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ORIGINAL PAPER

Comparative study of earthworm communities, microbial biomass, and plant nutrient availability under 1-year *Cajanus cajan* (L.) Millsp and *Lablab purpureus* (L.) Sweet cultivations versus natural regrowths in a guinea savanna zone

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Abstract In tropical savannas where soils are generally sandy and nutrient poor, organic farming associated with enhanced soil biological activity may result in increased nutrient availability. Therefore, legumes have been introduced in the humid savanna zone of Côte d'Ivoire, owing to their ability to fix atmospheric N and to continually supply soil with great quantity of organic materials in relatively short time. The main objective of this study was to assess the influence of two legume (*Cajanus cajan* and *Lablab purpureus*) cultivations on earthworm communities and P and N availability. Trials were carried out under farmers' field conditions; *C. cajan* was planted on savanna soils (trial 1) while *L. purpureus* was established on new *Chromolaena odorata*-dominated fallow soils (trial 2). Native vegetations were considered as controls. Changes in soil properties (earthworm abundance and diversity, microbial biomass carbon (MBC), and plant available P and N) were assessed using the biosequential sampling. After 1 year, both the legume stands showed a significantly higher density of earthworms, compared with the respective controls. This trend was linked to an increase in the abundance of the detritivores *Dichogaster baeri* Sciacchitano 1952 and *Dichogaster saliens* Beddard 1893, and the polyhumic *Stuhlmannia zielae* Omodeo 1963. Equally, legume had beneficial impacts on the average number of earthworm species, the Shannon–Weaver index of diversity and MBC in savanna (trial 1). Available P and ammonium significantly increased under both legume cultivations and were significantly and concurrently linked to litter quality and earthworm activities as shown by multiple regressions. As a result, legumes could improve nutrient availability in the sandy soils of central Côte d'Ivoire by positively affecting soil biological activity and this could bring farmers to cultivate crops on savanna lands.

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Introduction

Soils from humid savannas in central Côte d'Ivoire are characterized by a low fertility level (Delmas 1967) leading to major constraints in crop production. Their sandy status and the low activity clays they contain are the main factors driving this deficiency. Although savanna lands are the most frequently occurring in the region, they remain less cultivated, even marginalized because they are more nutrient poor. Farmers prefer cultivating on *Chromolaena odorata* (Eupatorium, Siam weed) fallows or the rare forest lands which have more fertile soils. However, there is not enough of these lands to meet the increasing need for agricultural production. Therefore, (1) there is a great need to implement soil management strategies that practically could reduce fallow periods, from 5 to 6 years as currently practiced to 2–3 years. (2) It is also of importance to improve the fertility level of savanna lands; this would help farmers to cultivate crops on these lands in the future.

Faced with the kind of soil encountered in the region, organic farming may constitute a promising alternative (Craswell and Lefroy 2001). Indeed, in the absence of high exchange capacity clay, SOM becomes the main determinant of fertility, nutrient storage, aggregate stability, and microbial activity (Feller 1995). For this reason, leguminous plants have recently been introduced in central Côte d'Ivoire and are being promoted among farmers (Koné et al. 2008a, b). These are known to supply N rich and easily decomposable litter materials, leading to soil organic matter build up and increased plant available N (Dinesh et al. 2004; Fofana et al. 2005), and therefore, these plants might be highly beneficial for savanna ecosystems which are generally nutrient poor, especially for nitrogen. Nevertheless, the use of legume may result in increased soil N mineralization, leading to greater concentration of nitrate (Scherer-Lorenzen et al. 2003), which is known to be easily lost from the rhizosphere through leaching or denitrification. However, this risk may be restrained by soil organic matter in the long term.

The issue of plant P availability in soils has been of a great concern for agronomists and farmers inasmuch as this element is mostly present in soil in insoluble forms (Holford 1997). In the moist savanna zones of West Africa where P is the second most limiting nutrient after N (Nwoke et al. 2003; Chivenge et al. 2010), the efficiency of its cycling which drives its availability in soil take a great importance, particularly in low-input farming. This ecological process gains more importance in central Côte d'Ivoire given the fact that soils are inherently P poor (Delmas 1967). Therefore, it may be highly important to know about the influence of legumes on P cycling in this region. There are some reports on the potential of some legumes to improve plant available P by dissolving immobilized soil P through exudation of organic acids (Kamh et al. 1999; Lyasse et al. 2002). Other studies reported that supplying organic residues to low-P soils leads to improved plant P availability through decreasing the precipitation of P as insoluble compounds, desorbing the fixed P in soils and providing extra supply of P during their decomposition (Cong and Merckx 2005; Ikerra et al. 2006).

