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RESEARCH PAPER

Shifts in earthworms community structure and soil properties in very short term *Mucuna pruriens*-based fallows in Cocoa based farming systems in South West Côte d'Ivoire

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Abstract

The scarcity of arable lands in the cocoa economy-oriented Nawa region greatly changed food crop production systems currently characterized by severe fallow period reduction (one year in many cases) and even it disappearing. Used *Mucuna pruriens* for reducing fallow period is an agro-ecological solution in the tropics for sustained soil fertility. This study aimed to compare earthworms' communities and soil properties of two improved fallow (*M. pruriens* fertilized or not with chemical fertilizer) with natural fallow. Soil samples were analysed and earthworms collected, identified and counted at six months and 12 months. Comprehensively, no significant difference was recorded for soil properties apart from P increase recorded for all treatments after 12 months of fallowing. Earthworms distributed into three trophic groups and *Mucuna pruriens*-based fallows harboured the highest earthworm'density and biomass notably when fertilized with NPK. This confirms that restoration of fertile or fertilizers-enriched soils is faster than poor soils. The detritivorus group, which feeds on plan litter, had highest biomass and density under the fertilized *Mucuna pruriens* plots. However, no species was clearly impacted by none of the treatments. This study clearly demonstrated the swift answer of earthworms to change in vegetation and soil mineral components.

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Introduction

Plants and the biotic diversity beneath them are tightly linked, directly by soil herbivores, pathogens, and symbionts and indirectly through decomposition of dead plant material and return of inorganic nutrients to plants. Plants are the basis for most biotic soil food webs that comprise an enormous diversity of species whose multiple interactions function to help regulate nutrient cycling, which in turn influences plant growth (Sylvain and Wall, 2011). Among this diversity of organisms, earthworms are the most abundant animal biomass in the majority of terrestrial ecosystems (Lavelle and Spain, 2001). They are known for more than a century as one of the key organisms of soil functioning as they affect his formation, development and fertility (Darwin, 1881). Their role as ecosystem engineers was firstly considered by Jones *et al.* (1994). Since, diverse studies focused on their role in soil functioning and on ecosystem services such as soil fertility. Earthworms are typical ecosystem engineers as they have a large impact on soil structure, which is not necessarily associated with trophic relationships (Blouin *et al.*, 2013). They perform a range of physical (aeration, bioturbation and litter fragmentation) and biological (microbial interactions, exudate production) roles in soil (Lavelle *et al.*, 1997; Bertrand *et al.*, 2015; Butt and Briones, 2017). Because of their functional importance, earthworms have emerged as a major taxon for biomonitoring and biomarker assessments of human induced pressures on soil communities (Behera and Patnaik, 2016).

Legume cover crops are proposed in agroecological systems for soil quality restoration and/or conservation by regulating soil microbial biomass, affecting carbon mineralization and having beneficial impacts on the “ecosystem engineers” that modify the physical state of the soil and resource availability for other species (Blanchard *et al.*, 2006; Bertrand *et al.*, 2015). In Côte d’Ivoire, studies evaluating the potential of *Mucuna pruriens* for soil restoration emphasized on changes in soil chemical properties and plant yields (Koné *et al.*, 2008a &b; Koné *et al.*, 2012). Little studies investigated biologically mediated processes occurring with this legume cover crop (Ortiz-Ceballos *et al.*, 2005; Blanchard *et al.*, 2006).

Here, we investigated effects of the legume cover crop *Mucuna pruriens* with or without the fertilizer NPK on soil properties and earthworm’s communities in very short term fallows in the Nawa region (South West Côte d'Ivoire). This region is known as the main cocoa production zone of the country where 30% of the cocoa is produced (Diby *et al.*, 2014). Cocoa and others tree crop (coffee, rubber, oil palm) expansion led to high pressure on lands. Food crops are grown on very small areas (<1ha) notably by women for household consumption and for making money. During a food crop production situational analysis survey performed in 2015 on 636 producers in the framework of a multi stakeholder process, 51% of farmers declared practicing fallowing. Among them, 46% declared to realize fallows of only one year while about 50% realize fallow of one to three year. Furthermore, a virtual absence of soil fertility management is noticed in the region (Diby *et al.*, 2014). This experiment addressed the change in earthworms’ composition and abundance in presence of *Mucuna pruriens* var. *utilis* with or without fertilizer. We hypothesize that the presence of the legume cover crop would support higher abundance and diversity of earthworm than natural fallow.

