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Agroforestry Technique for Minimal Extra-Labour: Influence of Chromolaena-Cajanus Combination on Soil Chemistry and Biology, and Yam Yields

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Abstract

Despite the beneficial effects of legumes on soil fertility, their adoption by farmers remains low due to the extra labour entailed. Lifting this constraint is of paramount importance for sustainable agriculture. This issue was dealt with in the present study which was carried out in central Côte d'Ivoire through assessing the response of soil (chemical and biological parameters) and subsequent yam yield to two fallow systems: natural *C. odorata* fallow (control) *vs.* Combination of *C. odorata* and *Cajanus cajan*. The mixed plot was obtained by loosely introducing at the onset of fallow *C. cajan* which withstands competition by *C. odorata*. Soil chemical parameters, abundance and diversity of decomposer macrofauna, microbial parameters and subsequent yam tuber yield were measured. After a 27-month period of time, the P content in *C. cajan* leaf litter increased in the mixed plot. The density of diplopods in leaf litter was lower in the mixed fallow while the average order number in soil was higher. No significant change occurred in earthworm abundance and diversity, nor in microbial activities. SOM and available P increased in the mixed fallow, as well as nitrates. Yam yield increased by 35 % in mixed plots, the controlling factors being soil C and nitrates contents, and leaf litter P, K and Ca stocks (GLM). Although the tested fallow appeared promising, the study should be repeated over a longer period taking into account other macrofauna decomposers for a better understanding of the mechanisms underlying the observed changes.

Keywords: Agroecological intensification, Decomposer macrofauna, Nutrient stock in litter, Microbial activity, Minimal extra-labour, Yam production

1. Introduction

For long times, legumes have been promoted in agroforestry systems in order to improve crop production, based on the fact that these species accelerate soil rehabilitation through biological nitrogen fixation and soil biological activity improvement (Franzel, 1999). As far, the level of adoption by farmers, which is the keystone of the success of agroforestry or (more broadly) agroecology techniques, remains low. Many reasons account for this situation, such as inefficient or lack of strong policies at government level (Meijer, Catacutan, Ajayi, Sileshi, Nieuwenhuis, 2015; Simelton, Catacutan, Dao, Dam, Le, 2016, Rahman, Jacobsen, Healey, Roshetko, Sunderland, 2017). Another constraint is the extra labor entailed. Thus, the lifting of these constraints constitutes a challenge to be urgently addressed (Simelton et al., 2016).

In forest and forest-savannah transition zones of West Africa, land abandoned to fallow are dominated by the shrub *Chromolaena odorata* (L) King and Robinson (Asteraceae) wich is now the successional vegetation (Koné et al., 2012; Norgrove & Hauser, 2016). Farmers and part or researchers consider the species as a soil fertility indicator (Norgrove & Hauser, 2016) or as improving soil fertility (Koutika & Rainy, 2010, Koné et al., 2012). However, the *C. odorata* fallowing has a major limitation: it takes at least 5 years before turned into farm, time which exceeds the cropping period (2-3 years, in central Côte d'Ivoire). This leads to land shortage, especially in the current context of rapid growth of the human population.

Cajanus cajan (L.) Millsp.) (Fabaceae) also called Pigeonpea is a tropical multi-purpose grain legume with huge untapped potential for improvement of production in Africa (Odeny, 2007). The plant is a prolific seed producer and its grains are popularly consumed in India, Asia, and Africa; it can be managed as an annual shrub or a perennial plant that can live up to four or five years (Sheahan, 2012). Also, it is one of the most drought-tolerant legumes and does not require additional soil moisture after the seedling growth stage. This potential is attributed to its deep taproots and osmotic adjustment in the leaves (Subbarao, Chauhan, & Johansen. 2000).

Agroecological intensification involves the use of ecological processes more intensively in a sustainable manner in agriculture. Soil macrofauna are considered important for ecological intensification of crop production as they are involved in key soil functions such as decomposition and nutrient cycling (Pramanik, Sarkar, & Joy, 2001; Moura, Aguiar, Piedade, & Rousseaux, 2015) and water infiltration (Bottinelli et al., 2010). However, the efficiency of these organisms depends upon abiotic factors such as diversity, quantity and quality of residues (Suzuky, Grayston, & Prescott, 2013). The positive interactions between the functional group components of the soil macrofauna and soil residue cover may increase the efficiency of tropical agrosystems (Moura et al., 2015). So, the key to successful soil management can be the use of mixed cover that provides a combination of litters of contrasted quality. This may ensures adequate nutrient release rates thereby improving nutrient supplies throughout the crop cycle.