Soil organisms are key components in soil fertility; they gain more importance in sandy savanna soils as they control the cycling of nutrients (Lavelle 1997; Knapp et al. 2011). However, their efficiency in nutrient cycling depends upon abiotic factors such as the characteristics of organic residues (Knapp et al. 2011). In this respect, earthworms which are recognized as significantly impacting nutrient cycling and soil fertility (Blanchart et al. 1997; Fonte et al. 2009; Le Bayon and Milleret 2009) were reported to be influenced by the diversity (Tondoh et al. 2007), the quantity (Norgrove et al. 2003; Curry et al. 2008), and the quality (Tian et al. 1993; Belote and Jones 2009; Norgrove et al. 2009) of plant litters. Therefore, it would be highly relevant to examine the influence of the introduced legumes on the communities and the activities of these organisms.

Most of the works dealing with herbaceous legumes in guinea savannas of West Africa focused on the availability of N and the yield of cereal crops (Tian et al. 2000; Fofana et al. 2005; Franke et al. 2004). However, very few studies focused on the impacts of the legumes on soil invertebrates, particularly earthworms (Blanchart et al. 2006). Likewise, their impact regarding P cycling was less investigated, due to the fact that N supply in general is the principal reason of the use of legumes. The objective of this study was to compare (1) soil biology, particularly earthworm communities and microbial biomass C, and (2) plant available P and N between 1-year stands of *Cajanus cajan* and *Lablab purpureus* and native vegetations represented by savanna stands and *C. odorata* fallows, respectively.

Material and methods

The study area

The study was conducted in humid savannas of the "V Baoulé", precisely around the village of Ahérémou-2 (6′10–6′15 N and 4′55–5′00 W). The vegetation structure is a mosaic of secondary forests, shrubby and woody savannas, *C. odorata* fallows, and various agroecosystems. Savannas are the most represented vegetation feature and characterized by the presence of *Hyparrhenia diplandra* and *Imperata cylindrica* grass species, as well as shrub species such as

Bridelia ferruginea, *Cussonia barteri*, *Crossopteryx febrifuga*, and *Terminalia glaucescens*. The palm tree *Borassus aethiopum* is an important component of the landscape.

The climate is of a subequatorial type with four seasons: a long dry season from December to February, a long wet season from March to July, a short dry season in August, and a short wet season from September to November. The temperature was nearly constant throughout the year, averaging at 27°C. The annual rainfall averaged 1,200 mm.

Soils were moderately leached Ferralsols with granite as the main bedrock. Upper layers were generally of sandy texture (60% to 80% of the elements have sizes higher than 500 µm). Clays consisted of illites and slightly crystallized kaolinites, with a low adsorption capacity (Delmas 1967).

Experimental design and plot description

The study was carried out under farmers' field conditions from June 2009 to June 2010. Changes in soil properties were assessed through biosequential sampling, where soils under adjacent different land use systems are sampled at the same time (Tan 1996). The main underlying assumption is that the treated soil and the non-treated one (control) are similar and that differences observed in soil properties are attributed to the treatment. Even if this is not always the case, we considered that soils were similar given the relatively small size of our plots. The data supplied by the biosequential samples provided useful information and such a sampling strategy has been used in much of the works conducted in tropical region on soil changes after land invasion by or introduction of plants (Koutika et al. 2001, 2004; Dinesh et al. 2004; Osunkoya and Perrett 2011).

This study was composed of two trials. In trial 1, *C. cajan* was tested in natural savanna plots (n=3) which have never been cultivated and where soils are light colored, with an average finer particle content of 8% in the top soil. The dominant grass species were *H. diplandra* and *I. cylindrica*. In trial 2, *L. purpureus* was tested on soils newly left to fallow dominated by the shrub *C. odorata* (n=3) and which were yellow in color with higher finer particle content (about 15% in the topsoil). Before being left to fallow, the *C. odorata* lands were cultivated for 3 years on average with different crop plants in the following order: yam (*Dioscorea* spp.), plantain (*Musa* sp.), and cassava (*Manihot esculenta*). In total, the study involved six sites distant from each other and which GPS coordinates (latitude, longitude, and elevation, respectively) were the followings: in trial 1: 6°12.4′ N–4°58.1 W, 121 m; 6°13.9′ N–4°57.2 W, 102 m; and 6°13.3′ N–4°55.4 W, 87 m; in trial 2: 6°13.6′ N–4°56.0 W, 108 m; 6°13.5′ N–4°56.2 W, 110 m; and 6°13.2′ N–4° 57.3 W, 128 m. In each trial and at each site, the legume and the control plots were laid side by side, and investigations were conducted concurrently on both plots.

It is important to mention that farmers from the area of study do not usually cultivate on savanna soils. In this experiment, legumes were planted in savanna to see how they can increase the level of fertility of soils and allow the cultivation of cereals in future seasons. The two species, *C. cajan* and *L. purpureus*, were originally planted on these soils since their residues do not interfere with the planting of maize. Unfortunately, *L. purpureus* has not grown on these soils because of low fertility and insufficient rains after planting. However, *C. cajan* could grow. On the other hand, trials were conducted on soil colonized by *C. odorata* for yam production, which is highly nutrient demanding. On these soils, only *L. purpureus* was planted because derived residues do not interfere with the mounding.

