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Improving soil fertility and biology, and nutrient use efficiency through Conservation Agriculture in the Lamto region (Mid-Côte d'Ivoire)

Improving soil fertility and biology, and nutrient use efficiency through Conservation Agriculture in the Lamto region (Mid-Côte d'Ivoire)

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ABSTRACT

In the forest-savanna transition zone of Côte d'Ivoire, farmers are still practicing shifting and slash-and-burn agriculture, which is known to be harmful to the environment. In order to overcome this situation "Conservation agriculture" is being implemented in the region. The present study aims on one hand, to assess the impact of short-term legume cover crops on soil fertility, biology and agricultural production and on the other hand, to assess the efficiencies with which legume-derived N and P are taken up by food crops, compared to those on fertilized plots and the current cropping system. Two groups of cropping systems were tested using a randomized complete block experimental design with three replications. The first consisted in legume-based systems with *Mucuna pruriens*, *Pueraria phaseoloides*, *Lablab purpureus* and legume mix. The second consisted in four maize-based continuous cropping systems: maize fertilized with urea (Maize-U), maize fertilized with triple super phosphate (Maize-Sp), maize fertilized with both urea and triple super phosphate (Maize-USp) and fertilizer-free maize (Maize-Tradi), as control. After one year, soil N content increased significantly by 15 to 23.6 % under legume-based systems, compared to the initial content while no significant increase was observed under the control. In general, soil soluble P content increased (+90%, on average) under legume plots while it decreased under continuous cropping (-40%, on average). The earthworm density increased significantly only under *P. phaseoloides* and *L. purpureus*; it remained constant under the two others legume plots and decreased significantly under the continuous cropping plots. Maize grain yield varied significantly among treatments, with higher values for the legume plots. Indeed, it varied from 472 ± 58 $kg.ha^{-1}$ (*M. pruriens*) to 836 ± 151 $kg.ha^{-1}$ (*P. phaseoloides*) while values under inorganic fertilization ranged between 284 ± 120 $kg.ha^{-1}$ (Maize-Sp) and 559 ± 98 $kg.ha^{-1}$ (Maize-USp). The lowest yield was observed with the control (184 ± 98 $kg.ha^{-1}$). Nnutrient uses were more efficient on legume plots as indicated by higher apparent N and P recovery as well as values of NFRI and PFR superiors to the rate of fertilization (50 kg ha^{-1} and 30 kg ha^{-1} for urea and triple superphosphate, respectively). These results revealed the potential of herbaceous legumes in improving, in the short run, the agronomic effectiveness of humid savannah soils. Therefore, they can be use as an alternative to slash-and-burn agriculture in Central Côte d'Ivoire.

Keywords: Conservation Agriculture, Herbaceous legumes, Humid savannas, Nutrient use efficiency, Côte d'Ivoire.

INTRODUCTION

Soil conservation is one of the most effective ways to improve the productivity of small farmers. It aims to maintain soil fertility by preserving soil structure, organic matter, nutrients, water and organisms (Lal and Pierce, 1991). Soil organisms are known to provide a variety of essential services for the sustainable functioning of all ecosystems and are important resources for sustainable management of agroecosystems (Altieri, 1999; Lavelle et al., 2006). These ecological services include recycling of nutrients, regulation of microclimate and local hydrological processes, suppression of undesirable organisms and detoxification of noxious chemicals (Blanchart et al., 1997; Decaëns et al., 2001; Araujo et al., 2004)

Many studies conducted in central Côte d'Ivoire reported the inherent low fertility level of soils and this has been recognized the principal cause of poor agricultural productivity (Bonvallot, 1968; Riou 1974; Gilot-Villenave et al., 1996; Hgaza et al., 2010). They are sandy (coarse particles >85%) and clays are constituted of illite and kaolinite, which are known to have low adsorption capacity. In addition, these soils experience rapid mineralization of organic matter (Abbadie, 1990) leading to a rapid drop in soil fertility after conversion to food crop. Therefore, farmers are still practicing shifting and slash-and-burn agriculture which is known to constitute an important source of CO_2 emissions. In order to overcome this situation and mitigate carbon dioxide emissions, novel agricultural systems that meet the "Conservation agriculture" should be implemented in the region. Using green manure is a promising option of conservation agriculture. Legume cover crops are known to provide many services to agroecosystems. In particular, they improve soil nutrient retention, and build soil organic matter, decrease soil erosion, improve water infiltration and reduce runoff (Battany and Grismer, 2000; Tian et al., 2001, Okpara et al. 2005; Koné et al., 2008a).

