses with rhizobium and mycorrhiza, respectively. In order to find out the best legume species for a specific area, one needs to know how far the nutrients supplied by legumes are efficiently used by crops (Mat Hassan *et al.*, 2012).

The improvement of nutrient use efficiency is a

requisite for the expansion of crop production into marginal lands; this however depends on the ability of foodcrops to efficiently take up available nutrients from the soil, and also mobilize its usage within the plant (Roberts, 2008). According to Mosier *et al.* (2004), NUE can be expressed by four agronomic indices : partial factor productivity (PFP, kg crop yield per kg nutrient applied); agronomic efficiency (AE, kg crop yield increase per kg nutrient applied) ; apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied) ; and physiological efficiency (PE, kg yield increase per kg nutrient taken up). Plant nutrients rarely work in isolation as deficiency in one may restrict the uptake and use of another (Roberts, 2008). For example, the impact of the interactions between N and P on crop yields and N efficiency was shown by Fofana *et al.* (2005). The present study aimed to : (1) assess the use efficiency of nutrients from preceding legume crops, especially N and P, by a maize crop and (2) quantify the relative importance of these legumes as a source of nutrients relative to inorganic fertilizers. The overriding hypothesis was that the use of legume-derived nutrients by maize is at least as efficient as that from inorganic fertilizers.

MATERIAL AND METHODS

SITE DESCRIPTION

The study took place at the boundary of the Lamto reserve (6°13' N, 5°20' W) in central Côte d'Ivoire, located at an average altitude of 150 m above sea level. The climate is of tropical savannah type according to the Köppen-Geiger classification (Peel *et al.*, 2007). Rainfall is bimodal and occurs from March to July and September to November. The mean annual rainfall is 1200 mm and the temperature is nearly constant throughout the year, averaging 28°C (Figure 1 a & b). Vegetation consists of a mosaic of forest and savannah islands. The latter is dominant and has a woody stratum dominated by *Bridelia ferruginea*, *Crossopteryx febrifuga*, *Piliostigma thonningii*, *Cussonia barteri* and

Annona senegalensis, and an herbaceous stratum by *Hyparrhenia diplandra* and *Imperata cylindrica*.

Soils are classified as moderately leached Ferralsols (FAO classification), with granite being the main bedrock. The prevalent clays are illites and slightly crystallized kaolinities. The

characteristics of the 0 - 10 cm soil layer are as follows : fine fraction : 170 g kg^{-1} ; $\text{pH}_{(\text{water})} = 6.6$; total C : 7.5 g kg^{-1} , total N : 0.5 g kg^{-1} , total P : 163.5 mg kg^{-1} , available P : 17.2 mg kg^{-1} , CEC : $4.7 \text{ cmol (+) kg}^{-1}$, Ca^{2+} : $2.0 \text{ cmol (+) kg}^{-1}$, K^{+} : $0.3 \text{ cmol (+) kg}^{-1}$, and Mg^{2+} : $0.6 \text{ cmol (+) kg}^{-1}$ (Koné *et al.* 2008b).

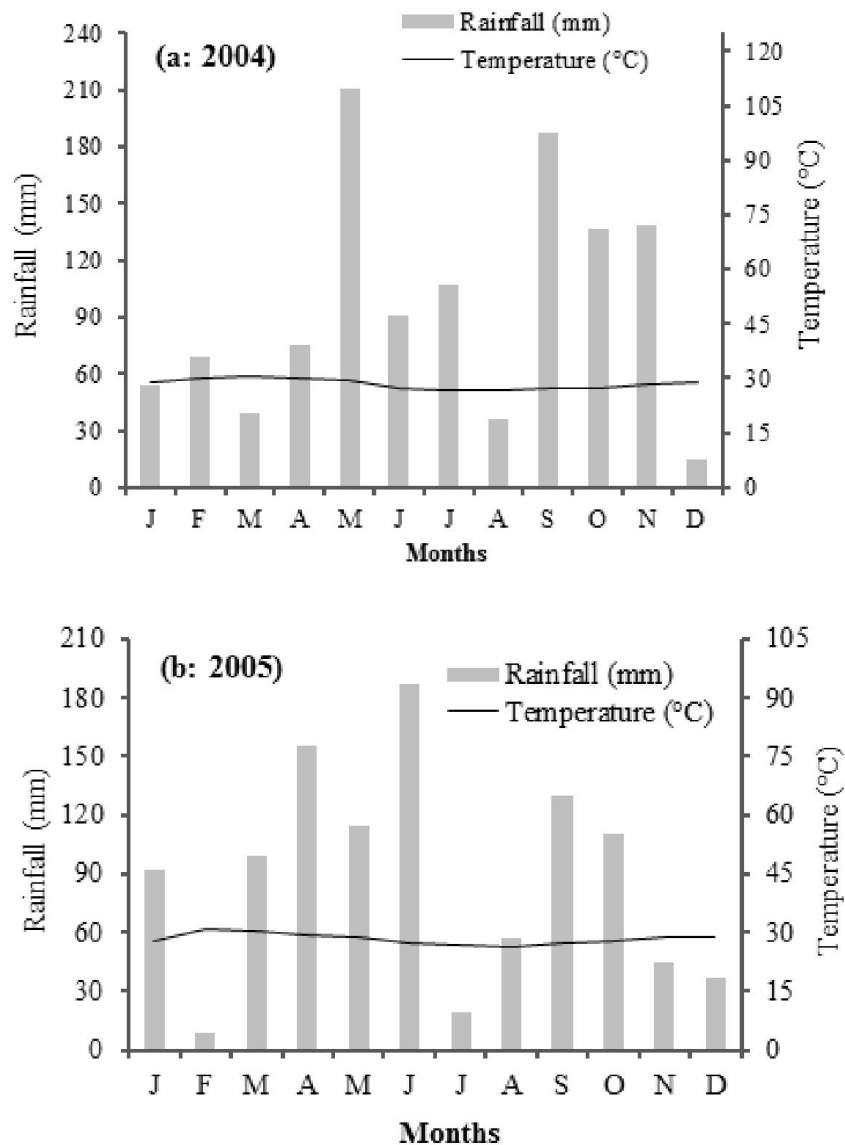


Figure 1 : Monthly variations of rainfall and temperature during the two years of experimentation (a : 2004 ; b : 2005)

Variations mensuelles de la pluviométrie et de la température au cours des deux années d'expérimentation (a : 2004 et b : 2005).