Yam is one of the main staple subsistence in West Africa. In Côte d'Ivoire, it is consumed by the two-third of the population. Because it is a nutrient-demanding plant, yam is usually cultivated at first at fallow conversion to farm. In continuous cropping, yield may decrease by 60 % within three years (Gnahoua et al.; 2008). Despite this importance and cropping requirements, very few research activities focused on soil fertility management in yam production. N'Goran et al. (2011) did not observed any improvement when intercropping yam and annual legumes in the Centre-west of Côte d'Ivoire. Other works were conducted in the central and northern parts of Côte d'Ivoire testing chemical fertilizers with contrasted results (Soro, Dao, Girardin, Tié Bi, & Tschannen, 2003; Diby *et al.*; 2009) and probably with less chances of adoption as farmers lack financial wherewithal.

Legumes are known as improving soil N while *C. odorata* is efficient in P cycling (Koné et al., 2012). Both the two types of plants are conducive to soil biology (Tian, Brussaard, & Kang, 1993); *C. cajan* also proved resistant to *C. odorata*. As such, combining them in a same plot may form a promising fallow system and a model of ecological intensification. The aim of this study was to develop an efficient and minimal extra-labour agroforestry technique based on the traditional *C. odorata* fallow and which could boost legume adoption among farmers. Specifically, it assesses the response of soil and subsequent water yam (*Dioscorea alata*) yields to a two years and quarter old mixed fallow consisted of *C. odorata* and *C. cajan*. We hypothesize this combination alters the nutrient content in leaf litter from each of the species as well as the abundance and diversity of the soil macrofauna, and this will subsequently result in optimal nutrient availability and increased yam yield.

2. Material and Methods

2.1 The Study Area

The study was conducted in the forest-savannah transition zone in central Côte d'Ivoire (between Pacobo and Ahérémou-2 villages): 6'10-6'15 N, 4'55-5'00 W, 120 m above sea level. The vegetation consists of a mosaic of forests islands, savannahs, *C. odorata*-dominated fallows. The climate is of tropical savannah type according to the Köppen-Geiger classification (Peel, Finlayson, & McMahon, 2007), 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 air temperature is nearly constant throughout the year, averaging 28°C. As for the rainfall, it stabilized around 1 200 mm. The cumulative rainfall over the common yam cropping period (April-December) was as high as 994 mm over the ten precedent years in average, and 796 mm in 2014, the year yam was cropped for this study, i.e. ~200 mm gap. Considering that in 2014, the cropping started with a 1-month delay, the actual rainfall which benefited to yam was 645 mm (Figure 1). Soils are moderately leached Ferralsols, with granite being the main bedrock. Topsoils are generally of sandy texture (60 to 80 % sand).

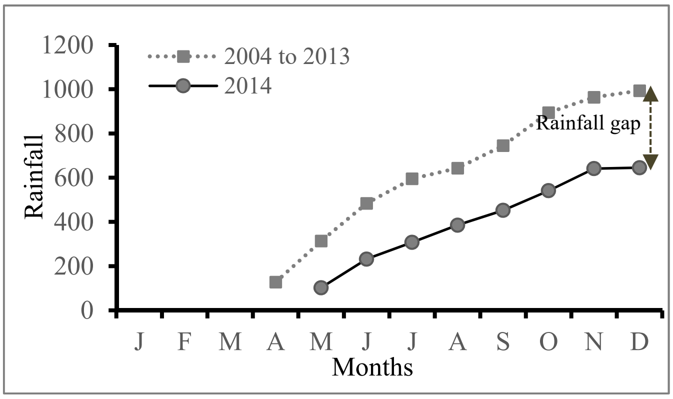

Figure 1. Monthly cumulative rainfall over the common yam cropping period in region of study

2.2 Experimental Design and Fallow Settlement

The study was carried out under farmers' field conditions from February 2012 to January 2015 at three sites distributed in the cultivated area. Experimental sites (25 m x 45 m) were demarcated on soils newly left to fallow. Soils were in general sandy with low clay to sandy clay (10-15 % clay) and yellow in colour. Before fallowing, the sites were cultivated for three years. Trials included two types of fallow: the pure *C. odorata* fallow and the mixed one, associating *C. odorata* and *C. cajan* (Figure 2). The latter was obtained as follows: instead of abandoning previously cultivated lands to total recolonization by *C. odorata*, *C. cajan* was sown at low density (2 m x 2 m spacing) in disarray: this was the only additional labour. The legume shares the characteristics of shrub species recommended for improved fallows: fast growing, fertility-boosting, drought tolerant and it competes well *C. odorata*. Moreover, *C. cajan* grains are used both for human and animal feeding, making it potentially commercially productive. Weeding did not occur as the intended fallow system is supposed to minimize extra-labour, while combining advantages from the legume and *C. odorata*. On the other side, the plot was left covered by the natural *C. odorata* regrowth, and the two plots were kept in place for a 27-month term. The mixed fallow and the control had the same size (20 m x 25 m) and were laid side by side, separated by a 5-m gap. Measurements were conducted concurrently. The main underlying assumption is that treated and control soils are initially similar and that differences observed in soil properties are attributed to the treatment (Bernoux et al., 2006).