Prior to planting legumes, the savanna and *C. odorata* lands were slashed (May 2009) and plant residues were left at the soil surface; stems were retrieved from the *C. odorata* plots. The plots were 42×31 m in size subdivided into two subplots of 20×15-m size. On the one, the legume was planted at 0.5×0.5 m spacing during the rainy season (early June 2009) and grown for 1 year while the other (control) was covered by the native vegetation.

Earthworm sampling design and identification

Earthworms were sampled at the end of June 2010, following the standardized tropical soil biology and fertility methods (Anderson and Ingram 1993). In each plot, five distinct soil monoliths of 25×25×30-cm size each were extracted. Specimens were collected by hand sorting and stored in a 4% formaldehyde solution until they were identified. Identification was done at the Laboratory of Invertebrate Ecology of the National Centre of Ecological Research of Côte d'Ivoire. Earthworms were identified to species levels or, when this proved difficult, to numbered morphospecies (which can be defined as taxonomic species that differ in some morphological respect from all other species). Individuals were then counted and classified following their feeding behavior since this has implications in nutrient cycling. There were mainly the detritivores which feed at or near the soil surface on plant litter and the geophagous which feed deeper in the soil and derive their nutrition from soil organic matter ingested with mineral soil (Lee 1985). The geophagous were divided into three groups: the polyhumics which feed on decaying residues mixed with little mineral soil, the mesohumics which feed on soil fairly rich in organic matter, and the oligohumics which feed on organic matter-poor soil (Lavelle 1981).

Soil sampling and chemical analyses

Soil sampling was conducted concurrently to earthworm sampling. All samples were collected from the 0–10-cm layer at five distinct points distributed over each plot (one at the center and near each of the corners) using an auger. These samples were pooled and thoroughly mixed as a single composite sample, which was further subdivided into two parts. The first was immediately stored in an ice chest and taken to the laboratory where it was kept at 4°C for determining the microbial biomass C (MBC) and mineral N (ammonium (NH_4^+) and nitrate (NO_3^-)); the second was air dried for 1 week, sieved at 2 mm, and kept in plastic bags for chemical analyses.

Soil analyses were conducted on composite samples at the rate of one per plot, i.e., three measurements (replications) for each of the treatments. Plant available P was extracted according to the Bray-1 procedure (Olsen and Sommers 1982) and determined using a Technicon AutoAnalyzer (Technicon Industrial Systems 1977). Carbon was determined using a modified Anne method (Nelson and Sommers 1982). Total N was extracted according to Nelson and Sommers (1980) and determined using Technicon AutoAnalyzer (Technicon Industrial Systems 1977). Exchangeable bases (Ca^{2+}, Mg^{2+}, and K^+) and cation exchange capacity (CEC) were extracted with acetate ammonium and then determined using atomic absorption spectrometry techniques (Thomas 1982). Soil acidity (pH) was determined with a glass electrode in 1:2.5 soil:water ratio. Soil mineral N (nitrate and ammonium) was determined following Bremner (1965) method. Soil MBC was measured using the chloroform fumigation–extraction method (Vance et al. 1987).

Leaf litter sampling and chemical analyses

Both total plant biomass and leaf litter biomass productions by the legumes were determined when they carried dry pods. On each plot, sampling was carried out within a 1×1-m quadrant at three points. The biomass obtained for a plot was the mean of the three pseudo-repetitions. Measurements were done on the respective control plots at the same period.

The chemical composition of leaf litter from each plot was determined on composite samples obtained by mixing the litter materials from the three quadrants. For the savanna plots, chemical analyses were done on senesced leaves cut from the grass tufts. Organic C was determined after mineralization of plant residues using a sulfochromic solution (Walkley and Black 1934), and N was determined using the standard Kjeldahl digestion method (Anderson and Ingram 1993). Phosphorus was determined by colorimetric method following nitri–perchloric acid digestion and molybdenum blue color development (Olsen and Sommers 1982). Major cations were extracted using ammonium acetate buffer (pH 7) and determined by means of atomic absorption spectrophotometry techniques (Anderson and Ingram 1993).

Data treatment

The diversity of earthworms for each treatment (or type of plot) was estimated through two parameters: the species richness and the Shannon–Weaver index of diversity (*H*′) (Pielou 1966). $H' = -\sum Pi.\log_2 Pi$, with $Pi = \frac{ni}{N}$: ni is the number of individuals of a species *i* and *N*, the total number of worms in a soil monolith. The calculations were made as follows: first, the two parameters were determined at the plot level making the average of the values obtained from the five soil monoliths, and second, they were determined at the treatment (*C. cajan*, *L. purpureus*, and *C. odorata*, savanna) level, making the average of the values obtained for the three plots. In addition, changes in earthworm species composition between both legumes and controls plots were estimated using the complementarity index (*C*) of Colwell and Coddington (1994):

$$C = \frac{\text{Sum of species specific to each treatment}}{\text{Combined species richness}} \times 100$$

The mean comparisons between each legume stand and its control were done using the Wilcoxon test which is suited for paired samples, at the 5% level. Since there was a chance that multivariate correlations between leaf litter quality parameters and earthworm densities exist (Tian et al. 1993; Belote and Jones 2009), multiple regressions using General Linear Model procedures were performed on the data to determine how much variation in available P or N can be explained by litters or earthworms. All these statistical analyses were carried out using STATISTICA 6.0 Software program (Statistica, Tulsa, OK, USA).