The potential of herbaceous legumes as green manure crops and for soil conservation has been well documented. However, up to now, studies focusing on the legume-derived nutrient use efficiency by crops in sandy soils remain scarce. Indeed, it has been reported that the efficiency of nutrient use by crops is a function of an array of factors such as the soil and the source of nutrients (Kho, 2000; Chikowo et al., 2009). In addition, more information is needed regarding the response of earthworms to legume cover crops in such sandy soils. Beside, studying the ability of different legumes species in a given agroecological zone is essential in determining the most relevant for this zone.

The aim of this study was first, to examine, in the short run, the efficiency of legume cover crops to improve soil N and P contents as well as the density of soil invertebrates, particularly, earthworms. Second, this study intended to assess the efficiencies with which N and P provided by legume residues are taken up by maize, compared to N and P mineral fertilizers.

MATERIALS AND METHODS

Study site

The study was carried out in the surrounding zone of the Lamto reserve (6°13' N and 5°20' W) located in middle Ivory Coast. Vegetation structure was a mosaic of forests and savannas. The slash-and-burn agriculture is the main agricultural system in the region. The climate is of a subequatorial type with two wet seasons and two dry seasons. The temperature is nearly constant throughout the year, averaging 27 °C. The annual rainfall averages 1200 mm (Pagney 1988). Soils are Alfisols (American system). The experiment was laid on a slightly acidic soil, with pH values around 6. Surface soil fine fraction was about 17%; the chemical characteristics, measured on the 0-10 and 10-20 cm layers, were the followings, respectively: organic C: 7.5-6.7 g kg^{-1}, total N: 0.52-0.49 g kg^{-1}, available P: 17-13 mg kg^{-1}, cation exchange capacity (CEC): 4.75-3.3 cmol kg^{-1} (Koné et al., 2008b).

Experimental design

The experiment has been described in detail by Koné et al. (2008b). A randomised complete-block design, with three replications, was set up in a 6240 m² area located in a shrubby savanna. The blocks were separated by 4 m intervals, and plots of 192 m2 (8 x 24 m), by 2 m intervals. Eight treatments, involving four legumes cover crops and four continuous maize cropping were used (1) Mucuna pruriens (Mucuna), (2) Pueraria phaseoloides (Pueraria), (3) Lablab purpureus (Lablab), (4) a combination of the legumes (Legume mix), (5) maize fertilized with urea (50 kg ha-1) (Maize-U), (6) maize fertilized with triple super phosphate (30 kg ha-1) (Maize-Sp), (7) maize fertilized with the two fertilizers at the same rate (Maize-USp) and (8) continuous maize cropping without fertilizer (Maize-Tradi, Control).

Growth conditions

Trials lasted two years. Legumes and maize were hand-sown during the rainy season. Legumes were grown for 12 months, at 0.5 x 0.5 m spacing. Maize plots were cropped twice in the same period, at 31 000 ind. ha^{-1}. By the end of the first year, the legume covers and the natural regrowth on the continuous cropping plots were slashed and applied as mulch, then maize was sown on all plots. Triple super phosphate was applied to maize once at sowing, at the rate of 30 kg N ha^{-1}. Urea was applied at the rate of 50 kg N ha^{-1}, into two applications: 1/3 at sowing and 2/3 at 40 days after sowing, according to the standard of the international Institute of Tropical Agriculture (IITA) (Kang, 1997). No fertilizer was applied to plots with previous cover crops.

Soil sampling protocol and analyses

Soil from each plot was sampled before land clearance and 12 months after treatments establishment. On each plot, soil samples was collected from nine points using an auger and then, mixed into a composite sample. This composite sample was air-dried at ambient temperature and then, crushed and sieved at 2 mm before being stored in plastic bags for chemical (N and P) analyses.