2.3 Plant Biomass Sampling in Fallows and Chemical Analyses

On each plot, plant biomass sampling was carried out within a 1m × 1m frame at three points at the break of fallow (April 2014). Three categories were considered: aboveground, green leaves and leaf litter. The quantity obtained for one plot was the mean of the three pseudo-replicates. The leaf litter quality from each plot was determined on composite samples obtained by mixing litter materials from the three frames. The C content was determined according to Walkley and Black (1934), and N was determined using the standard Kjeldahl digestion method (Anderson & Ingram, 1993). Phosphorus was determined according to Murphy and Riley (1962). Major cations were extracted using ammonium acetate buffer (pH 7) and determined by means of atomic absorption spectrophotometry techniques (VARIAN SPECTRAA 220 SF model).

2.4 Soil Macrofauna Sampling and Identification

Soil macrofauna was sampled concomitantly with litter according to TSBF methodology (Anderson & Ingram, 1993). Five soil monoliths of 25 cm × 25 cm × 30 cm depth were taken in each replicate plot. Macrofauna was collected by hand sorting on plastic trays. Litter diplopod were collected using quadrants. Earthworms were fixed in a 4 % formaldehyde solution while diplopods were stored in 70 % alcohol until they were identified. They were identified to species and order levels using key reference specimens. Individuals were then enumerated and weighed.

2.5 Soil Sampling and Analyses

Samples were collected from the 0-10 cm layer at 5 distinct points distributed over each plot, using an auger. These samples were pooled and thoroughly mixed as a single composite sample which was air-dried, sieved at 2 mm and kept in plastic bags for chemical analyses.

Total C and total N were determined by dry combustion using a CHN autoanalyzer (EA1112 Thermo Finnigan Series, France) for dried 25 mg and ground samples (0.2 mm). Available P was extracted according to the Olsen-

Dabin method (in a mixture of $NaHCO_3$ and NH_4F, at pH 8.5) and measured colorimetrically at 660 nm (Murphy & Riley, 1962). Soil pH was determined using a glass electrode in 1:2.5 soil:water ratio. Exchangeable bases and CEC were obtained using standard methods (Anderson & Ingram, 1993). Soil bulk density was determined for the same depth on core samples obtained by the cylinder (Ø: 5 cm, height: 10 cm) and oven-dried at 105°C for 48 h.

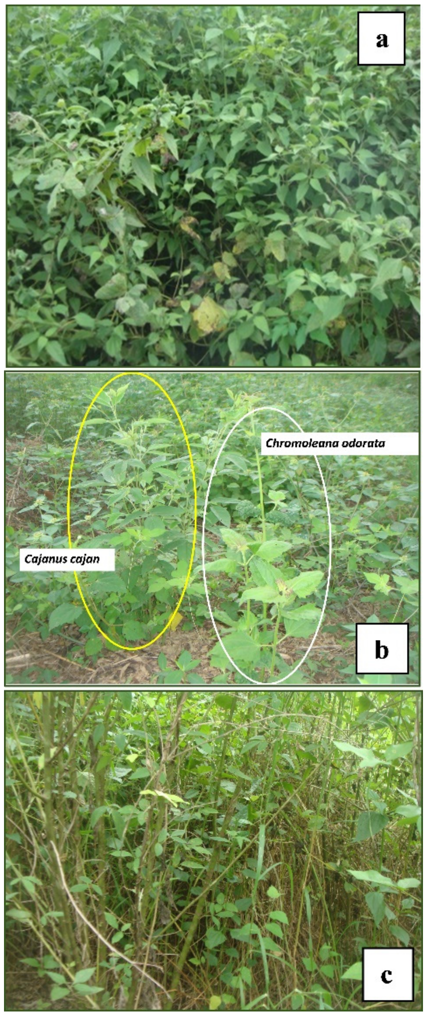

Figure 2. Pure *C. odorata* plot (a), *C. cajan* and *C. odorata* seedlings growing on the same plot (b) and 2 years and quarter old mixed fallow (c)

The microbial biomass C (C_{mic}) was determined using the chloroform fumigation-extraction method (Amato & Ladd, 1988). The C_{mic} was obtained from the quantity of ninhydrin-N reactive compound released from microbial walls. This compounds was extracted from 10 day-fumigated and unfumigated soil samples (10 g), using a 2 M KCl solution and measured using a spectrometer (SpectrAA 220FS, Varian Inc., Buc, France) at 570 nm. The C_{mic} ($\mu g \cdot C \cdot g^{-1}$ soil) was calculated as the difference in ninhydrin-N reactive compounds between fumigated and unfumigated soil samples, multiplied by 21. The soil C fraction sequestered by miccroorganisms is estimated by the C_{mic}:C_{org} ratio.