EXPERIMENTAL DESIGN

Trials were conducted within a randomized complete-block design with three replications. Blocks were separated by 4m intervals; each included eight 8m x 24m size plots separated by 2m intervals. There were eight treatments of which four legume-maize crop successions with *Mucuna pruriens* L. (*Mucuna*), *Pueraria phaseoloides* Roxb. (*Pueraria*), *Lablab purpureus* L. (*Lablab*) and a mixture of the three legume species (*LegMix*). These species were identified as promising for soil fertility improvement in West African savannah zones (Okpara *et al.*, 2005). The four others treatments were continuous maize cropping (CC) with application of urea (U), triple superphosphate (TSP), urea and triple superphosphate (U+TSP) and a control (C) without any fertilizer addition.

PHASES OF EXPERIMENT AND PLANT GROWTH CONDITIONS

The experiment held in two phases : the first phase experiment (FPE) and the second phase experiment (SPE).

First phase experiment (FPE)

The FPE lasted from April 2004 to April 2005. After original vegetation was cut, legumes were grown for one year at 0.5m x 0.5m spacing (40 000 plants ha⁻¹) on the relevant plots. In order to ease legume growth, plots were weeded twice with a 1-month interval, and residues were left on the soil surface.

On the other plots, maize (variety Pioneer, 120-day cycle) was grown at the density of 31 000 plants ha⁻¹ from May to August 2004, and from October 2004 to January 2005. Phosphorus and nitrogen were applied as TSP (45% P) and urea (46% N), respectively, on the relevant plots according to the IITA protocol (Kang, 1997). Phosphorus was applied once at sowing, at the rate of 30 kg P ha⁻¹; nitrogen was applied at the rate of 50 kg N ha⁻¹, in two splits : 1/3 at sowing and 2/3 at 40 days after sowing. Plots were also weeded twice at the beginning of the cycle (1-month interval), and residues were left on the soil surface. At maturity, only grains were harvested; the other parts were left as mulch. Thereafter, plots were left covered by natural re-growth dominated by *Imperata cylindrica*.

Second phase experiment (SPE)

The second phase experiment (SPE) ran from May 2005 to September 2005 and consisted in growing maize in all the plots, both continuous maize cropping and legume plots, in order to assess maize response to the treatments applied in the FPE. The surviving cover crops and any natural vegetation on all kind of plots were slashed and left *in situ* as mulch, and then maize was grown uniformly at the density of 31 000 plants ha⁻¹ directly in the mulch. This mulch consisted of legume residues on legume plots while it consisted of maize stover and grass (*Imperata cylindrica*) residues on CC plots. On the CC plots, TSP and urea were applied in the same way as in the FPE. No fertilizer was applied to plots previously cultivated with legumes. Here too, plots were weeded twice at the beginning of the cycle (1-month interval), and residues were left on the soil surface as mulch. At maturity, all the maize parts were sampled and weighed.

PLANT BIOMASS, CHEMICAL ANALYSES AND NUTRIENT UPTAKE DETERMINATION

The dry-matter yield of the legumes and associated nutrient stocks were measured at the dry pod stage, during the FPE. The sampling of fresh and dead materials was done within a 1m x 1m frame, at three points well distributed over each plot.

For each cropping cycle, maize yields (grain and residue biomass) were determined at harvest as follows: On each plot, measurements were done on 25 plants belonging to 5 series of 5 plants from 5 different maize rows well distributed on the plot. The average weight obtained after oven-drying at 60 °C for 72 hours was multiplied by the total number of plants on the plot at harvest and expressed in Mg ha⁻¹.

Chemical analyses were conducted on composite plant samples for each type of material from each plot. Nitrogen concentration was determined using the standard Kjeldahl digestion method while phosphorus was determined according to Murphy and Riley (1962). Potassium, calcium and magnesium were extracted with ammonium acetate buffer (1 N; pH 7; litter:extractant ratio of 1: 20, g:ml), and determined by atomic absorption

spectrophotometry techniques (Anderson and Ingram, 1993). Nutrient uptake by legumes or maize was calculated as follows:

$$\text{N or P uptake (kg ha}^{-1}\text{)} = \text{Plant biomass (kg ha}^{-1}\text{)} \times \text{N or P concentration (g kg}^{-1}\text{)} \times 10^{-3}$$

SOIL PARAMETER MEASUREMENTS

Soil was sampled at the start (April 2004) and the end of the FPE (April 2005) from the 0-10 cm depth since the short duration of experimentations (one year) probably could not allow changes in deeper horizons. On each plot, samples were collected at nine points using an auger and thoroughly mixed into one composite sample. These were air-dried at ambient temperature, crushed and sieved at 2mm before being analysed chemically. Total N was determined using the Near Infrared Reflectance Spectroscopy (NIRS) technique (Ludwig *et al.*, 2002). Mineral N was determined following the Bremner (1965) method. Available P was extracted according the Olsen-Dabin method (in a mixture of NaHCO_3 and NH_4F , at pH 8.5) and measured colorimetrically at 660 nm (Murphy and Riley, 1962). Exchangeable bases and CEC were measured using standard methods (Anderson & Ingram, 1993). Soil pH was determined using a glass electrode in 1 : 2.5 soil : water ratio.

NUTRIENT USE EFFICIENCY BY THE SUBSEQUENT MAIZE CROP

The legume N (N_{legume}) and P (P_{legume}) use efficiencies was estimated through two parameters: the apparent recovery (AR) and the Fertilizer replacement indices (N-FRI and P-FRI, respectively) of the legumes. Calculations included nutrient uptake by maize on the control plot as a proxy for the indigenous nutrient supply of the soil.