Soil N were determined using the Near Infrared Reflectance Spectroscopy (NIRS) technique (Ludwig *et al*., 2002; McCarthy *et al*., 2002). Soluble P was extracted according the Olsen-Dabin method (in a mixture of $NaHCO_3$ and NH_4F, at pH 8.5) and measured by colorimetry at 660 nm (Murphy and Riley 1962).

Earthworm sampling protocol and identification

Earthworms were sampled following the method described in the TSBF handbook of methods (Anderson & Ingram 1993). In each plot, sampling was done in the following way: 2 soil monoliths of 25x25x30 cm size each were taken. Earthworms were collected directly by hand sorting and then stored in a 4 % formaldehyde solution until they are identified. They were identified either using reference specimens confirmed by the Natural history Museum in Budapest (Hungary) or following the identification keys by Omodeo and Vaillaud (1967) and Csuzdi and Tondoh (2007). Individuals were then counted and weighed, in order to determine their abundance.

Plant biomass, chemical analyses and nutrient stocks

The dry-matter yields of the cover crops were measured at they carried dry pods. Above-ground biomass sampling was done within a 1 x 1 m quadrat, at three points distributed over each plot, i.e. a total of nine replicate samples per treatment. Fine roots were sampled using soil monoliths of 25 x 25 x 40-cm size disposed within the 1-m² quadrat defined above. Maize stover and grain yields were determined at harvest. Plant samples were oven-dried at 60°C for 72 h, then weighed. A 20-g subsample of each plant material was finely ground and stored in a plastic bag for chemical (N, P) analyses.

Nitrogen was determined using the standard Kjeldahl digestion method. Phosphorus was determined by colorimetry after nitriperchloric acid digestion and subsequent molybdenum-blue colour development.

Nitrogen and phosphorus stocks in legume and maize biomasses were determined as following: N or P stock (kg ha^{-1}) = N or P concentration (%) x Plant dry-matter yield (kg ha^{-1})

Apparent legume-N and P recovery in maize

Apparent recovery of legume-N and P in maize was calculated in the same manner. For instance for legume-N (Moura et al, 2010):
Apparent Recovery of legume-N in maize (%) = [(Total maize N uptake after legume – Total maize N uptake in control)/ N stock in legume] x 100.

Legume N and P fertilizer replacement indexes (N-, P-FRI)

The legume N- and P-fertilizer replacement indexes were calculated in the same manner, according to Tian et al. (2000)/. For instance:

PFRI (kg P ha^{-1}) = ($QP_{maize\ after\ legume}$ – $QP_{maize\ on\ control}$)/ Maize total P uptake increase by P fertilizer; With Maize total P uptake increase by P fertilizer = ($QP_{maize\ with\ \mathrm{superphosphate}}$ - $QP_{maize\ on\ \mathrm{control}}$)/30; Where QPmaize $_{after\ legume}$ is the P uptake in maize grown on the legume plot, $QP_{maize\ on\ control}$ P uptake in maize grown on the control, $QP_{maize\ with\ \mathrm{superphosphate}}$ P uptake in maize grown on plots fertilized with triple superphosphate and 30 is the rate of application of the inorganic P (triple superphosphate).

Statistical analyses

Statistical analyses were performed using STATISTICA 6.0 Software. Data related to the soil chemical parameters were subjected to the Mann-Whitney and the Kruskal-Wallis ANOVA tests while earthworm density were subjected to one-way anova for mean comparisons. The statistical analyses were done at $\alpha = 0.05$ level.

RESULTS

Legume biomass yields

Total biomasses comparison did not chow any significant difference between legumes, even *P. phaseoloides* yielded the highest biomass (Table 1). However, there were significant differences regarding belowground biomasses. *H diplandra* (control) was by far higher than the legumes. *P. phaseoloides* and *L. purpureus* showed similar belowground biomasses, and both were higher than *M. pruriens*.