Material and methods

Study area

This study was carried out in the Nawa region (Southwest Cote d’Ivoire), one of the most densely populated region of the country. This situation is due to cocoa economy which attracts many migrants from other parts of the country and West African countries (Smoot *et al.*, 2013). The global landscape of the region is very heterogeneous and dominated by agriculture with mosaic of tree crop plantations and food crops (Diby *et al.*, 2014).

The Nawa region is located in the Guinean forest zone and characterized by a subequatorial climate with a bimodal rainfall pattern of two rainy seasons and two dry seasons. Rainy seasons occur generally between April and June and between September and November, while dry seasons are from December to March and from July to august.

Each rainy season represents a food crop growing season. The annual rainfall ranges between 968 mm and 1767 mm and the average temperature between 23°C and 36°C (Diby *et al.*, 2014).

Study site and experimental design and setup

The experiment was set up at the end of September (second food crop production cycle) in Petit-Bondoukou (N 05.79236°; W 006.59480°), village where hundreds hectares of cocoa plantation are destroyed by cocoa swollen shoot virus disease (CSSVD).

Experiments were laid out using a split-splot experimental design of two plots with three treatments and four replicates on sub-plots of 100m² (10m x 10m) size. The two plots were distant from 3m and sub-plots were distant from 2m. The three treatments were (1) "Control": natural fallow; (2) "*Mucuna pruriens*": fallow improved with *M. pruriens* var. *utilis*; (3) "*Mucuna pruriens*+NPK": sub-plots on which, NPK (12-22-22) was applied before sowing *M. pruriens* var. *utilis* at the dose of 100Kg. ha^{-1}. *M. pruriens* was grown at 40cm x 40cm density. The first plot was sampled six months later while the second plot was sampled a year later.

Soil sampling and chemical analyses

Soils samples were collected at 20cm depth using an auger. A soil sample was collected in each sub-plot from five sub-samples homogenously mixed. Soil analyses were performed for organic C (Walkley and Black, 1934), total N by Kjeldahl method (Bremner, 1960), available P (Olsen, 1952), exchangeable K+, cation exchange capacity (CEC) and pH water.

Earthworms'sampling and identification

Earthworms were sampled during the rainy periods, following the modified tropical soil biology and fertility methods (Anderson and Ingram, 1993). In each subplot, two distinct soil monoliths of 50×50×30cm size were extracted. All specimens of the monoliths were collected by hand sorting and identified at species level (Tondoh and Lavelle, 2005; Csuzdi and Tondoh, 2007). Individuals were counted and weighted for each earthworm population and then classified by feeding behaviour since this has implications in nutrient cycling. Detritivorus earthworms feed at or near the soil surface on plant litter and the geophagus feed deeper in the soil and derive their nutrition from soil organic matter ingested with mineral soil (Lee, 1985). Geophageous earthworms were divided into three groups: polyhumics which feed on decaying residues mixed with little mineral soil, mesohumics which feed on soil fairly rich in organic matter and oligohumics which feed on organic matter-poor soil (Lavelle, 1981).

Data analyses

Statistical analysis was performed using STATISTICA 7.1 software. The significance of differences was analyzed using one-way ANOVA followed by Duncan's test with the acceptance level of significance of 5%.

Results

Soil properties and dynamic

Comprehensively, soil was acidic ($6.3 < pH < 6.8$) with low to medium levels of organic matter ($1.2 < C < 1.8$), low cation exchange capacity ($7 < CEC < 11$) and poor in P and K. From six to 12 months, significant increases in P value were recorded and to a lesser extentK value for all the treatments while no significant difference was recorded for the others soil parameters (Table 1).

Earthworms' community per treatment after six and 12 months of fallowing

Eleven species distributed into three trophic groups, three families (Acanthodrilidae, Eudrilidae and Ocnerodrilidae) and five genera were collected at six months. Acanthodrilidae was the most diversified and represented 73% of the species richness.

Populations of *Dichogaster eburnea* and *D. mamillata* were observed only in *M. pruriens*-based fallows while the geophageous mesohumic *D. saliens* was recorded only in control. The others species were collected in any treatments (Table 2). After 12 months, overall earthworm community richness decreased from 11 to 9 species and distributed into three trophic groups, three families and five genera. *D. mamillata* and *D. saliens* were not recorded. The species *D. eburnea* was observed only in "*M. pruriens* + NPK" plots either at six and at 12 months (Table 2).