Results

Initial soil characteristics

Soil was slightly acidic in natural savannas while it was neutral in *C. odorata*-dominated fallows. Organic C and total N contents were higher under *C. odorata* fallows than savannas; the reverse trend was observed for the C:N ratio. Plant available P under the fallow reached nearly three times than that under savannas. CEC and exchangeable bases under fallows were twofold higher than under savannas (Table 1).

Biomass production and leaf litter quality

In trial 1, there was no significant difference in total biomass production between the legume and the grass. However, the leaf litter quantity under the legume was higher than that under the grass cover (Table 2). In trial 2,

Table 1 Main initial soil characteristics (mean±SE, $n=3$) from the two original vegetation features

Soil parameters	Savanna	*C. odorata* fallow
pH water	6.4±0.1	7.2±0.2
Organic C (g kg^{-1})	6.2±1.5	16.9±4.0
Total N (g kg^{-1})	0.3±0.1	1.0±0.2
C/N ratio	22.1±4.9	15.4±1.9
Available P (mg kg^{-1})	6.5±1.1	9.1±7.2
C.E.C. (cmol kg^{-1})	2.7±0.2	7.0±1.6

the total biomass production by the legume was found to be significantly ($p=0.04$) lower than that by *C. odorata*; the reverse trend was observed for leaf litter quantity.

Leaf litter from the legume in savanna was of a higher quality compared to that from the grass (Table 3). It showed significantly higher N, P, K, Ca, Mg and lower C:N and C:P ratios. In trial 2, significant differences were observed between leaf litters from the legume and *C. odorata* in terms of cation contents, the former showing higher Ca and K, and lower Mg (Table 3).

Diversity and abundance of earthworm populations

Overall, 16 species and morphospecies were found on the different plots (Table 4). In trial 1, the average number of species detected in the legume plots (3.1±0.5 species m^{-2}) significantly increased ($p=0.04$) relative to the savanna plots (1.9±0.2 species m^{-2}) while in trial 2, no significant difference was observed between the legume (6.0±1.1 species m^{-2}) and *C. odorata* (5.6±0.4 species m^{-2}) stands (Fig. 1a). The cumulative number of species did not show any significant difference between the legume plots and their respective controls (Fig. 1b). The legume induced a twofold increase ($p=0.04$) in the Shannon–Weaver index of diversity (H') relative to the natural savanna, while no significant change was observed relative to *C. odorata* (Fig. 1c). The species composition of earthworm communities did not strongly differ between the legume plots and the respective controls, as indicated by the relatively low complementary indexes: 33.4% in savanna and 18.7% in *C. odorata*.

Table 2 Plant biomass production (mean±SE, $n=3$) on the different plots

	Total biomass (Mg ha^{-1})	Leaf litter (Mg ha^{-1})
Trial 1		
C. cajan	4.9±0.5	1.2±0.2
Grass	5.4±0.6	–[a]
p	ns	–
Trial 2		
L. purpureus	5.7±0.7	0.8±0.1
C. odorata	12.8±3.0	0.2±0.1
p	0.04	0.04

[a] Not determined because the senesced or dead leaves remained linked to grass tufts together with the green leaves.

The density of earthworm populations was significantly enhanced ($p=0.04$) in the two legume stands (Fig. 2): +62% and +38% relative to the savanna and *C. odorata* stands, respectively. These differences were closely associated to two feeding groups: the detritivores and the polyhumics (Fig. 3a and b) which were twice more abundant in legume plots than in native vegetations.

At the species level, *Dichogaster saliens*, *Dichogaster baeri*, and *Stuhlmannia zielae* were the most responsive to the introduction of legumes. In savanna, the legume induced a fivefold ($p=0.03$) and a onefold ($p=0.04$) increases of the density of *D. saliens* and *S. zielae*, respectively. In trial 2, the legume induced a fourfold ($p=0.04$) and a twofold ($p=0.04$) increase of the density of *D. saliens* and *D. baeri*, respectively.

Soil physicochemical and microbial properties

One year after legume establishments, the soil organic C and total N contents were not significantly impacted, although an increment of 20% was recorded (Table 5).

In trial 1, the C:N ratio rather decreased significantly in the legume plots ($p=0.04$) relative to the savanna plots. The microbial biomass C, the available P, and the soil moisture also significantly increased under the legume ($p=0.04$). No significant change was recorded in mineral N; ammonium prevailed over nitrate.

In trial 2, the C:N ratio recorded under the legume was not significantly different from that under *C. odorata* (Table 5). On the contrary, a twofold increase ($p=0.04$) in available P was observed in the legume plots. Contrary to the observation made in trial 1, nitrate prevailed over ammonium. Soil content in ammonium significantly increased under the legume while that in nitrate decreased. The other soil parameters did not show any significant change.