Earthworm density evolution

Data showed that the earthworm density increased significantly (p = 0.03) over time under *L. purpureus* and *P. phaseoloides* (Table 2). Values shifted from 45.3±15.1 to 143.3±36.8 ind. m^{-2} under the former, and from 34.7±13.9 to 61.3±11.2 ind.m^{-2} under the later, between the start and the end of trials. These corresponded to 211.8% and 76.9 % increment, respectively. In contrary, a significant decrease (-77.8%) was observed under the control (continuous cropping without fertilizer). Variations were not significant under the others treatments though a constant decrease occurred on fertilized plots.

Between-treatment comparisons showed significant differences at 12 months (anova 1, p = 0.001, F = 4.3), with higher values for *L. purpureus* and *P. phaseoloides.*

When considering the treatments regarding the two main systems, legume systems *vs* continuous cropping, the earthworm density increased over time under the former while it gradually decreased under the later (Figure 1). The density value was higher under the legume systems than the continuous cropping one, at 12 months (72.0 ± 13.6 ind.m^{-2} *vs* 28.0 ± 7.5 ind.m^{-2}; p = 0.006).

Evolution of Total N and soluble P in soil

Total soil N increased significantly under the legume plots and those fertilized with urea (Table 3). Increments were the highest under legumes, with values varying from 14.9% (*M. Pruriens*) to 23.6% (*L. purpureus*). In total, the increment observed for the legume systems averaged 19.3% whilst that for the continuous maize was 12.1% at 12 months after treatments establishment. However, comparing total soil N contents between individual treatments at that period did not show any significant differences.

As for soil soluble phosphorus, significant differences ($p = 0.03$) were observed between treatments at 12 months after sowing, with higher values for the legume plots (Table 4). Mean soluble P content for the legume system was 29.0 ± 4.3 g kg^{-1} *vs.* 12.3 ± 2.8 g kg^{-1} for the continuous cropping one. When considering evolution over time, significant increases were observed under the legume plots, particularly *M. Pruriens*, *L. purpureus* and the legume mix. In contrary, soil P decreased on the continuous cropping plots. The decrease was more pronounced on plots fertilized with urea (*i.e.* U and USp). Overall, soil soluble P increased by up to 66.6%, on average, under the legume system whilst it decreased by up to 34.4% under continuous cropping.

Maize yield

Maize yield varied significantly between treatments, particularly regarding grain yield ($p = 0.04$) and total biomass ($p = 0.04$). Values were higher for the legume plots, compared to the continuous cropping ones, despite N and P applications (Figure 2). Total maize biomasses on legume plots were 3.5, 2.5, 2.3 and 2.2 t ha^{-1} for *P. phaseoloides*, *M. pruriens*, legume mix et *L. purpureus* respectively while maize grain yield were 836.3, 652.6, 579.5 and 471.8 kg ha^{-1}, for *P. phaseoloides*, legume mix, *L. purpureus* and *M. pruriens* respectively. As for the continuous cropping plots, total maize biomasses were 1.6, 1.3, 1.2 and 0.8 t ha^{-1} and grain yields, 559.4, 414.0, 283.6 and 184.2 kg ha^{-1}, on Maize-USp, Maize-U, Maize-Sp and the control, respectively.

N accumulation in legume biomasses, and use efficiency by maize

Total N accumulation in legume biomasses varied significantly from one species to the other. Values were all higher than the rate of application of N-Urea (50 kg ha^{-1}). The N accumulation was the highest in *L. purpureus*, intermediate in *M. pruriens* and the lowest in *P. phaseoloides* (Table 5). However, apparent N recovery in maize grown on *P. phaseoloides* plots was the highest (29%), compared to the two legume plots; they showed similar values, but this was higher than that of N-urea (13%).

The N uptake by maize on the legume plots was significantly higher than that on the urea-plots (12.3 kg ha^{-1}). Differences between legume plots were not significant; the highest value was record on *P. phaseoloides* and the lowest on *M. pruriens* (Table 5). The N-FRI recorded on the legume plots ranged from 131 (*M. pruriens*) to 195 (*P. phaseoloides*) corresponding to an equivalent application as urea. Therefore, the contributions of legumes to maize biomass yield were higher than that of an application 50 kg ha^{-1} of urea.