No significant difference was observed ($p > 0.05$) for species richness and Simpson diversity index from a treatment to another both at six and at 12 months after fallowing (Table 2).

Table 1. Soil parameters recorded as means±standard-errors. Comparisons were performed per soil parameter combining the two sampling periods; means with different letters differ significantly ($p < 0.05$).

Period	Treatments	pH water	C (%)	N total (%)	Olsen P (ppm)	K^+ ($cmol.kg^{-1}$)	CEC ($cmol.kg^{-1}$)
Six months fallowing	Control	6.53±0.09ab	1.27±0.14a	0.12±0.01a	34.00±5.42ab	0.03±0.00a	8.22±0.61a
	M. pruriens	6.32±0.03a	1.27±0.30a	0.11±0.02a	33.33±1.08a	0.03±0.01a	6.93±1.31a
	M. pruriens + NPK	6.74±0.05b	1.21±0.01a	0.12±0.01a	39.00±5.34b	0.05±0.01ab	8.02±1.05a
12 months fallowing	Control	6.45±0.14ab	1.39±0.25a	0.13±0.03a	54.91±2.16c	0.07±0.02ab	8.98±2.06a
	M. pruriens	6.37±0.21ab	1.48±0.27a	0.13±0.03a	52.90±0.56c	0.11±0.03b	9.84±2.79a
	M. pruriens + NPK	6.44±0.08ab	1.76±0.36a	0.17±0.04a	54.36±2.54c	0.08±0.02ab	10.56±1.93a

Table 2. Occurrence of earthworms per treatment after six and 12 months of fallow; species richness and impson diversity index recorded as means±standard-errors for each treatment at both fallow periods ($p > 0.05$).

			6 months of fallowing			12 months of fallowing		
Families	Species	Trophic group	Control	*M. pruriens*	*M. pruriens* +NPK	Control	*M. pruriens*	*M. pruriens* +NPK
Acanthodrilidae	*Dichogaster baeri* (Sciacchitano, 1952)	D	1	1	1	1	1	1
	D. erhrhardti (Michaelsen, 1898)	D	1	1	1	1	1	1
	D. papillosa (Omodeo, 1958)	D	1	1	1	1	1	1
	D. eburnea (Csuzdi and Tondoh, 2007)	D	0	0	1	0	0	1
	Dichogaster sp.	D	1	1	1	0	1	1
	D. mamillata (Csuzdi and Tondoh, 2007)	D	0	1	1	0	0	0
	D. saliens (Beddard, 1893)	MG	1	0	0	0	0	0
	Millsonia omodeoi (Sims, 1986)	MG	1	1	1	1	1	1
Eudrilidae	*Hyperiodrilus africanus* (Beddard, 1891)	PG	1	1	1	1	1	1
	Stuhlmannia zielae (Omodeo, 1958)	PG	1	1	1	1	1	1
Ocnerodrilidae	*Ocnerodriliae* sp. (Stephenson, 1928)	PG	1	1	1	1	1	1
Total Species richness	11		9	9	10	7	8	9
Mean species richness			4±0b	4±0.7b	4.5±0.5b	3.1±0.4	3.4±0.6ab	4±0.5ab
Simpson diversity index			0.3±0	0.5±0.1a	0.3±0a	0.4±0.1	0.5±0.1a	0.4±0a

* D: Detritivorus, MG: Mesohumic geophageous, PG: Polyhumic geophageouss (1: present; 0: absent).

Overall earthworms' density and biomassper treatment after 6 and 12 months of fallowing

Overall earthworms' density

Significant differences were recorded for overall earthworm density between treatments ($p < 0.05$) after six months. "*M. pruriens* + NPK" allowed significant increase of earthworms' density (105±29 ind.m^{-2}) compared with the control (48±11 ind.m^{-2}). No significant difference was observed between *M. pruriens* (65±13 ind.m^{-2}) and "*M. pruriens* + NPK" despite density gap recorded (Fig. 1).

The same situation was observed at 12 months with a marginalized decrease of overall density for all the treatments. "*M. pruriens*+ NPK" harboured 103±21 ind.m^{-2}, *M. pruriens* harboured 63±12 ind.m^{-2} and the control harboured 40±9 ind.m^{-2} (Fig. 1).