Apparent nutrient recovery

The AR of both nutrients were calculated as follows (e.g. for N_{legume}):

$$\text{AR-N}_{\text{legume}} (\%) = [(\text{Total maize N uptake after legume} - \text{Total maize N uptake in control}) / \text{Legume N uptake}] \times 100 \text{ (Equation 1).}$$

This equation also applied for the AR of $\text{N}_{\text{-urea}}$ and $\text{P}_{\text{-TSP}}$. In these cases, U and TSP plots were

considered, respectively, instead of legume plots.

Legume N- and P-fertilizer replacement indices

The *i*-FRI of a given legume species can be viewed as its importance as a source of the nutrient *i*, relative to the inorganic fertilizer *i*. This index is merely an estimation of the quantity of inorganic fertilizer *i* that should be applied to equal the effect the legume had on the crop yield. This implies that the value of the index may be either lower or higher than the quantity of nutrient *i* the legume is supposed to supply to soil (Tian *et al.* 2000). Thus, depending on the standard rate of application (SRA) of the fertilizer *i*, a legume species may have the potential to partially (*i*-FRI < SRA of *i*) or fully (*i*-FRI = SRA of *i*) replace the fertilizer *i*, or even have a higher fertilizing potential (*i*-FRI > SRA of *i*). Both N- and P-fertilizer replacement indices of the legumes were calculated as follows (Tian *et al.* 2000):

$$\text{P-FRI (kg TSP ha}^{-1}\text{)} = (\text{PU}_{\text{maize after legume}} - \text{PU}_{\text{maize in control}}) / \text{Total maize PU increase in TSP treatment (Equation 2), with}$$

$$\text{Total maize PU increase in TSP treatment} = (\text{PU}_{\text{maize with TSP}} - \text{PU}_{\text{maize in control}}) / 30 \text{ (Equation 3)}$$

where $\text{PU}_{\text{maize after legume}}$ is maize P uptake in the legume plots, $\text{PU}_{\text{maize in control}}$ maize P uptake in the control, $\text{PU}_{\text{maize with TSP}}$ maize P uptake in plots supplemented with TSP and 30 the SRA of fertilizer P. The N-FRI was obtained by considering N instead of P, U plots instead of TSP ones and 50 (the SRA of fertilizer N) instead of 30 in equations 2 and 3.

STATISTICAL ANALYSES

Significant changes over time were tested using the MANOVA while differences among individual treatments at a given time were tested using two-way ANOVA after verification of homogeneity of variances with Levene's test. Orthogonal comparisons were performed to test for differences between mean average of groups of treatments (Legume, Fertilization and Control) using the Tukey test when a significant interaction between main effects occurred. General Linear Model procedures were performed for analyzing relationships between variables. These analyses were processed using the R ver. 2.13.1 software (<http://www.r-project.org/>) at the 5 % level.

RESULTS

LEGUME BIOMASS YIELD AND NUTRIENT UPTAKE, AND NUTRIENT CONCENTRATION IN LEAF LITTER

No significant difference was observed between legume species in terms of biomass (Table 1). Compared with the native grass *H. diplandra*, legumes showed significantly lower root biomass ($P = 0.02$).

The N uptake by legumes significantly varied among species ($P = 0.04$) with the highest value for *L. purpureus* and the least for *P. phaseoloides*

(Figure 2a). Variation in P uptake between legume species was not significant (Figure 2b). The N uptakes by legume were all higher than the SRA of N_{-urea} (50 kg ha^{-1}) while P uptakes were all lower than the SRA of P_{-TSP} (30 kg ha^{-1}).

Leaf-litter showed significant between-treatment differences for all the nutrients, except for P (Table 2). The highest N concentration among legumes was obtained with *M. pruriens*, followed by *L. purpureus*, and with U among CC treatments. Average litter concentrations in legumes were higher than in maize under fertilization and in the control ($P < 0.001$ for all those nutrients).

Table 1. Legume biomass yields (mean \pm S.E.M.) compared to that of the dominant grass species of the savannah, measured during the first phase of experiment

Biomasses végétales sur parcelles de légumineuse et en savane (moyenne \pm erreur standard ; n = 3), mesurées au cours la première phase d'expérimentation.

Plant species	Biomass yield (Mg ha ⁻¹)		
	Aboveground	Belowground	Total
<i>M. pruriens</i>	4.8 \pm 0.7 a	0.1 \pm 0.0 b	4.9 \pm 0.7 a
<i>P. phaseoloides</i>	5.9 \pm 0.4 a	0.6 \pm 0.1 b	6.4 \pm 0.4 a
<i>L. purpureus</i>	5.2 \pm 0.6 a	0.5 \pm 0.1 b	5.7 \pm 0.7 a
Legume mixture	nd	nd	nd
<i>H. diplandra</i> *	4.4 \pm 0.5 a	1.0 \pm 0.1 a	5.4 \pm 0.6 a

nd (not determined) : biomass yield was not measured for the legume mixture because the different species reached the dry pod stage at distinct times.

(Non déterminé : la biomasse végétale n'a pas été mesurée sur la parcelle mixte car la production de gousses par les différentes espèces n'intervenait pas à la même période.)

*Dominant grass species in the savannah, biomass was measured around the experimental design.
(Espèce de graminée dominante dans la savane, l'estimation de la biomasse a été faite aux alentours du dispositif expérimental.)

In the same column, means with the same letter are not significantly different at the 5 % level.

(Dans la même colonne, les moyennes affectées d'une même lettre ne sont pas significativement différentes au seuil de 5 %.)