P accumulation in legume biomasses, and use efficiency by maize

Unlike N, the P accumulation in legume biomasses was lower than the rate of triple superphosphate application (30 kg ha^{-1}) (Table 6). Between-legume species differences were not significant. However, apparent P-recovery in maize varied significantly (p=0.04), with the highest value on *P. phaseoloides* plots and the lowest on plots fertilized with triple superphosphate.

Except for *P. phaseoloides*, the P uptake by maize on the legume plots was similar to that on plots fertilized with triple superphosphate. However, the P-FRI recorded on the legume plots was higher than 30 kg ha^{-1}, indicating that the contribution of legumes to maize P-nutrition was higher than that of the application of 30 kg ha^{-1} of triple superphosphate. The higher value was recorded on *P. phaseoloides* plots.

DISCUSSION

Legume biomass yields

Biomass production by *M. pruriens* was similar to that reported (4.15 $t.ha^{-1}$) by Becker and Jonhson (1998) at Bouaké in central Côte d'Ivoire. However, the value was lower than that reported (10 $t.ha^{-1}$) by Azontonde et al. (1998) in Benin, the difference may be ascribe to a more fertile soil as the plot was grown with *M. pruriens* for a long time before measurements. Our value was higher than that (3.03 $t.ha^{-1}$) of Okpara et al. (2005) in Nigeria, may because of a higher soil P content (Houngnandan *et al*., 2001). This is probably the reason why biomass production by *P. phaseoloides* was also higher than that in Nigeria (1.2 to 2.7 t ha^{-1}) (Okpara et al., 2005). Value reported by Tian et al. (2001) was similar to that of our study. As for *L. purpureus*, its biomass yield was higher, compared to that reported (3.8 $t.ha^{-1}$) by Becker and Jonhson (1998) in Bouaké where rainfall was lower than at Lamto.

Impact of legume cover cops on earthworm population

Earthworms are influenced by several factors, of which the aboveground vegetation characteristics have been widely reported. Earthworm density was shown to be increased under N-richer litters (Mboukou-Kimbasta et al., 2007; Tian et al.; 1993). Data from this study are consistent with this observation since N content (r = 0.87 at 6 months) in litters and the C:N ratio (r = -0.9 at 6 months) significantly correlated with earthworm density. The continuous litterfall on legume plots is another factor that benefits earthworms; these organisms are provided with energy source regardless the maintenance of soil moisture (Norgrove et al., 2003; Schmidt et al., 2003; Ortiz-Ceballos and Fragoso, 2004). All these may explain why earthworm density was higher under legume plots than continuous cropping ones. The decrease in earthworm density under *M. pruriens*, unlikely to the other legume plots, can be ascribed to two reasons: (i) leaf litter from this species was harder than the others and (ii) the species completed its cycle after nine months and then, the soil was exposed to sunlight whereas the others legumes stands were still alive. The development of earthworms was more favoured by the introduction of *P. phaseoloides* and *L. purpureus* than *M. pruriens* and mineral fertilizer applications.

When considering the plots where fertilizers were applied, earthworm density was the highest on the U-fertilized ones (Maize-U and Maize-USp). This result may be explained by the probable increase in maize residue quality and the greater quantities left at the soil surface as mulch, after maize harvesting. Overall, a gradual decrease in earthworm density was observed on all the continuous cropping plots, this trend is attributable to soil perturbation (Birang et al., 2003; Tian et al., 2000). The results confirm other studies showing that soil macrofauna is deeply affected by management and land-use changes (Blanchart et al., 2006).

Nitrogen and phosphorus availability

Own to their ability to fix atmospheric N, legumes provided N-richer residues to soil, this is one reason for their use for soil fertility improvement in many parts of the world (Dinesh *et al*., 2004; Moura et al., 2010). This explains increase in N and P observed under legumes in the soil layer. The increase in soil N under continuous cropping (Maize-U and Maize-USp) is attributable to the association of maize residues and fertilizers which enhanced decomposition by soil microorganisms (Shrestha et al., 2002; Whitbread and al., 2003; Koné et al., 2008b). It could also result from the accumulation of inorganic N in soil.