Overall earthworms' biomass

Consequently to earthworm density variations, significant differences for overall earthworms' biomass were observed between treatments ($p < 0.05$) after six and 12 months of fallowing. Significant biomass increase was observed with the "*M. pruriens* + NPK" treatment (33.56±5.23g.m^{-2}) compared with the control (15.21±3.50g.m^{-2}) six months after fallowing (Fig. 1). This gap in biomass between the "*M. pruriens* + NPK" treatment (36.60±5.53g.m^{-2}) and the control (12.29±2.10g.m^{-2}) was also observed 12 months after fallowing (Fig. 1).

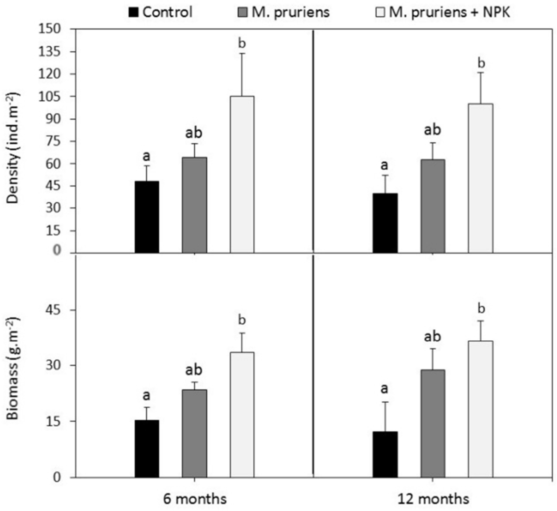

Fig. 1. Overall earthworm community density and biomass after six and 12 months of fallowing. Significant differences between treatments are indicated by different letters ($p < 0.05$).

Earthworms' trophic groups density and biomass

Earthworms' trophic groups' density

Significant differences were observed between treatments for some earthworms' trophic groups ($p < 0.05$) six months after fallowing.

These differences are related to detritivorus and polyhumic geophageous communities. Higher detritivorus densities were observed with the treatment "*M. pruriens* + NPK" (50±5 ind.m^{-2}) and the treatment *Mucuna pruriens* (42±4 ind.m^{-2}) while the control harboured a detritivorus density of 28±3 ind.m^{-2}. For the polyhumic geophageous community, only the treatment "*M. pruriens* +NPK" allowed significant density increase, 54±11 ind.m^{-2} against 22±7 ind.m^{-2} for *M. pruriens* treatment and 19±6 ind.m^{-2} for the control (Fig. 2).

After 12 months of fallowing, only the treatment "*M. pruriens* + NPK" allowed increase of detritivorus and polyhumic geophageous community density. "*M. pruriens* + NPK" harboured 47±11 ind.m-^{2} against 38±10 ind.m-^{2} for *M. pruriens* and 22±9 ind.m-^{2} for the control. For polyhumic geophageous community, the density of "*M. pruriens* + NPK" was 49±11 ind.m-^{2} against 26±5 ind.m-^{2} for *M. pruriens* and 17±7 ind.m-^{2} for the control plots (Fig. 2).