Soil respiration was measured on each soil sample in triplicate using the method by Anderson and Domsch (2010). Each soil replicate (10 g equivalent dry mass) was rehumidified at 12 % of water-holding capacity and incubated in a 120-ml jar at 28 ± 0.5 °C for 7 days. Air samples were analyzed every day for CO_2 production using direct injection into a micro-GC Analytical Instruments SRA (MTI P200, Microsensor Technology Inc., Fremont, CA, USA) with a TCD detector using Helium as carrier gas. After each CO_2 measurement, the headspaces were flushed with fresh air. Results were expressed as mg CO_2-C g^{-1} soil. The metabolic quotient (qCO2) was also determined as respiration per unit of C_{mic}.

The β-Glucosidase activity was determined using the method described by Hayano (1973). Hundred microliters of *p*-nitrophenyl-b-D-glucopyranoside as substrate and 400 ml of citrate–phosphate buffer (0.1 M, pH 5.8) were added to 100 mg of soil and incubated at 37°C for 2 h. The reaction was stopped by adding 3 ml of sodium carbonate (0.2 %, w/v). Released *p*-nitrophenol was determined using a spectrophotometer (Spectronic 401, Spectronic Instruments, France) at 400 nm. Results were expressed as µg *p*-NP released g^{-1}·soil·h^{-1}.

2.6 Yam Cropping and Fresh Tuber Yield Measurement

Water yam (*Dioscorea alata*) also called « Bètè-bètè », the staple subsistence in the region, was cultivated as test-crop from May 2014 to January 2015. Prior to sowing, the prevailing vegetation was slashed and applied as mulch. Then, the soil was hoe-ploughed at an approximate depth of 20 cm and heaped into mounds of approx. 50 cm in height (10 000 mounds ha^{-1}). Yam setts (approx. 100 g) were cut from tubers that had broken dormancy and buried, one per mound. Plots were weeded as per farmers. Yam yield was estimated on fresh tuber harvested at maturity within three 4 m x 4 m frames (16 mounds each) well distributed over each plot. The yield (Mg ha^{-1}) obtained for one plot was the mean of the three pseudo-replicates.

2.7 Data Treatment

The response of macrofauna to fallow types was studied through their abundance and diversity. The latter included species richness and the Shannon–Weaver index of diversity (H') (Pielou, 1966). Mean comparisons were done using the *U* test at the 5% error level. Multiple regressions using GLM procedures were performed to assess the influence of plant materials, macro-invertebrates and soil parameters on yam yield. These statistical analyses were processed using the R ver. 2.13.1 software.

3. Results

3.1 Plant Biomass Yields and Leaf Litter Parameters

Plant biomass production was significantly different from one fallow type to the other, particularly the aboveground (p = 0.03) and leaf-litter biomasses (p = 0.04). The highest values were recorded in the *C. odorata*+*C. cajan* plots (Figure 3).

With regard to nutrient concentrations in leaf litter, only C significantly varied between fallow types (p = 0.04), with the highest value in the mixed plot (Table 1).

Unlike concentrations, litter nutrient stocks in general significantly varied between the two treatments, except for K and Mg (Table 2). Values were higher in *C. odorata + C. cajan* compared with *C. odorata*.

Table 1. Leaf litter quality parameters two years and quarter after plot settlement (Mean± SE). In the same row, means with the same letter are not significantly different at the 5% level

Leaf litter parameters	*C. odorata*	*C. odorata + C. cajan*	*P value*
C (g kg^{-1})	402.9 ± 6.3 b	451.0 ± 2.9 a	*0.04**
N (g kg^{-1})	17.0 ± 0.9 a	18.2 ± 0.8 a	*> 0.05*
P (g kg^{-1})	1.1 ± 0.1 a	1.2 ± 0.3 a	*> 0.05*
K (g kg^{-1})	24.2 ± 1.4 a	28.5 ± 4.3 a	*> 0.05*
Ca (g kg^{-1})	51.0 ± 1.5 a	59.9 ± 4.8 a	*> 0.05*
Mg (g kg^{-1})	14.8 ± 1.6 a	15.4 ± 1.7 a	*> 0.05*
C/N	24.0 ± 1.2 a	24.8 ± 1.3 a	*> 0.05*

Table 2. Nutrient stocks in leaf litter two years and quarter after plot settlement (Mean ± SE). In the same row, means with the same letter are not significantly different at the 5% level.