The increase in soil soluble P content under legumes might be a consequence of the supply with great quantities of organic residues that reduced the sorption capacity of the soil and enhanced the P desorption rate (Dossa et al., 2008). In addition, legumes improved the availability of P through the secretion of root exudates (Horst and Kamh, 1998). As for the continuous cropping plots, soluble P content remained constant over time where urea was not applied. On contrary, where it was applied, the P availability decreased drastically, suggesting a detrimental effect of urea application on P availability in the study soil. The lack of increase in soil soluble P despite inorganic P application on Sp plots may be due to the conversion into immobile forms as usually observed (Holford, 1997). The difference between legume-based treatments and the others in term of N and P availability can also be linked to the difference in earthworm abundance. The role of these soil organisms in nutrient cycling has been reported by previous authors. They participate in litter decomposition, mix organic and mineral matter and their egested casts are higher in P and N, in comparison with surrounding soil (Jimenez et al., 2003, Kuczak et al., 2006). The transfer of the nutrients from the casts to the soil occurs through diffusion as well as after fragmentation by rain-drops (Mariani et al., 2007).

Nutrient (N and P) use efficiency

Our data showed that N stocks in legume biomasses were higher than quantity of fertilizer-derived N. This was not the case for P stocks in legume biomasses. However, the quantities of N and P recovered in maize on legumes plots were all superior to that on fertilized plots. Value recorded for *P. phaseoloide*s was similar to that reported by Tian et al. (2000b) while those of the two others legumes were lower. The urea-N recovered was also lower than that reported by the same authors (27%). These differences may be due to ascribe to difference in soil response to urea application, particularly at high rate.

Though the quantities of N in *P. phaseoloides* biomass was lower than those in the two others legumes, the quantity of N recovered in maize was the highest. This can be explained by the lower decomposition rate of *P. phaseoloides* litter and lower N release (data not shown), leading to the reduction of N losses. *L. purpureus* and *M. pruriens* completed their cycles about two and three months respectively, before the maize sowing whereas legumes stands were still alive on both the *P. phaseoloides* and the legume combination. Thus, leaf litters were subjected to rapid decomposition, and the soil, to rainfall and run-off, leading the lost of a part on the nutrient stock. As N, P experienced a slower release from *P. phaseoloides* litter; this can be considered a reason why the P recovery in maize was higher on this plots than on the others. It should be emphasized that the quantity of P in *P. phaseoloides* biomass and P recovery in maize seemed to have be under-estimated. Indeed, the legume biomass yield measurements were done when plants carried dry pods, supposed to correspond to the period of maximum biomass. However, biomass build-up continued on *P. phaseoloides* plots, as the species is a perennial one. Thus, the quantity of P in biomass right before slashing and maize sowing was actually higher than that measured at the pod stage. This is probably the reason why the P quantity recovered in maize was higher than that in *P. phaseoloides* biomass.

The N-FRI recorded in our study were all superior to those reported by Tian et al. (2000), this could be due to the lower fertility level of soils in our study. According to these authors, the lower the initial soil fertility level, the higher N-FRI, since calculations included maize biomass on the control (non-treated plot). The higher values of N- and P-FRI for the legumes, compared to the rate of fertilization (50 kg ha^{-1} and 30 kg ha^{-1} for urea and triple superphosphate, respectively), the nutrient uses were more efficient on legume plots. Litter accumulation under legume provided specific advantages, particularly the mulching effect which is known to improve nutrient uptake by crops. It consists in improving soil biological activity, soil structure and aeration, conserving soil humidity, etc. (Tian et al., 1993b; Vanlauwe et al., 2001; Salako et Tian, 2003).

CONCLUSION

This study showed that total soil nutrient contents as well as earthworm density were significantly improved under legume-based systems. Maize mineral nutrition was better on legume plots than in continuous cropping, leading to great increase in maize yield. Their adoption by farmers as conservation agriculture can serve as a basis for sustainable agricultural production in the area and therefore, as an alternative to slash-and-burn agriculture, leading to the reduction of carbon dioxide emission.