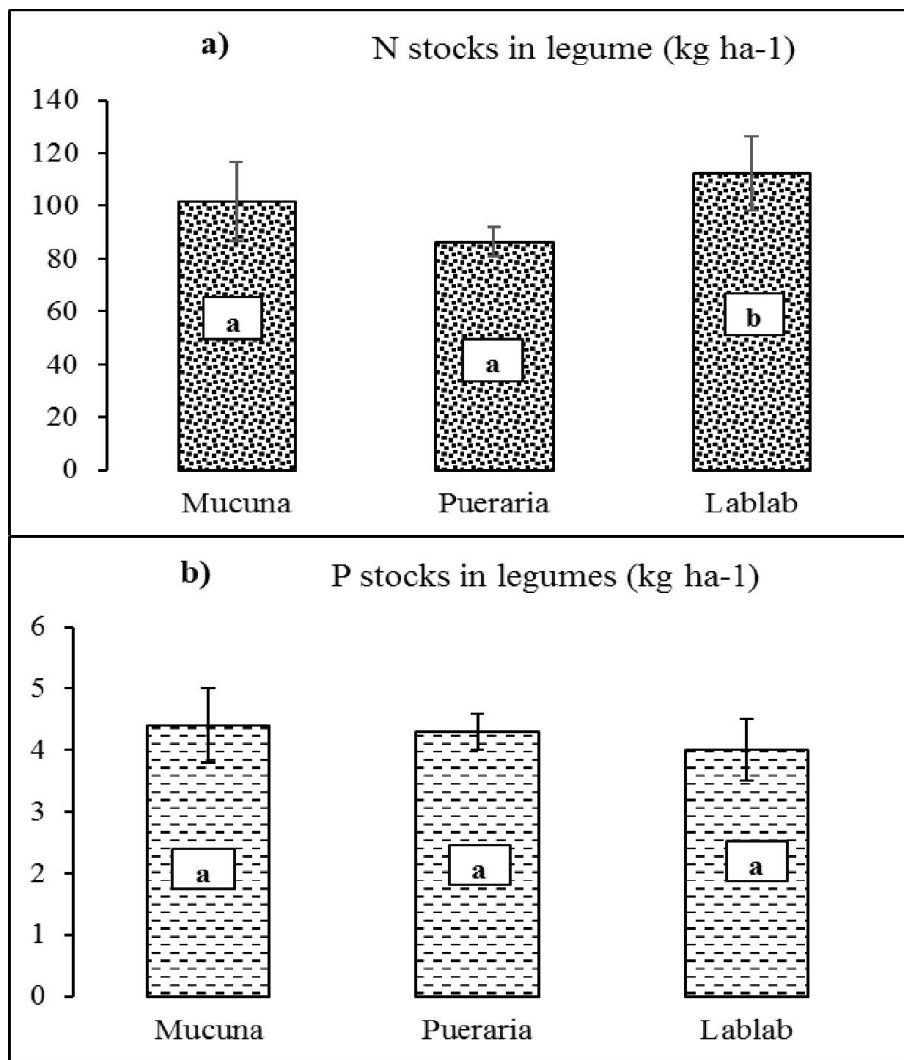


Figure 2 : Nitrogen and phosphorus stocks in legumes. Means with the same letter are not significantly different at the 0.05 level. Vertical bars denote standard error ; n = 3.

Stocks d'azote et de phosphore dans la biomasse produite par les différentes espèces de légumineuse. Les moyennes affectées d'une même lettre ne sont pas significativement différentes au seuil de 5 %. Les barres verticales représentent l'erreur standard ; n = 3.

Table 2 : Nutrient concentrations in leaf-litters (mean \pm S.E.M.) from legumes and maize measured during the first phase of experiment.

Teneurs des litières de feuilles en éléments nutritifs (moyenne \pm erreur standard ; n = 3), mesurées au cours la première phase d'expérimentation.

Treatments	N	P	K	Ca	Mg
(g kg ⁻¹ dry matter)					
Mucuna	17.5 \pm 0.7 a	1.1 \pm 0.1 a	9.4 \pm 0.5 ab	13.3 \pm 0.4 b	2.2 \pm 0.1 bc
Pueraria	8.1 \pm 0.5 bc	0.8 \pm 0.0 a	9.9 \pm 0.3 a	17.5 \pm 0.5 b	3.5 \pm 0.1 a
Lablab	13.6 \pm 1.2 ab	0.9 \pm 0.0 a	9.8 \pm 0.4 a	25.6 \pm 3.2 a	2.8 \pm 0.1 b
LegMix	11.1 \pm 0.2 b	0.9 \pm 0.1 a	9.8 \pm 0.3 a	19.1 \pm 2.4 ab	3.1 \pm 0.1 b
U	5.8 \pm 0.8 cd	0.6 \pm 0.1 a	6.4 \pm 0.8 b	2.3 \pm 0.3 c	1.7 \pm 0.2 bc
TSP	3.9 \pm 0.4 d	1.1 \pm 0.3 a	6.4 \pm 1.1 b	1.8 \pm 0.1 c	1.4 \pm 0.1 c
U+TSP	6.7 \pm 1.0 c	1.0 \pm 0.2 a	9.0 \pm 0.8 ab	2.4 \pm 0.3 c	1.5 \pm 0.2 bc
Control	4.5 \pm 1.2 d	1.0 \pm 0.1 a	6.0 \pm 0.7 b	2.3 \pm 0.2 c	1.8 \pm 0.1 bc

In the same column, means with the same letter are not significantly different at the 5 % level.

(Dans la même colonne, les moyennes affectées d'une même lettre ne sont pas significativement différentes au seuil de 5 %.)

CHANGES IN SOIL CHEMICAL ATTRIBUTES

Total N significantly increased in legume plots as well as in those CC plots with urea application ($P < 0.001$) relative to the initial time; the increments were the highest for legume treatments ($p = 0.04$) particularly LegMix and Lablab (Table 3). However, there were no significant differences between-individual treatments nor between-groups of treatments (legumes, fertilization and control) when comparisons specifically were made at the end of the FPE. With regards to mineral N, NH_4^+ concentration did not change significantly over time in none of the treatments. No significant between-treatment or between-group difference was observed at the end of FPE. On contrary, in terms of NO_3^- significant difference appeared between individual treatments ($P = 0.05$) with the highest values for LegMix and Mucuna. Significant difference also appeared between groups of treatments ($P = 0.03$) with the highest value for legumes ($28.1 \pm 1.81 \text{ mg kg}^{-1}$). The same trend was observed with total mineral N.