Nutrient stocks	*C. odorata*	*C. odorata + C. cajan*	*P* value
C (kg ha^{-1})	966.8 ± 221.6 a	1219.4 ± 209.3 b	*0.04**
N (kg ha^{-1})	40.3 ± 8.6 a	50.2 ± 7.1 b	*0.04**
P (kg ha^{-1})	2.4 ± 0.5 a	3.5 ± 0.5 b	*0.04**
K (kg ha^{-1})	58.4 ± 18.6 a	80.1 ± 20.2 a	*> 0.05*
Ca (kg ha^{-1})	118.5 ± 28.8 a	167.5 ± 30.3 b	*0.04**
Mg (kg ha^{-1})	33.9 ± 7.3 a	43.1 ± 6.3 a	*> 0.05*

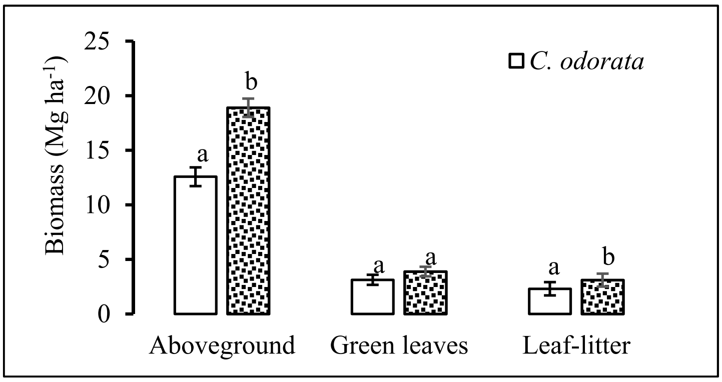

Figure 3. Plant biomass yield in the two follow types. Means with the same letter are not significantly different at the 5% level. Vertical bars denote standard error

3.2 Macrofauna Abundance and Diversity

A total of 10 earthworm species were detected in the plots; they belonged to two families: Acanthodrilidae and Eudrilidea (Table 3). None of the total earthworm abundance (biomass and density) and diversity (number of species and Shannon-Weaver index (H')) showed significant difference between types of fallow (Figure 4).

Three orders of diplopods were encountered: *Spirostreptida*, *Stemmiulida* and *Polydesmida*. Contrary to earthworms, some changes were observed in the diplopod community, specifically regarding density and mean order number (Table 4). The mixed fallow showed lower density in leaf litter ($p = 0.05$) but higher mean order number in soil ($p = 0.04$) relative the *C. odorata*.

3.3 Soil Attributes

Only three chemical parameters significant varied between fallow types: the organic C and the total N contents ($p = 0.05$) and the available P ($p = 0.03$), with higher values in the mixed fallow relative to *C. odorata* (Table 5).

In general, the microbial parameters showed similar values in both treatments, except for nitrate which significantly increased (up to 36 %) in *C. odorata* + *C. cajan* (Table 6).

Table 3. List of earthworm species and their abundance

Family	Earthworms species	Density (Individual. m^{-2})		Biomass (g m^{-2})	
		C. odorata	*C. odorata+C. cajan*	*C. odorata*	*C. odorata+C. cajan*
Acanthodrilidae	*Dichogaster baeri*	12.4 ± 6.4	8.2 ± 3.9	12.6 ± 6.4	6.9 ± 0.6
	D. saliens	-	4.9 ± 2.9	-	2.2 ± 0.2
	D. papillosa	2.7 ± 1.5	-	8.1 ± 5.0	-
	D. notabilis	1.8 ± 0.9	0.9 ± 0.9	0.3 ± 0.1	0.3 ± 0.3
	D. ehrhardti	10.7 ± 4.6	7.8 ± 2.6	5.8 ± 4.2	3.7 ± 1.7
	Millsonia omodeoi	26.7 ± 9.3	22.4 ± 5.4	50.5 ± 15.6	54.8 ± 24.2
Eudrilidae	*Stuhlmannia zielae*	40.9 ± 18.8	36.4 ± 5.4	1.4 ± 0.8	1.1 ± 0.3
	S. palustris	3.5 ± 2.3	6.2 ± 2.2	0.2 ± 0.0	2.5 ± 0.5
	Agastrodrilus multivesiculatus	3.5 ± 2.3	-	1.1 ± 1.0	-
	A. opistogynus	-	0.9 ± 0.9	-	0.8 ± 0.8