Multiple regressions performed after combination of all the plots showed that both available P ($R^2=0.97$, $p=0.02$, $F=235.9$) and ammonium ($R^2=0.95$, $p=0.05$, $F=64.2$) were significantly influenced by leaf litter quality and earthworms density. Particularly, available P was influenced by litter P ($\beta=1.1$, $p=0.03$) and the density of detritivores ($\beta=1.3$, $p=0.04$) while ammonium was influenced by litter N ($\beta=2.4$, $p=0.03$) and the density of polyhumics ($\beta=1.3$, $p=0.05$). In contrast, nitrate did not show any significant relationship with leaf litter quality or earthworm density.

Table 3 Quality parameters (mean±SE, n=3) of leaf litters from the different plant species

Litter parameters	Trial 1			Trial 2		
	C. cajan	Grass	*p*	*L. purpureus*	*C. odorata*	*p*
C (%)	41.4±3.0	40.6±0.3	ns	41.6±0.8	42.7±0.4	ns
N (%)	1.3±0.1	0.2±0.0	*	2.1±0.3	1.8±0.1	ns
P (g kg^{-1})	0.7±0.0	0.2±0.0	*	1.1±0.1	1.6±0.2	ns
Ca (g kg^{-1})	13.5±0.5	5.6±0.2	*	28.7±2.7	22.3±0.9	*
Mg (g kg^{-1})	3.6±0.5	1.8±0.1	*	3.8±0.1	8.3±0.7	*
K (g kg^{-1})	2.3±0.4	0.9±0.1	*	9.6±1.6	4.4±0.7	*
C/N	31.1±1.0	191.1±9.1	*	20.2±2.4	24.0±1.4	ns
C/P	581.9±6.8	2486.1±183.3	*	393.5±25.4	276.2±47.2	ns

Asterisk significant difference at the 5% level, ns: nonsignificant difference

Discussion

Initial soil characteristics and quality of leaf litters

Initial soils had low fertility level in both *C. odorata* and savanna lands. The soil C in savanna was lower than 11 mg kg^{-1}, defined as the threshold of fertility level for tropical soils by Lal (1997). This low soil C was linked to the coarse texture and the low exchange capacity clay (kaolinite, illite) which composed these soils (Delmas 1967).

Based upon the classification made by Jamaludheen and Kumar (1999) and considering N contents in litters of this study, leaf litter from *L. purpureus* and *C. odorata* can be considered as N rich (N>15 mg g^{-1}) while that of *C. cajan* was fairly N rich (10 mg g^{-1}<N<15 mg g^{-1}) and that from the savanna, N poor (N<0.10 mg g^{-1}). These N content levels have great influence on soil biological activity and nutrient cycling (Tian et al. 1993; Belote and Jones 2009).

Earthworm diversity and abundance

The introduction of legumes significantly impacted the earthworm community structure. These results are in line with observations made in previous studies which showed that plant species influence soil organisms through the quantity and the quality of their litter (Gonzàlez and Zou 1999; Belote and Jones 2009; Norgrove et al. 2009). In both trials, the density of earthworms was responsive to the introduction of legumes, particularly the detritivores (name-

Table 4 List of species and morphospecies of earthworms collected and their abundance beneath the two legumes covers and the respective controls (Savanna and *C. odorata*)

Family	Earthworm species	Feeding groups	Trial 1		Trial 2	
			C. cajan	Savanna	*L. purpureus*	*C. odorata*
Acanthodrilidae	*Dichogaster leroyi* Omodeo, 1958	Detritivore	+	+	++	++
	Dichogaster baeri Sciacchitano, 1952	Detritivore	+	+	++++	++
	Dichogaster saliens Beddard, 1893	Detritivore	+	+	++++	++
	Dichogaster papillosa Omodeo, 1958	Detritivore			+	+
	Dichogaster mamillata Omodeo, 1963	Detritivore			+	+
	Dichogaster notabilis Omodeo, 1958	Detritivore			+	+
	Dichogaster ehrhardti Michaelsen, 1898	Detritivore	+	+	+++	++
	Dichogaster sp.	Detritivore			+	+
	Millsonia omodeoi Sims, 1986	Mesohumic	++	+++	+++	+++
	Millsonia schlegeli Horst, 1884	Mesohumic				+
	Millsonia ghanensis	Oligohumic			+	
	Dichogaster terrae-nigrae Omodeo & Vaillaud, 1967	Oligohumic		+		+
Eudrilidae	*Agastrodrilus multivesiculatus* Omodeo & Vaillaud, 1967	Oligohumic		+	+	+
	Hyperiodrilus africanus Beddard, 1891	Polyhumic			+	+
	Stuhlmannia zielae Omodeo, 1963	Polyhumic	++++	+++	+++++	+++++
	Stuhlmannia palustris Omodeo & Vaillaud, 1967	Polyhumic	+		++++	++++