Between-treatment difference was observed in terms of available P at the end of the FPE ($P = 0.003$) with the highest values associated with LegMix and Lablab and the least where urea was applied (Table 4). Significance was also reached when comparing groups of treatments ($P = 0.001$); legumes showing higher value ($29 \pm 3.0 \text{ mg kg}^{-1}$) compared to fertilization ($10 \pm 3.0 \text{ mg kg}^{-1}$) and the control ($19 \pm 3.0 \text{ mg kg}^{-1}$) ($P < 0.001$). Relative to the start of trials, available P significantly increased only in Lablab ($P = 0.03$) and LegMix ($P = 0.002$). Overall, available P increased by 67 % on average in the legume group and decreased by 42 % under fertilization and by 12.5 % in the control plots.

At the 12-month term, soil pH significantly varied among individual treatments ($P = 0.001$), the highest value associated with LegMix and the least with Pueraria and U. Average value for fertilization (6.3 ± 0.02) was significantly lower than that for legumes (6.5 ± 0.06) plots. Between the start and the end of the FPE, soil pH significantly decreased in Pueraria ($P = 0.05$) and U + TSP ($P = 0.05$).

Table 3. Variation (Δ) in total and mineral soil N concentrations (mean \pm S.E.M.) between the start and the end of the first phase of experiment.

Variation des teneurs du sol en azote total et en azote mineral (moyenne \pm erreur standard; $n = 3$) entre le début et la fin de la première phase d'expérimentation.

Treatments	Total N (g kg ⁻¹ soil)			NH ₄ ⁺ (mg kg ⁻¹ soil)			NO ₃ ⁻ (mg kg ⁻¹ soil)		
	0 month	12 months	Δ (%)	0 month	12 months	Δ (%)	0 month	12 months	Δ (%)
Mucuna	0,54 \pm 0,01a	0,62 \pm 0,02 a	14,9*	8,9 \pm 1,5	7,2 \pm 1,5	-19,5	7,7 \pm 0,2	24,3 \pm 3,5	213,1*
Pueraria	0,51 \pm 0,02 a	0,59 \pm 0,01 a	17,1*	7,6 \pm 2,0	8,3 \pm 1,2	9,5	8,8 \pm 0,2	16,6 \pm 3,2	106,8*
Labiab	0,50 \pm 0,02 a	0,62 \pm 0,01 a	23,6*	8,8 \pm 1,1	6,7 \pm 1,4	-24,2	8,2 \pm 0,7	17,0 \pm 2,8	107,7*
LegMix	0,53 \pm 0,02 a	0,65 \pm 0,02 a	21,6*	6,1 \pm 2,3	7,7 \pm 2,1	26,2	8,4 \pm 0,3	24,4 \pm 0,8	188,9*
U	0,49 \pm 0,02 a	0,57 \pm 0,01 a	15,6*	8,5 \pm 1,9	6,5 \pm 0,3	-22,9	7,9 \pm 0,3	16,2 \pm 6,3	104,4
TSP	0,56 \pm 0,02 a	0,60 \pm 0,03 a	8,1	9,0 \pm 3,8	5,8 \pm 5,4	-34,8	7,5 \pm 0,1	20,4 \pm 3,8	170,7
U+TSP	0,53 \pm 0,01 a	0,59 \pm 0,01 a	12,3*	5,5 \pm 1,8	5,4 \pm 0,4	-2,2	8,8 \pm 1,1	18,5 \pm 1,9	109,2*
Control	0,54 \pm 0,03 a	0,51 \pm 0,03 a	-5,5	8,1 \pm 2,4	4,7 \pm 0,5	-41,1	7,7 \pm 0,2	16,3 \pm 2,8	111,7

*Significant variation over time.

In a same column, means with the same letter are not significantly different at the 5% level.

*Variation significative au cours du temps.

Dans la même colonne, les moyennes affectées d'une même lettre ne sont pas significativement différentes au seuil de 5 %.

Table 4. Variation in soil available P and pH (mean \pm S.E.M.) between the start and the end of the first phase of experiment.

Variation des teneurs du sol en phosphore disponible (moyenne \pm erreur standard ; n = 3) entre le début et la fin de la première phase d'expérimentation.

Treatments	Available P (mg kg ⁻¹)			pH _{water}		
	0 month	12 months	Δ (%)	0 month	12 months	Δ (%)
Mucuna	18.7 \pm 1.8 a	26.7 \pm 3.8 ab	42.9	6.6 \pm 0.12 a	6.6 \pm 0.03 ab	1.0
Pueraria	16.7 \pm 3.2 a	18.3 \pm 0.7 ab	10.0	6.6 \pm 0.06 a	6.3 \pm 0.12 c	-5.0
Lablab	17.7 \pm 0.9 a	32.3 \pm 5.2 a	83.0*	6.6 \pm 0.07 a	6.6 \pm 0.03 ab	-1.0
LegMix	16.8 \pm 2.7 a	38.7 \pm 6.2 a	130.6*	6.5 \pm 0.03 a	6.7 \pm 0.03 a	3.0*
U	16.3 \pm 1.3 a	7.4 \pm 0.7 b	-54.9	6.4 \pm 0.03 a	6.3 \pm 0.03 c	-1.6
TSP	17.0 \pm 1.5 a	15.3 \pm 8.6 ab	-9.8	6.4 \pm 0.02 a	6.4 \pm 0.03 bc	0.0
U+TSP	19.3 \pm 5.4 a	7.7 \pm 3.3 b	-60.3	6.7 \pm 0.03 a	6.4 \pm 0.03 bc	-4.5*
Control	21.3 \pm 2.4 a	18.7 \pm 2.9 ab	-12.5	6.3 \pm 0.21 a	6.5 \pm 0.09 b	2.6

*Significant variation.

Variation significative.

In a same column, means with the same letter are not significantly different at the 5% level.

Dans la même colonne, les moyennes affectées d'une même lettre ne sont pas significativement différentes au seuil de 5 %.

SUBSEQUENT MAIZE YIELD

The 2004-maize yields varied significantly among treatments (grain : $P = 0.002$; total biomass yield : $P = 0.03$). Both grains and total biomass yields were the highest on Pueraria followed by LegMix, and the least on the control (Figure 3). Average grain yield from legumes (635 ± 53.9 kg ha⁻¹) was significantly higher ($P = 0.002$) than those from fertilization (419 ± 79.5 kg ha⁻¹) and the control (184 ± 98.3 kg ha⁻¹). The same trend were obtained for total maize biomass production.