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Tables

Table 1: Legume biomass yields. (*: dominant grass species in the savana, used as control, ns: no between-species difference)

Legume species	Biomass (t ha^{-1})		
	Aboveground	Belowground	Total
M. pruriens	4.79 ± 0.7	0.09 ± 0.02	4.88 ± 0.7
P. phaseoloides	5.86 ±0.4)	0.57 ±0.05)	6.43 ± 0.4
L. purpureus	5.17 ± 0.65	0.5 ± 0.09	5.66 ± 0.7
*H. diplandra**	4.4 ± 0.5	0.97 ± 0.06	5.4 ± 0.6
Kruskal-Wallis, p	ns	0.004	ns

Table 2: Earthworm density evolution under treatments. Means with different letters in a column are significantly different at the 5% level.

Traitements	Earthworm density ($Ind.m^{-2}$)		
	0 month	6 months	12 months
M. pruriens	74.7 ± 34.5 a	72 ± 12.2 a	32 ± 13.7 b
P. phaseoloides	34.7 ± 14 a	53.3 ± 14 a	61.3 ± 11.3 b
L. purpureus	45.3 ± 15 a	69.3 ± 22 a	141.3 ± 37 a
Legume mix	58.7 ± 17.4 a	48 ± 14.3 a	53.3 ± 18.8 b
Maïs-U	53.3± 24.3 a	45.3 ± 19.1 a	34.7 ± 20 b
Maïs-Sp	56 ± 23.3 a	37.3 ± 14.7 a	16 ± 10 b
Maïs-USp	72 ± 22.5 a	56 ± 11.5 a	40 ± 19 b
Maïs-Tradi	96 ± 33.6 a	29.3 ± 11.3 a	21.3 ± 9.8 b

Table 3: Soil N contents under the different treatments. (*: significant different between the start and the end of trials at α = 5% level).

Treatments	N (g kg-1)		Increment (%)
	0 month	12 months	
M. pruriens	0.54 ± 0.01	0.62 ± 0.02	14.9 *
P. phaseoloides	0.51 ± 0.02)	0.59 ± 0.01	17.1 *
L. purpureus	0.5 ± 0.02)	0.62 ± 0.01	23.6 *
Legume mix	0.53 ± 0.0)	0.65 ± 0.02	21.6 *
U	0.49 ± 0.02	0.57 ± 0.01	15.6 *
Sp	0.56 ± 0.02	0.6 ± 0.03	8.1
USp	0.53 ± 0.01	0.59 ± 0.01	12.3 *
Tradi (control)	0.54 ± 0.03	0.61 ± 0.03	12.4

Table 4: Soluble P contents under the different treatments. (*: significant different between the start and the end of trials at α = 5% level).

Treatments	Soluble P (mg kg^{-1})		Increment (%)
	0 month	12 months	
M. pruriens	18.7 ± 1.8	26.7 ± 3.8	42.9*
P. phaseoloides	16.7 ± 3.2	18.3± 0.7	10.0
L. purpureus	17.7 ± 0.9	32.3 ± 5.2	83.0*
Legume mix	16.8 ± 2.7	38.7 ± 6.2	130.6*
U	16.3 ± 1.3	7.4 ± 0.7	-54.9*
Sp	17.0 ± 1.5	15.3 ± 8.6	-9.8
USp	19.3 ± 5.4	7.7 ± 3.3	-60.3*
Tradi (control)	21.3 ± 2.4	18.7 ± 2.9	-12.5

Table 5: N quantities in legume and maize biomasses, and maize N-nutrition parameters

Treatments	N stock in legume	Maize N uptake	Apparent N recovery (%)	N-FRI
	(kg ha-1)			
M. pruriens	101.5 ± 16.7	22.7 ± 6.6	16.6	130.8
P. phaseoloides	86.4 ± 9.5	31.0 ± 6.9	29.1	195.7
L. purpureus	112.4 ± 8.2	24.7 ± 7.0	16.8	146.8
Legume mix	-	26.8 ± 3.5	-	162.9
Maïs-U	50.0 ± 0.0	12.3 ± 3.1	12.9	50.0