Table 4. Diplopods diversity parameters two years and quarter after plot settlement (Mean ± SE). In the same row, means with the same letter are not significantly different at the 5% level

	Density (ind. m^{-2})		Mean order nb. (orders m^{-2})		Cumulative order nb. (Orders m^{-2})	
	Litter	Soil	Litter	Soil	Litter	Soil
C. odorata	0.7 ± 0.3 a	14.2 ± 7.7 a	0.5 ± 0.2 a	0.2 ± 0.2 a	1.7 ± 0.3 a	1.3 ± 0.9 a
C. odorata+C. cajan	0.4 ± 0.1 b	15.1 ± 3.9 a	0.3 ± 0.1 a	0.5 ± 0.2 b	1.0 ± 0.0 a	2.0 ± 0.0 a

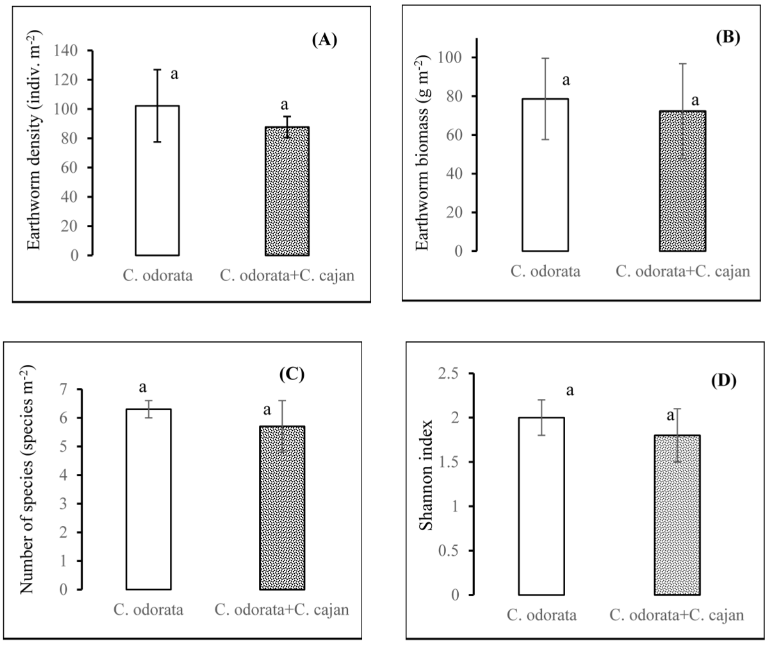

Figure 4. Earthworm abundance and diversity parameters. Means with the same letter are not significantly different at the 5% level. Vertical bars denote standard error

Table 5. Soil chemical and physical characteristics two years and quarter after plot settlement (Mean ± SE). In the same row, means with the same letter are not significantly different at the 5% level

Soil parameters	*C. odorata*	*C. odorata + C. cajan*
C ($g\ kg^{-1}$)	12.9 ± 0.4 a	15.1 ± 0.5 b
N ($g\ kg^{-1}$)	1.1 ± 0.1 a	1.5 ± 0.1 b
C/N	11.5 ± 1.2 a	10.4 ± 0.9 a
Available P ($mg\ kg^{-1}$)	20.3 ± 2.6 a	32.3 ± 3.5 b
CEC ($cmol_c\ kg^{-1}$)	6.9 ± 0.8 a	7.2 ± 0.5 a
Ca^{2+} ($cmol_c\ kg^{-1}$)	1.4 ± 0.0 a	1.6 ± 0.1 a
Mg^{2+} ($cmol^c\ kg^{-1}$)	0.6 ± 0.0 a	0.4 ± 0.1 a
K^+ ($cmol_c\ kg^{-1}$)	0.1 ± 0.0 a	0.2 ± 0.0 a
Na^+ ($cmol_c\ kg^{-1}$)	0.1 ± 0.0 a	0.1 ± 0.0 a
pH_{water}	7.1 ± 0.1 a	7.0 ± 0.0 a
Bulk density ($g\ cm^{-3}$)	1.1 ± 0.0 a	1.0 ± 0.0 a
Moisture (%)	8.6 ± 0.1 a	9.0 ± 0.7 a

Table 6. Soil microbial parameters two years and quarter after plot settlement (Mean ± SE). In the same row, means with the same letter are not significantly different at the 5% level