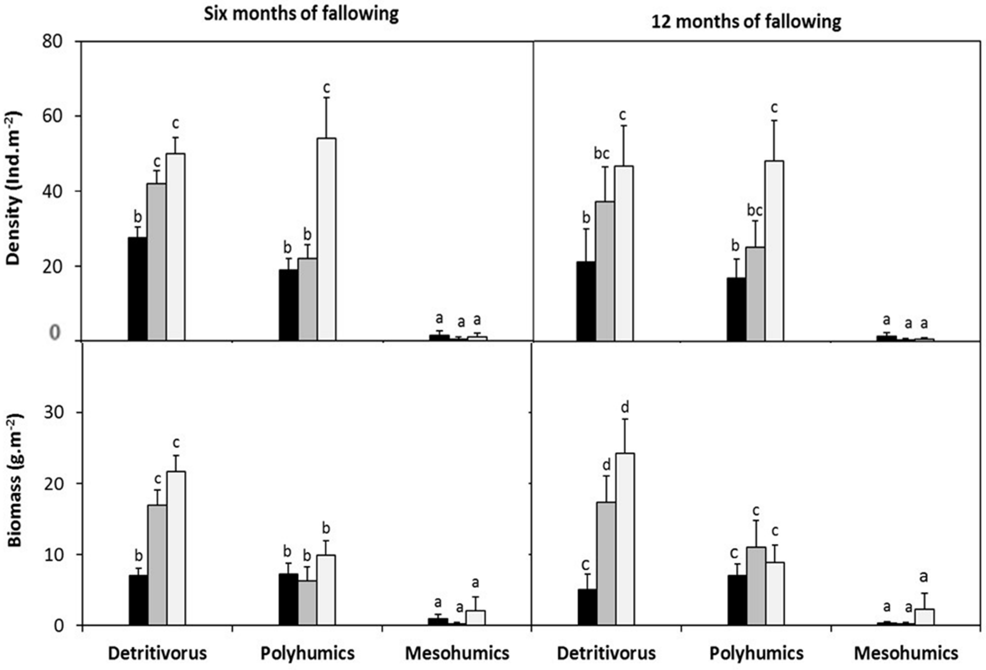

Fig. 2. Density and biomass of earthworms' trophic groups after six and 12 months of fallowing. Significant differences between treatments are indicated by different letters ($p < 0.05$).

Earthworms' trophic groups' biomass

Significant differences were observed from a treatment to another by regard with trophic groups' community biomass. After six months of fallowing, the *M. pruriens*-based plots, with or without add of NPK, allowed significant increase ($p < 0.05$) of detritivorus community biomass: 21.73±2.20g.m^{-2} for "*M. pruriens* + NPK"-based plots and 16.95±2.15g.m^{-2} for *M. pruriens*-based plots against 7.07±1.02g.m^{-2}. Despite the significant difference observed for polyhumic geophageous community density, no significant difference was observed for the biomass of this trophic group (Fig. 2). After 12 months, only detritivorus community biomass was significantly increased by *M. pruriens* fallows with or without add of NPK: 24.31±4.80g.m^{-2} for "*M. pruriens* + NPK"-based plots and 17.36±3.76g.m^{-2} *M. pruriens*-based plots against 5.01±2.23g.m^{-2} for the control plots. Biomasses of the others trophic group community were not affected by treatments (Fig. 2).

Relative abundance of earthworms' populations

The main species in terms of relative density were *Dichogaster papillosa*, *Hyperiodrilus africanus*, *Stuhlmannia zielae*, *D. erhrhardti* and *D. baeri*. These species were dominant in all treatments and at both fallow periods. None earthworms population' abundance was influenced by treatments. Moreover, significant gaps were sometimes recorded for an earthworm species for a same treatment.

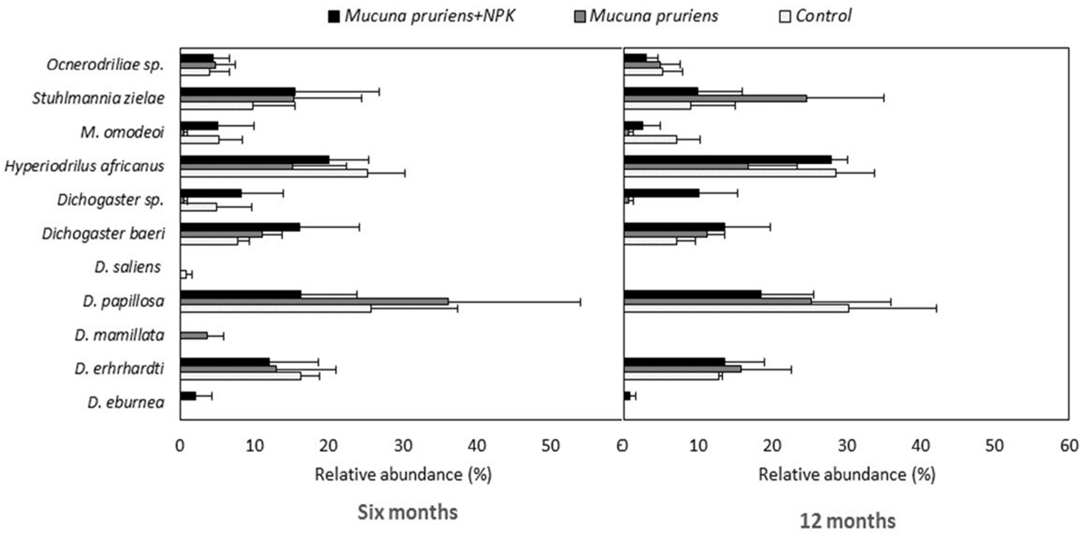

Fig. 3. Density and biomass of earthworms' trophic groups after six and 12 months of fallowing. No significant difference between treatments was recorded for each earthworm population and at both fallow period ($p > 0.05$).