Plus sign (+) indicates presence (+ 1–10, ++ 11–30, +++ 31–50, ++++ 51–100, +++++ >100 individual m^{-2})

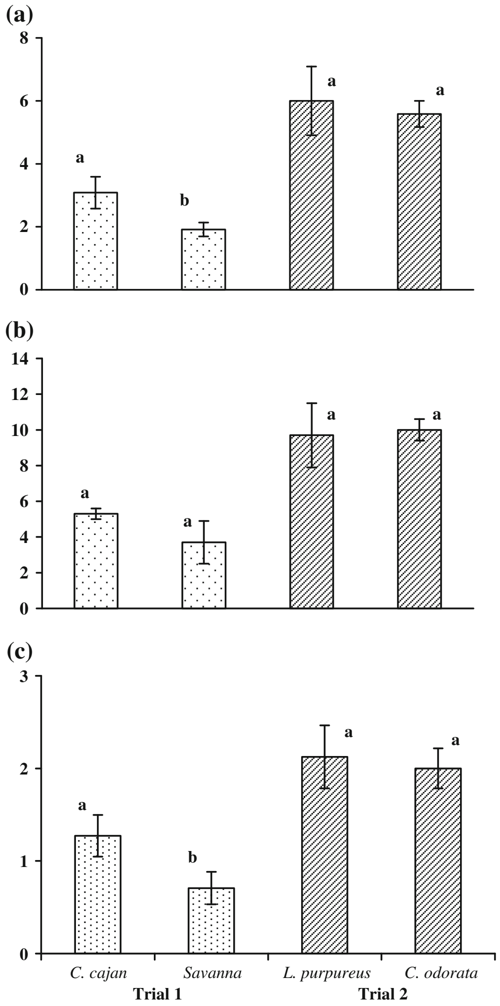

Fig. 1 Diversity parameters of earthworm populations beneath treatments: **a**. average species number (species m^{-2}), **b**. cumulative species number (species plot^{-1}) and **c**. Shannon–Weaver index. For the same trial, *means with the same letter* are not significantly different at the 5% level. *Vertical bars* denote standard errors

ly *D. saliens* and *D. baeri*) and polyhumics (such as *S. zielae*). This can be explained by their high reproductive potential and their rich diet (Tondoh and Lavelle 2005). The species from the others groups did not show any response in the presence of legumes, probably because they live deeper in the soil profile and they depend less upon organic residues or because 1 year is a too short time span. Species such as *Millsonia omodeoi* (mesohumic), *Dichogaster terrae-nigrae* (oligohumic), and *Agastrodrilus multivesiculatus* (oligohumic) which have low reproductive potential and high survival rate (Lavelle 1978, 1981) were reported to be well adapted to disturbed systems (Tondoh et al. 2011). On the other hand, earthworm diversity was responsive to the legume introduction only in savanna, emphasizing the importance of the litter quality in attracting earthworms.

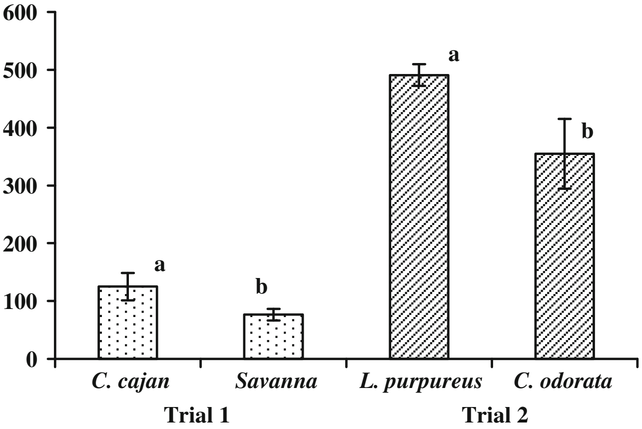

Fig. 2 Density (individual m^{-2}) of earthworm populations beneath treatments. For the same trial, *means with the same letter* are not significantly different at the 5% level. *Vertical bars* denote standard errors

In trial 1, the legume's leaf litter was higher in N and lower in C:N ratio, compared to *H. diplandra*, the dominant grass species of the savanna. These characteristics of litter were reported to be conducive to enhanced earthworm population growth and activities. Indeed, Belote and Jones (2009) observed in a pot experiment that litter consumption by earthworms were enhanced for those with lower C:N ratios. When studying soil organisms under Eucalypt