Microbial parameters	*C. odorata*	*C. odorata + C. cajan*	*P* value
C_{mic} (μg^{-1} soil)	189.0 ± 6.0 a	194.7 ± 10.2 a	*0.6*
C_{mic}:C_{org} (%)	1.5 ± 0.1 a	1.3 ± 0.1 a	*0.1*
Basal respiration ($\mu g\ CO_2$-C g^{-1} soil)	234.3 ± 21.2 a	225.8 ± 22.8 a	*0.7*
qCO_2 (h^{-1})	1.2 ± 0.1 a	1.2 ± 0.1 a	*0.5*
Ammonium (μg^{-1} soil)	158.0 ± 36.6 a	141.5 ± 44.3 a	*0.7*
Nitrates (μg^{-1} soil)	248.4 ± 46.7 a	337.3 ± 58.1 **b**	***0.04****
Nitrates : Total mineral N (%)	61.4 ± 4.6 a	69.9 ± 9.6 a	*0.4*
β-Glucosidase (µg *p*-NP g^{-1} soil))	45.5 ± 2.5 a	42.9 ± 2.6 a	*0.7*

3.4 Fresh Yam Tuber Yield

Fresh yam tuber yield was significantly higher (35% increase; $p = 0.04$) in the mixed fallow compared to the pure *C. odorata* (Figure 5). Multiple regressions showed that yam yield was influenced by soil chemical parameters ($R^2 = 0.9$, $p = 0.01$, $F = 24.8$) as well as nutrient stocks in leaf litter ($R^2 = 0.7$, $p = 0.03$, $F = 9.8$). With regard to soil parameters, yam yield was influenced by organic C ($\beta = 0.9$, $p = 0.04$) and nitrate ($\beta = 0.9$, $p = 0.02$). On the other hand, it was determined by litter P stock ($\beta = 1.6$, $p = 0.04$); litter K stock ($\beta = 0.8$, $p = 0.03$) and litter Ca stock ($\beta = 0.9$, $p = 0.01$).

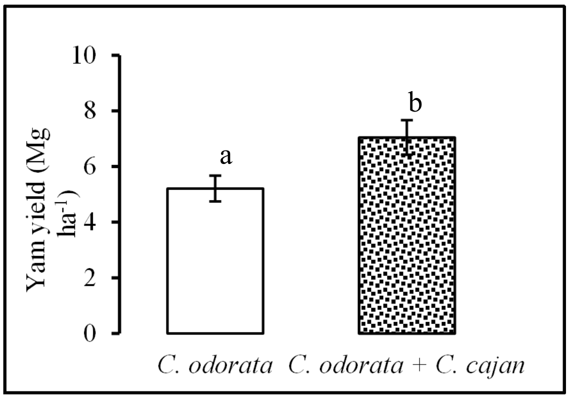

Figure 5. Fresh yam tuber yields. Means with the same letter are not significantly different at the 5% level. Vertical bars denote standard error

4. Discussion

The mix of *C. odorata* and *C. cajan* significantly improved soil fertility, particularly C, N and available P relative to the pure *C. odorata* plots. However, this positive influence of the mixed treatment was not observed on considered decomposer macrofauna. This may have been hindered by leaf litter from *C. cajan* which is harder than *C. odorata* litter. Moreover, its seed are known to contain tannin which proved detrimental to earthworms (Gonzàlez & Zou, 1999). With regard to diplopods, the effect of litter quality was not clear. Thus, the increase in SOM can hardly be attributed to the considered macrofauna. For example, *Millsonia omodeoi* which is a large-size earthworm species (adult: 15-25 cm) and which is known to process large amounts of soil quantities (450 to 800 t ha^{-1} yr^{-1}; Lavelle, 1978) was of similar abundance in the two types of fallow. In this context, soil macrofauna such as termites which are not lignin-sensitive or soil microorganisms which are responsible for litter mineralization could have been useful in explaining change in SOM. As a matter of fact, microbial activities are not necessarily consistent with macrofauna abundance; their activity can be higher where macrofauna abundance is lower. For instance, Koné *et al.* (2008) reported specific soil respiration of 0.32 and 0.53 mg C-CO_2.g^{-1} microbial biomass-C under *Mucuna pruriens* and a mixed legume plot respectively, with respective densities of 45 and 33 earthworms m^{-2}. The authors also reported specific respiration of 0.51 and 0.19 mg C-CO_2.g^{-1} microbial biomass under *Pueraria phaseoloides* and *Lablab purpureus*, respectively, where earthworms were collected at the densities of 61 and 141 indiv. m^{-2}.