NITROGEN AND PHOSPHORUS UPTAKES AND USE EFFICIENCY BY MAIZE

The N uptake by maize crop (Figure 4) significantly varied between individual treatments ($P = 0.02$). Pueraria had the highest value followed by the three others legume treatments. The lowest N uptake was obtained with the TSP and the control. The average maize N uptake also varied between groups of treatments ($P < 0.001$). Value from legume plots (26.3 ± 2.80 kg ha⁻¹) were significantly ($P = 0.001$ and $P = 0.003$, respectively) higher than those in fertilization

(11.0 ± 2.09 kg ha⁻¹) and the control plots. No significant relationship was observed between available P and maize N uptake ($R^2 = 0.11$, $P = 0.1$, $F = 2.9$). The AR-N by maize in Pueraria treatment doubled that in the U treatment (Table 5). The legume N-FRIs ranged between 131 (Mucuna) and 195 (Pueraria), suggesting that N_{urea} theoretically should have been applied at the rate of 131 to 195 kg/ha to result in maize yields obtained on legume plots, though N stocks in legumes varied from 86.4 to 112.4 kg ha⁻¹.

The P uptake by maize also significantly varied between treatments ($p = 0.04$), Pueraria plots showing the highest value. The parameter varied between groups of treatments ($P = 0.04$) following the same trend as for N uptake. The AR-P by the maize crop in legume treatments was 6 (Lablab) to 21 times (Pueraria) more efficient than that in the TSP treatment. The legume P-FRIs ranged between 27.5 (Lablab) and 96 (Pueraria), suggesting that P_{TSP} theoretically should have been applied at the rate of 27.5 to 96 kg ha⁻¹ to result in maize yields obtained on legume plots, though P stocks in legume ranged between 4.0 and 4.4 kg ha⁻¹.

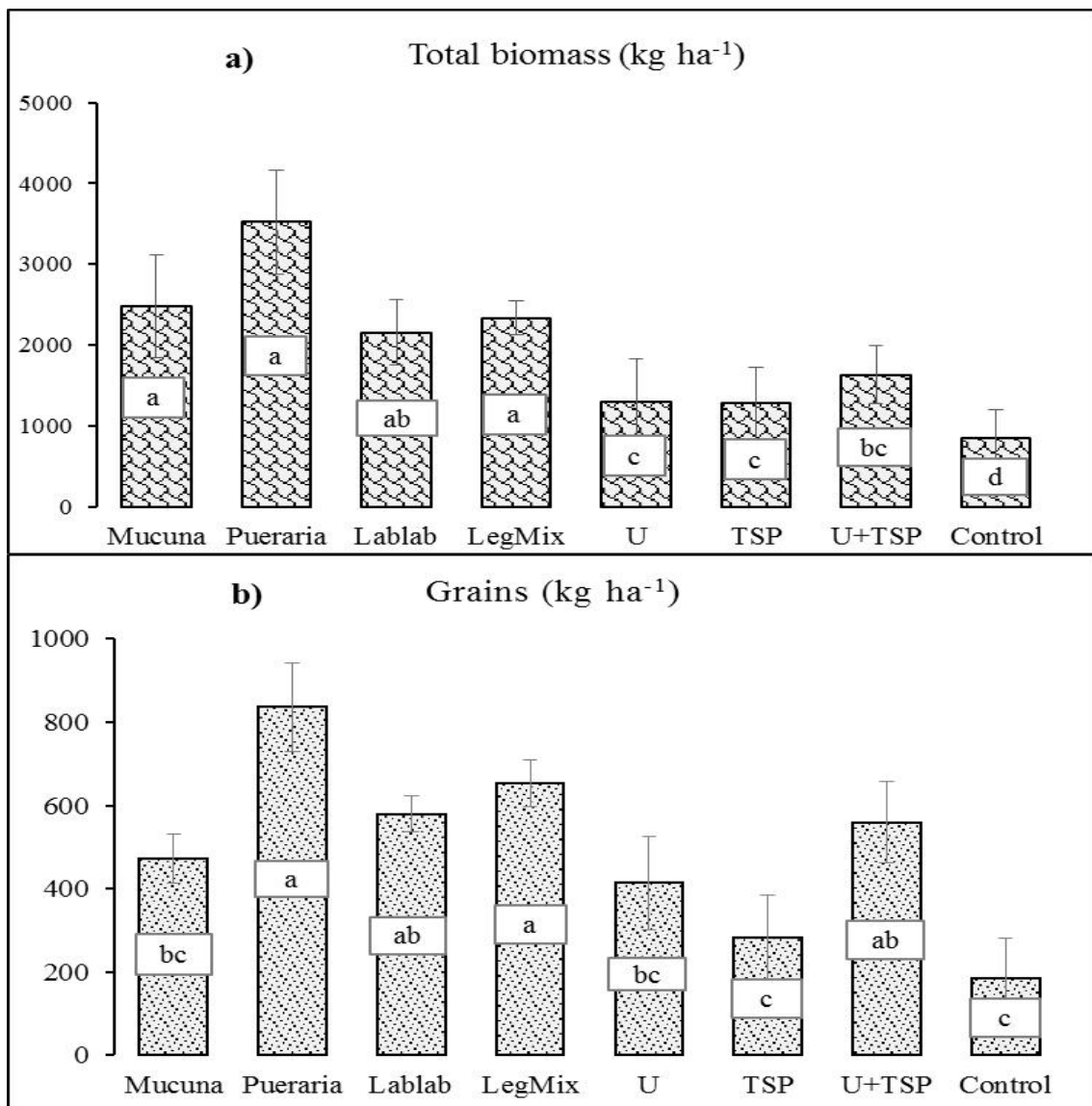


Figure 3 : Maize crop yields following legume and continuous cropping treatments applied during the first phase of experiment. Means with the same letter are not significantly different at the 0.05 level. Vertical bars denote standard error ; n = 3.