Table 6: P quantities in legume and maize biomasses, and maize P-nutrition parameters

Treatments	P stock in legume	Maize P uptake	Apparent P recovery (%)	P-FRI
	(kg ha-1)			
M. pruriens	4.4 ± 0.7	2.8 ± 0.8	34.6	35.5
P. phaseoloides	4.3 ± 0.5	5.4 ± 1.1	92.8	96.0
L. purpureus	4.0 ± 0.3	2.4 ± 0.6	29.5	27.5
Legume mix	-	3.1 ± 0.6	-	43.6
Maïs-Sp	30.0 ± 0.0	2.5 ± 1.1	4.3	30.0

Figures

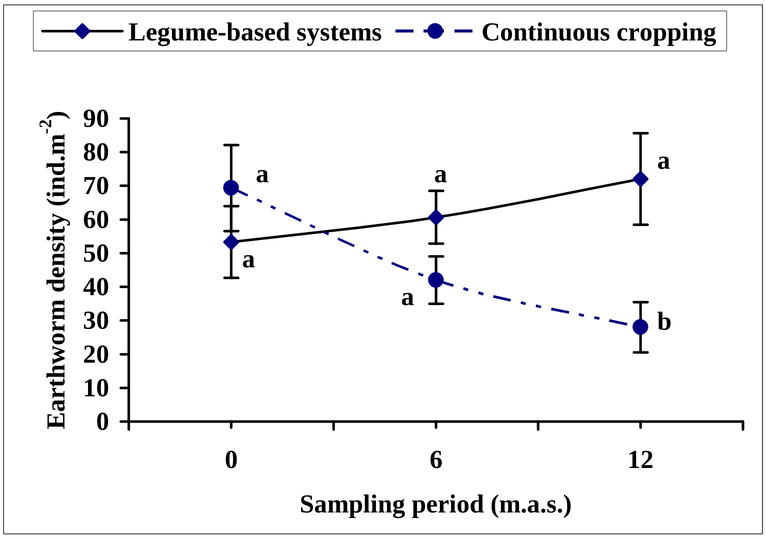

Figure 1: Earthworm density evolution under the two main cropping systems. For the same sampling period, means with different letters are significantly different at the 5% level.

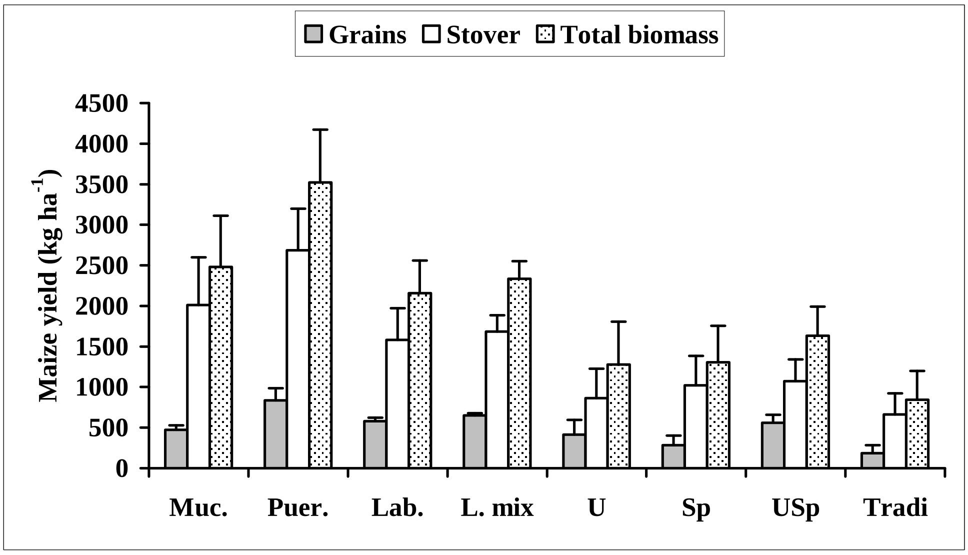

Figure 2: Maize yields recorded on the different treatments.