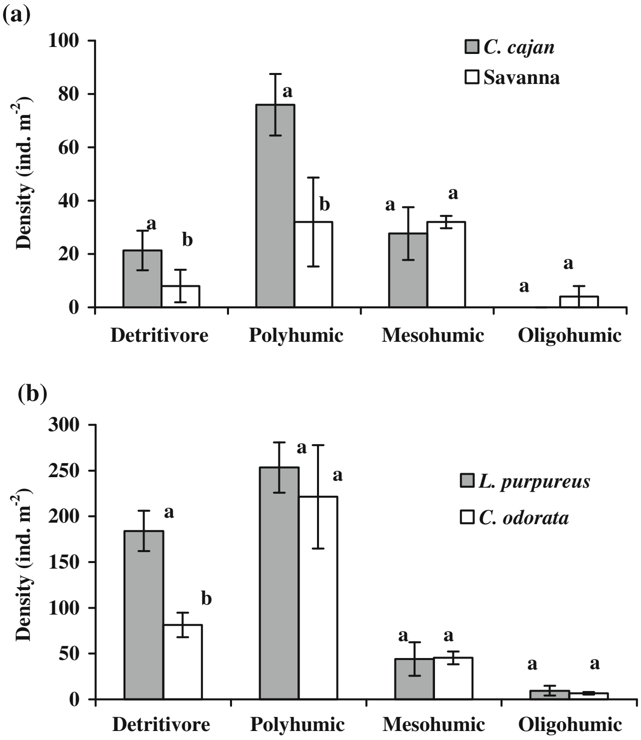

Fig. 3 Density of the feeding groups of earthworms beneath legumes and the respective controls. *Means with the same letter* are not significantly different at the 5% level. *Vertical bars* denote standard errors

Table 5 Soil physicochemical and microbial parameters (mean±SE, *n*=3) beneath legumes and the respective controls after 1 year of cultivation

Soil parameters	Trial 1			Trial 2		
	C. cajan	Savanna	*p*	*L. purpureus*	*C. odorata*	*p*
Organic C (g kg^{-1})	7.3±2.1	5.0±0.6	ns	20.3±3.7	16.0±2.3	ns
Total N (g kg^{-1})	0.4±0.1	0.3±0.0	ns	1.8±0.4	1.5±0.2	ns
C/N ratio	16.5±0.1	18.1±0.1	*	11.3±0.5	10.9±0.3	ns
Soluble P (mg kg^{-1})	10.5±0.6	7.0±1.0	*	19.3±3.8	10.3±2.0	*
pH water	6.0±0.1	6.0±0.1	ns	6.7±0.4	6.1±0.2	*
$NH4^+$ (mg kg^{-1})	15.0±4.2	11.0±1.6	ns	19.1±5.9	8.8±5.0	*
NO_3^-(mg kg^{-1})	4.0±1.7	4.2±0.9	ns	41.6±4.7	63.7±5.8	*
MBC (mg kg^{-1})	28.0±3.1	20.3±1.7	*	84.0±19.5	88.3±16.7	ns
Moisture (%)	9.8±1.4	6.4±0.8	*	16.3±1.8	16.3±2.5	ns
Bulk density (g cm^{-3})	1.4±0.0	1.5±0.0	ns	1.3±0.1	1.3±0.1	ns

Asterisk significant difference at the 5% level, ns nonsignificant difference

plantations, Mboukou-Kimbasta et al. (2007) observed that the density of earthworm was the highest in plots invaded by the weed *C. odorata* and attributed this trend to the quality litter supplied by the weed. In an experiment designed to test the effect of different substrates on the earthworm *D. saliens*, Huerta and De la Cruze-Mondragon (2006) observed that substrate with 1.5% *Mucuna pruriens* residue showed higher individual fresh weight, growth rate, cocoon biomass, and casts with the highest content in organic matter and available P compared to substrate with 1.5% cow manure. The higher quantity of litter under the canopy of the legume was likely another factor that could explain the higher earthworm diversity and density, relative to the savanna plots. In a study dealing with the influence of *Heliconia caribea* (Heliconiaceae) on earthworm abundance and community structure, Gonzàlez and Zou (1999) observed that the addition of litter resulted in an increase in total dry weight of earthworms. Likewise, Norgrove et al. (2003) reported a higher earthworm activity (cast production) in plots where leaf litter from above ground vegetal cover was left at the soil surface as mulch, compared with plots where the litter was removed or burnt. The maintenance of higher soil moisture under the legume may also explain these results in savanna (Tondoh 2006; Mainoo et al. 2008).

The difference between the legume and the savanna plots in the composition of earthworm communities focused on three species: *Stuhlmannia palustris* was observed in the legume plot but not in the savanna plot and conversely, *D. terrae-nigrae* and *A. multivesiculatus* were identified in savanna, not under the legume. In the first case, *S. palustris* which depends on organic matter was very rare on savanna plots with little litter. However, it is likely that this species existed in the surrounding woods. These groves are composed of a mixture of shrubs, often with *C. odorata* and a layer of litter on the soil surface. Once established, the legume probably created conditions similar to those groves (humidity and litter stand) which were conducive to *S. palustris* development. In the second case, the absence of *D. terrae-nigrae* and *A. multivesiculatus* in *C. cajan* could be explained by the fact that these oligohumic species were present in very low density, which eventually negatively impacted their capture by the sampling protocol used.