Rendements de maïs sur précédent légumineuse et en culture continue. Les moyennes affectées d'une même lettre ne sont pas significativement différentes au seuil de 5 %. Les barres verticales représentent l'erreur standard ; n = 3.

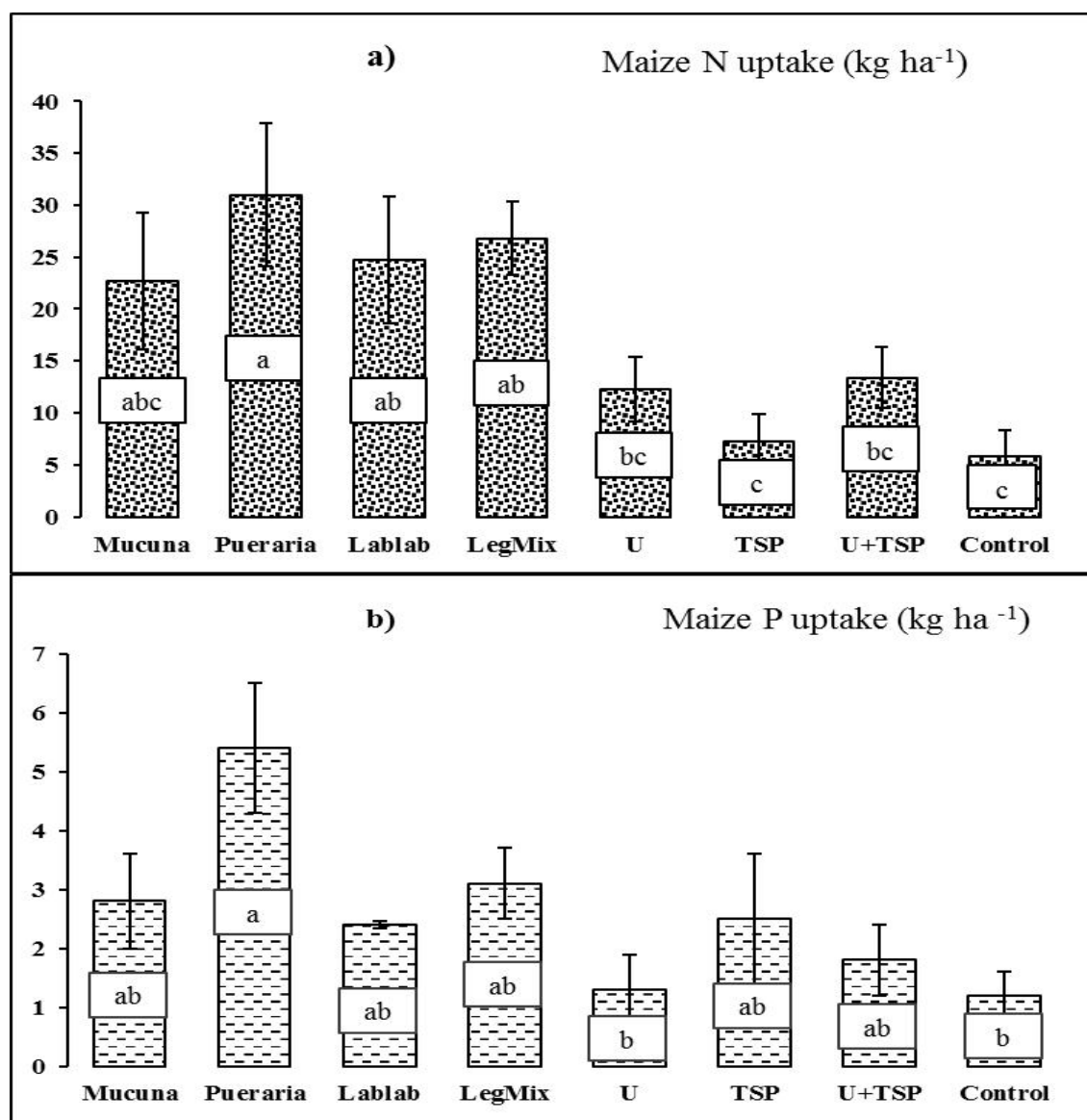


Figure 4 : Nitrogen and phosphorus uptakes by maize following treatments, measured in the second phase of experiment. Means with the same letter are not significantly different at the 0.05 level. Vertical bars denote standard error.

Stocks d'azote et de phosphore mesurés dans la biomasse de maïs sur précédents légumineuse et en culture continue. Les moyennes affectées d'une même lettre ne sont pas significativement différentes au seuil de 5 %. Les barres verticales représentent l'erreur standard ; n = 3.

Table 5. N and P recovery by maize (AR-N, AR-P) and legumes N- and P- fertilizer replacement indices (N-FRI, P-FRI), measured in the second phase of experiment.

Taux de recouvrement de l'azote et du phosphore par le maïs (AR-N, AR-P) et indices de remplacement des engrais inorganiques par les légumineuses (N-FRI, P-FRI).

Treatments	AR-N (%)	N-FRI	AR-P (%)	P-FRI
Mucuna	16.6	130.8	34.6	35.5
Pueraria	29.1	195.7	62.8	96.0
Lablab	16.8	146.8	29.5	27.5
LegMix	<i>Nav</i>	162.9	<i>Nav</i>	43.6
U	12.9	50.0*	<i>Nap</i>	<i>Nap</i>
TSP	<i>Nap</i>	<i>Nap</i>	4.3	30.0*
U+TSP	<i>Nap</i>	<i>Nap</i>	<i>Nap</i>	<i>Nap</i>
Control	<i>Nap</i>	<i>Nap</i>	<i>Nap</i>	<i>Nap</i>

Nav : Not available : biomass yield and related N and P stocks were not measured for the legume mixture because the different species reached the dry pod stage at distinct times.

Pas disponible : la biomasse végétale et ses stocks en N et P n'ont pas été mesurées sur la parcelle mixte car la production de gousses par les différentes espèces n'intervenait pas à la même période.

Nap : not applicable.

Pas disponible.