Discussion

This study demonstrated the quick answer of earthworms to vegetation and soil mineral composition changes. The introduction of both *Mucuna pruriens* and chemical fertilizer in fallows significantly increased earthworm density and biomass. Six and 12 months after adding NPK and *Mucuna pruriens*, the overall earthworms' abundance increased from two to three times compared with natural fallows. Our results corroborate other studies highlighting that soil macrofauna is deeply affected by management and land-use changes (Blanchart *et al.*, 2006); this has been widely demonstrated for earthworms (Fragoso *et al.*, 1999).

The increase in nutrient availability through fertilization and organic matter release by *Mucuna pruriens* residues to soil not only favour earthworms' development but could also help improved subsequent crops' growth. Adding organic matter promotes earthworm abundance and improves soil structure and soil organic matter (SOM) cycling through beneficial earthworm-microbial interactions. This point is particularly important because agricultural activities tend to decrease SOM worldwide (Blanchart *et al.*, 2006; Betrand *et al.*, 2015; Butt and Briones, 2017). Our results are in line with observations made in previous studies that showed that plant species influence soil organisms through the quantity and the quality of their litter release (Belote and Jones 2009; Norgrove *et al.*, 2009; Koné *et al.*, 2012; Bertrand *et al.*, 2015).

During both fallow period, earthworms' abundance was responsive to *Mucuna pruriens*, in particular the detritivores such as *Dichogaster papillosa*, *D. erhrhardti* and *D. baeri* and also the polyhumics namely *Hyperiodrilus africanus* and *Stuhlmannia zielae*. This can be explained by their high reproductive potential and their rich diet (Tondoh and Lavelle, 2005). The accumulation of litter and organic matter under *Mucuna* covers may provide a resource base for “litter transformers” and "geophageous" (sensu Lavelle) (Lavelle and Spain, 2001). The two mesohumic species, namely *Millsonia omodeoi* and *Dichogaster saliens* did not show any response in the presence of legumes, probably because of their deeper position in soil profile and depend less upon organic residues. Previous studies reported that *Millsonia omodeoi* was not particularly affected by scarcity of soil organic carbon in disturbed soils. The species *M. omodeoi* is well adapted and able to survive in plots low in organic matter (Gilot *et al.*, 1995; Guei and Tondoh, 2012) due to the capability of juvenile individuals to consume huge amounts of soil that enable them to find the threshold needed for their growth and expansion (Lavelle, 1978).

Despite the significant increase of earthworm abundance already at six months of fallowing, no significant impact of *Mucuna pruriens* fertilized or not with NPK was observed on soil components even after 12 months of fallowing. Earthworms are recognized important decomposers contributing to nutrient cycling processes involving nitrogen (Cortez *et al.*, 2000), phosphorus (Chapuis-Lardy *et al.*, 1998) and carbon (Lavelle *et al.*, 1992; Curry *et al.*, 2007). The fact that significant increase in earthworms' density and biomass in the *Mucuna pruriens* plots fertilized with NPK didn't affect soil nutrient dynamic could be explained by the short fallow duration. This short duration couldn’t allow enhancing soil chemical properties whether in natural fallows or in improved fallows of *Mucuna pruriens*. Lavelle *et al.* (1992) highlighted the importance of earthworm feeding behaviours, which may contribute to the long-term effects of earthworms on nutrient cycling processes. From six to 12 months, only the P and K levels had significantly increased irrespective the fallow system. During earthworm feeding, P and K, are converted into an available form for plants (Lemtiri *et al.*, 2014). Moreover, these increases in P and K levels especially after 6 months of fallowing may be explained by addition of fertilizer NPK in the soil.

Conclusion

Our study showed that *Mucuna pruriens*-based fallows increased P,K, and earthworm’s abundance especially detritivorus and polyhumics populations when fertilized with NPK. These results confirm the idea that restoration of fertile or fertilizers-enriched soils is faster than poor soils. Further research is also needed to understand the reasons of these modifications even if different parameters can be proposed: quality and quantity of organic matter, P and K availability, and microclimate. These results also confirm the idea that a better use of cover plant may increase the functional properties of ecosystems and allow better agricultural ecosystem sustainability (Blanchart *et al.*, 2006).

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