Although the improvement of P availability can be accounted for by the P desorption by legume roots exudates and cycling from deeper soil layers (Mat-Hassan, Marschner, & Mcneill-Tang, 2012), it is likely that roots colonization by arbuscular mycorrhizal fungi (AMF) played a great role. Indeed, the P content in *C. cajan* leaf litter recorded in the region of the study usually varied between 0.6 to 0.8 g kg^{-1}, which is lower than the range 1.1 - 1.3 g kg^{-1} recorded in *C. odorata* leaf litter from the same age (2-3 years). Notably, in the present work, leaf litter from the mixed fallow showed P content of 1.2 g kg^{-1}. Since *C. cajan* leaf litter (with lower decomposition rate) was predominant at the time of litter sampling, we suggest that an increase in *C. cajan* leaf litter P occurred in the mixed fallow. This could be due to an increased root colonization by AMF in the common rhizosphere developed by the two species, induced by *C. odorata* as observed by Derelle, Declerck, Genet, Dajoz, and van Aarle (2011) in the association of highly and weakly mycorrhizal seedlings. Indeed, roots of *C. odorata* were reported to be highly prone to developing symbiosis with AMF (Onguene, 2007) hence accounting for the increase in yam yield observed in the mixed plots.

The increase in yam yield in the mixed fallow was linked to SOM and nitrate as well as litter P, K and Ca stocks (GLM). The dependence of yam on SOM and nitrates was reported in previous works (Diby et al., 2009; Agbede, Adekiya, & Ogeh, 2013) and explains why yam is usually cultivated at first when turning fallow to farm. On the other hand, the quantity of leaf litter appeared as other key factor that determines yam yield, as previously observed by Gnahoua et al. (2008) in the Centre-West Côte d'Ivoire and Agbede et al. (2013) in Nigeria. In our study, the significant influence of P and K quantities in litter incorporated into mounds can be highlighted. The influence of soil fauna on yam yield was not evident, likely because abundance and diversity did not significantly differed between fallow types.

Although yam yield increased in the *C. odorata*+*C. cajan* treatment, the observed values remained by far lower than those usually recorded in the region. For example, Koffi (2014) recorded 17.9, 17.6 and 10.5 Mg ha^{-1} fresh tuber yields in *C. odorata* fallow, forest and savannah respectively. The level of yield in our study might be attributed to many factors such as the short duration (2 years and quarter) of the fallow as reported by Gnahoua et al. (2008). The drop in rainfall during yam cropping season in 2014 could also be pointed out. As a matter of fact, the average rainfall recorded during the cropping season (April to December) over the 10 precedent years was as high as 994 mm while that during this study was 796 mm (i.e. a gap of ~200 mm). More notably, we do have wait till mid-May before cropping yam, for soil conditions to be favorable to soil organisms and favour their come back to normal state and activity before conducting sampling. This resulted in an additional 200 mm loss in rainfall. This situation was detrimental to yam which is water demanding particularly during the first five months after sowing (Anonymous, 1991).

According to Franzel (1999), the willingness of farmers to adopt a new agroforestry techniques for improved fallowing is determined by three criteria: feasibility, profitability, and acceptability. Based on these criteria, Tassin, Kull, and Rangan (2012) suggested that the key factors are input costs; labour cost, cash income, multipurpose use and the duration of the fallow. Small farmers fear that costs associated with the new technology outweigh the cash benefits it might offer. In the present fallow system, *C. Cajan* seeds are available in the region as the species is grown under governmental control for feedstock purpose, and can be obtained for free or at insignificant cost. Anyhow, the plant is a prolific seed producer. The only extra labour required is sowing which was limited as it was done at low density. There is no labour related to weeding and management as the species competes with *C. odorata*. Other benefits are conceivable with this practice as commonly reported for agroforestry in general (Simelton et al., 2016; Rahman et al., 2017). For instance, Cajanus' grains are highly nutritional and suitable for feeding both human and animals, and the plant offers fuelwood (Odeny, 2007). The species can be managed as an annual shrub or a perennial plant, but it can live up to 4 years which remains shorter, compared to the common fallow length in the region. In addition, the tested fallow system was efficient in improving soil fertility and crop yields. Thus, farmers can derive benefit without significant investment in input or extra labour costs, making this mixed fallow an alternative and adaptive one.

5. Conclusion

Despite the short length of fallow, *C. odorata* + *C. cajan* improved soil fertility and yam yield. Unlike expectations, no increase in macrofauna abundance was observed, nor microbial parameters changed. Although soil fertility may explain the increase in yam yield (organic C and nitrate), leaf litter quantity and litter P, K, and Ca stocks also appeared as determining factors, thereby highlighting the importance of residue management. Thus, the mixed fallow appears promising but trials should be carried out on a longer period (3-4 years), taking into account a wider range of macrofauna including termites to confirm these findings.

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