In trial 2, the change in earthworm abundance can be closely associated to the quantity of plant residues at the soil surface since both the legume and *C. odorata* provided litter of similar quality and ensured constant soil moisture maintenance. The difference in litter biomass resulted from the fact that the legume continuously supplied litter to soil contrarily to *C. odorata* especially in its younger stage. Furthermore, *C. odorata* leaf litter was reported to decompose at the soil surface twice more rapidly (k= 5.4 $month^{-1}$) than that from *L. purpureus* (k=2.6 $month^{-1}$) due to its lower content in Ca^{2+} and C:P ratio (Koné 2009). As a consequence, leaf litter accumulation at the soil surface was adversely influenced thereby limiting the survival of detritivores and polyhumic worms. Also, the lower acidity under the legume may have favored earthworm densities and activities, as reported by Mboukou-Kimbasta et al. (2007).

Similarly to trial 1, there were some differences between the legume and *C. odorata* regarding species compositions of the earthworm communities. *Millsonia ghanensis* was observed under the legume but not under *C. odorata*, while *D. terrea-nigrae* and *Millsonia schlegeli* were only observed under *C. odorata*. As discussed earlier, the recorded low densities may be indicative to these differences.

Soil chemical parameters

Data showed an improvement in soluble P and ammonium in legumes stands relative to the controls. In trial 1, this trend could be attributed to the quality of litter continuously provided to soil by the legume (Dinesh et al. 2004; Koné et al. 2008a) compared to dead leaves of grass. The role of N, P, C:N, and C:P ratios of organic residues in their decomposition rate has been shown in numerous works. According to McGrath et al. (2000), the lower the C:P ratio, the faster the P release from decomposing plant materials. Indeed, with lower C:P ratio, P is likely to be less immobilized by microorganisms, resulting in an increase in available P beneath the legume compared to the grass cover. The earthworm feeding activities, particularly the detritivores and the polyhumics, could also explain this result as shown by the multiple regressions test. Since they did not ingest (detritivores) or did ingest little mineral soil (polyhumics), the casts they egested were presumably low bulk density, leading to easy fragmentation and rapid release of nutrients in soil (Curry and Schmidt 2007). In the short term, this resulted in increased plant nutrient availability in soil (Araujo et al. 2004). The level of microbial biomass recorded under the legume can be explained by the readily decomposable materials it provided or by the promotion of earthworm decomposing activity. Indeed, mucus production associated with water excretion in earthworm guts was found to enhance soil microbial biomass and activity (Bhadauria and Saxena 2010). The prevalence of ammonium over nitrate in savanna soils was previously reported by Lata et al. (2000, 2004). The authors attributed this trend to allelopathic compounds released by the roots of *H. diplandra*, the dominant grass species in the savanna and argued that this was likely a strategy for the grass species to limit N loss in the N-poor soils encountered in the region. In this study, the introduction of legume did not reverse this trend although it supplied soil with N-richer litter. Indeed, nitrate concentration remained by far lower than that of ammonium. The reason could be that the bacterial communities present in that soils were not necessarily specific to litter materials from the legume (Diouf et al. 2010; Knapp et al. 2011). The sandy status of soils which is conducive to enhanced nitrate leaching was likely another reason to the results.

In trial 2, however, the decomposition and the mineralization rates of *C. odorata* leaf litter were probably the main factors explaining the difference in mineral N between the legume and *C. odorata* stands. Unlike the observation made in trial 1, mineral N was dominated by nitrate. Despite its lower total N, the soil under *C. odorata* exhibited higher content in nitrate; this could be an indication that nitrification was accelerated in *C. odorata* leaf litter. This form of N is known to be subjected to rapid loss from the soil system through leaching or denitrification, leading to a significant reduction of plant N availability in case of litter shortage. On the contrary, under the legume, nitrification was lowered as indicated by higher soil content in NH_4^+ although litter from this species had higher N content and lower C/N ratio. The difference in nitrate observed between the legume and *C. odorata* could have been easily explained, had we investigated the specific composition of microbial communities under these stands. This is highly relevant since the microbiota attached to the litter may considerably differ depending on the plant type (Diouf et al. 2010; Knapp et al. 2011). Although there was no significant difference between the legume and *C. odorata* in terms of litter P, available P was higher under the former. This may be related to the activities of earthworms, particularly the detritivores. The role of earthworms in P cycling has been reported in previous works. Most of them showed that egested casts were characterized by higher content in soluble P (Jiménez et al. 2003, Kuczak et al. 2006) in comparison with the surrounding soil. The transfer of this element from the casts to the soil occurs along with the other nutrients through diffusion as well as after fragmentation by raindrops (Mariani et al. 2007).

Conclusion

One year after legume introduction in savanna zone in central Côte d'Ivoire, the density and the diversity of earthworms communities were improved, as were the availability of plant P and N. The improvement in nutrient availability was concurrently linked to the quality of legume litters and earthworm activities, showing the importance of biological activity in savanna soil fertility. Thus, after 1 year, leguminous plants could allow the development of savanna lands through the production of cereals, which are not demanding in terms of nutrients. Nonetheless, further studies are needed to characterize the bacterial community embedded in the different leaf litters in order to better explain the patterns of nutrient mineralization.

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