* Here, 50 and 30 are the rates of application of N_{urea} and P_{TSP} respectively; these are considered as the references to which FRI obtained for the legumes were compared. However, these could have been obtained by considering U or TSP plots in place of «legume plot» in the equation.

Ici, 50 et 30 sont respectivement les doses d'application de l'urée et du superphosphate triple, considérées les valeurs-références avec lesquelles les indices de remplacement des engrais par les légumineuses sont comparés.

DISCUSSION

The increase in total soil N in legume plots at the end of the FPE relative to the initial time and relative to the CC treatments are attributable to the continuous supply of N-rich residues likely coupled with increased faunal residue-decomposing activity (McGonigle *et al.*, 2011) compared to the graminea (both maize and prevailing grass). The N increase in U and U+TSP treatments within the same span of time is hardly attributable to an accumulation of the urea applied during the FPE since soil was sandy-textured. It was more likely due to the combination of residues and urea which is known to increase microbial-mediated residue decomposition as a consequence of a decrease in the residue C : N ratio (Whitbread *et al.*, 2003).

In the CC plots, available P concentration remained constant over time in absence of urea application and greatly decreased in urea-applied plots. It may be due to a decrease in pH following urea application below the original level owing

to nitrification and leading to increased P sorption (Hartikainen and Yli-Halla, 1996). It could be hypothesized that the hydroxyl ions (OH⁻) that compete with phosphate for sorption sites were bound into neutral H₂O molecules by the free H⁺ generated during nitrification, resulting in P adsorption in soil. The decrease in available P can hardly be attributed to P exportation through grain harvests during the FPE as usually observed (Verma *et al.*, 2013) since mineral P was applied during each maize cropping. The unchanged concentration of available P in TSP treatment despite P supply is hypothetically a result of the conversion of P_{-TSP} into immobile forms (Aye *et al.*, 2009). Contrary to the CC plots, legume plots showed an increased available P probably as a result of P release from the abundant decomposing plant residues with reduced potential to convert into poorly available forms (Koné *et al.*, 2008a; Mat Hassan *et al.*, 2012), and the supply to soil with organic anions that compete with phosphate for sorption sites (Guo *et al.*, 2009). This could also be accounted for by the P desorption by legume

roots exudates and cycling from deeper soil layers (Mat Hassan *et al.*, 2012).

Despite total soil N increase in legume plots relative to the start of trials, no significant differences were observed between treatments at the end of PFE specifically. Available P was greater in legumes than in CC plots but this did not match maize yields. As supported by works by Ojiem *et al.* (2014) and Arcand *et al.* (2014), one can conclude that the positive effect of legumes on maize yield was not solely explained by N and P improvement. In turn, this could be accounted for by the improvement in soil biology which is conducive to efficient assimilation of supplied nutrients by plants (Salako and Tian, 2003 ; McGonigle *et al.*, 2011). As a matter of fact, earthworm which are good indicators of soil quality increased in density (60.7 ± 7.8 to 72.0 ± 13.6 individuals m^{-2} in average, *i.e.* +19 %) under legumes while it decreased under CC (42.0 ± 7.1 à 28.0 ± 7.5 individuals m^{-2} , *i.e.* -33 % (Koné, *unpublished data*). Moreover, GLM tests revealed significant influence of earthworm density on N uptake by maize ($F_{(1,6)} = 18.8$; $R^2 = 0.8$; $P = 0.007$). Accordingly, ARs of legumes (N_{legume} and P_{legume}) were far higher than those from inorganic fertilizers (N_{urea} and P_{TSP}). The AR of legume nutrients by maize in general was moderate but legume FRIs were high as these are functions of fertilizer uptake by maize, which in turn is influenced by soil conditions. In this study, legume residues appeared as more important sources of N and P than inorganic fertilizers since values of legume N-FRI and P-FRI (except for *L. purpureus*) were higher than the SRA of N_{urea} and P_{TSP} , respectively. It should be noted that the application of fertilizer during the FPE possibly impacted soil conditions negatively, increasing FRI values to some extent. Although legume P uptakes were all lower than the quantity of inorganic P (13.5 kg ha^{-1}) applied on TSP and U+TSP plots, the proportions of legume P recovered by the 2004, maize crop were higher than that of P_{TSP} . One explanation to this result could be the gradual released of P from legume residues, which is not susceptible to fixation, contrary to inorganic P (Thorup-Kristensen *et al.*, 2003). Likewise, maize yield increase in legume plots also may be explained by fresh material left on soil surface following slashing of the surviving cover crops at the start of the SPE, releasing quantities of N for maize, particularly

in Pueraria and LegMix plots. Unlike *L. purpureus* and *M. pruriens* which are annual species and which dried up before the end of the FPE, *P. phaseoloides*, a perennial species was still growing.

Ladha *et al.* (2005) reported an average of 65 % fertilizer N recovery efficiencies for maize crop on experimental plots. However, such plots do not accurately reflect the efficiencies obtainable on-farm. We found a value of 13 % in the current work, which is lower than the range of 20 to 30 % indicated by Roberts (2008) but falls within the 10 to 20 % one reported by Giller and Cadisch (1995). Roberts (2008) reported that recovery of applied fertilizer P ranges from less than 10 to 30 % ; these values are much higher than that in the current study (4.3 %). However, there is some likelihood that long-term recovery of the applied P increases owing to its low mobility in soil.

It should be mentioned that maize cycle should have been repeated for a better evaluation of grain production potential on legume plots compared to the continuous cropping plots.

CONCLUSION

This paper stressed the importance of legume residues as source of nutrients for maize relative to inorganic fertilizer. Although legumes substantially improved P availability in soil, this parameter did not clearly influence maize N uptake. The legume-derived nutrient use efficiency by maize was greater than fertilizers, probably as a result of improvement in soil biological quality and the supply of fresh materials. In the soil-plant-climate conditions of this study, the legumes showed a higher fertilizing potential compared with inorganic fertilizer since legume N- and P-FRIs were higher than the standard rates of inorganic N and P applications. The best results was obtained with *P. phaseoloides* ; it thus may be recommended for marginal land reclamation in guinea savannah zone of West Africa.

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