International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 67 No. 1 Jun. 2023, pp. 119-128

http://www.ijisr.issr-journals.org/

Involvement of earthworm populations in indicating the physico-chemical state of soil under three types of perennial crops in the department of Daloa (Centre-West of Ivory Coast)

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ABSTRACT: The ecosystem services provided by earthworm populations are poorly studied under perennial crop agrosystems in Côte d'Ivoire. The present study, carried out in the Daloa department, aims to identify groups of responses within earthworm populations to changes in edaphic parameters in three types of perennial crops. To this end, earthworm populations and physico-chemical parameters were sampled on three transects per plantation, in nine plantations divided between three facies: cocoa, oil palm and rubber. The stand of the nine plantations was found to be rich in 13 species of earthworms. Six species dominated the stand, of which four, namely *Hyperiodrilus africanus, Stuhlmannia zielae, Dichogaster baeri* and *Gordiodrilus paski* showed a preference for crops. Indeed, *Hyperiodrilus africanus, Stuhlmannia zielae* and *Gordiodrilus paski* were indicative of sandy soils under palm plantations; the detritivore *Dichogaster baeri* was associated with cocoa and rubber plantations where the soils are silty-sandy and have a high organic matter content. These results open up new avenues of research on the roles of earthworms in the functioning of soils in cocoa, palm and rubber plantations in the region. For example, it will be investigated whether earthworm populations can be used in the development of a holistic index similar to the general soil quality index to assess soil quality.

KEYWORDS: Soil quality, earthworms, physico-chemical properties, preference, perennial crops.

1 INTRODUCTION

Since its independence, Côte d'Ivoire has based its economy on agriculture. This has led to the destruction of a large part of its forest area at the expense of crops. The forest cover in Côte d'Ivoire was estimated at 12 million hectares in 1960 and at 4 million hectares in 2000 [1]. Today, it has been reduced to about 2.5 million hectares [2]. Most of this deforestation is carried out for cash crop agriculture dominated by perennial crops such as cocoa (*Theobroma cacao*), coffee (*Coffea rabusta* and *Coffea canephora, Rubiacea*), rubber (*Hevea brasiliensis*) and oil palm (*Elaeis guinnensis*) [3].

The central-western part of Côte d'Ivoire, which used to be an important production area for these perennial crops, is now mainly covered by degraded forests. Today, this area is characterised by increasingly low crop production due, among other things, to the ageing of orchards [4], but also to the degradation of the physico-chemical and biological properties of the soil. Indeed, the biological compartment of soils plays an essential role and provides key ecosystem goods and services (nutrient cycling, soil formation, food production, climate, erosion and pest regulation), by intervening in soil structuring and functioning [5; 6].

Earthworms, which hold the largest biomass of the soil macrofauna [7], play a central role in improving and maintaining the productivity of agrosystems [8; 9]. They substantially affect many important soil processes such as stabilising organic matter through its incorporation into macroaggregates, stimulating the formation of these macroaggregates, increasing water infiltrability and regulating soil structure [10]; key factors that determine the soil's ability to sustainably support improved agricultural production [11; 12].

Earthworm diversity can be used both as a diagnostic tool for fertility and as a resource for improving soil functioning [13]. Earthworms as soil 'engineers' provide ecosystem services such as decomposition of organic matter, recycling of nutrients, decontamination of soils with heavy metals and maintenance of plant-friendly soil physical properties [14]. They show a diversity of responses through habitat and diet diversity [15]. Thus, the study of the assemblage pattern of these fauna in a context of agricultural intensification could constitute an alternative for the promotion of the sustainability of the quality of agricultural systems as they interact with the morphological, physical, chemical and biological compartments of the soil.

Currently, there is very little information on the variation of earthworm communities and the physico-chemical properties of soils in cocoa, palm and rubber plantations in Côte d'Ivoire and, in particular, in the Haut-Sassandra region. Moreover, the potential of these organisms as indicators of the quality of agrosystems on the basis of edaphic properties is very little documented. Thus, as part of the promotion of the sustainability of agricultural production systems, this study was initiated with a view to contributing to the development of a system for monitoring soil quality in perennial crop agrosystems based on earthworm populations. More specifically, the aim is to: (i) determine variations in the abundance and diversity of earthworm populations under three types of perennial crops, namely cocoa, palm and rubber plantations; (ii) evaluate the physico-chemical properties of the soils of these agrosystems; (iii) determine the influence of the physico-chemical conditions of the soils on the ecological preference of earthworm species.

2 MATERIALS AND METHODS

2.1 PRESENTATION OF THE STUDY AREA

The study was carried out in three villages (Tapeguhé, Zepreguhé, Tahiraguhé) in the department of Daloa, located between 6^0 and 6^0 45' West longitude and 6^0 30' and 7^0 20' North latitude. This department is the capital of the Haut-Sassandra region of Côte d'Ivoire. According to [16], this department is very humid with a climate with four seasons: the long rainy season, which extends from April to mid-July, is marked by inter-seasons and thunderstorms; it is followed by the short dry season (mid-July to mid-September) and the short rainy season (mid-September to November); the long dry season covers the months of December to March.

The average annual temperature is 25.6 °C. Dry and wet seasons alternate with temperatures ranging from 24.65°C to 27.75°C on average. Annual rainfall has fallen from 1868.5 mm in 1968 to 1120.4 mm in 2005, a decrease of 40 percent [17]. Hydrographically, the department is watered by the Sassandra River and its tributary, the Lobo, whose branches, the Dé and the Goré, flood the department, giving rise to numerous cultivable lowlands.

The vegetation is homogeneous and consists of dense humid forest in the south and wooded savannah in the north. This forest is experiencing accelerated degradation due to the intensification of cash crops (cocoa, coffee, oil palm and rubber). The relief of the department is made up of plateaus at 200-400m altitude cut in places by plains and lowlands [18]. Soil studies by [19] have shown that the soils of Daloa department are generally ferrallitic and moderately leached (or desaturated).

The formations that make up the substratum of the region have undergone alteration and lateralisation characteristic of regions with a hot and humid climate. From a lithological point of view, the bedrock consists of granitoids of constant mineralogical composition. These are alkaline to sub-alkaline granites contained in metamorphic formations (gneiss and migmatites) of very similar composition. These formations are very rarely visible in the outcrop because they are masked by a thick cover of clay and sand alteration.

2.2 STUDY OF THE BIOLOGICAL DIVERSITY OF EARTHWORMS

2.2.1 SAMPLING STRATEGY

The biological inventory was conducted in three agricultural production sites, namely Tapeguhé, Zepreguhé and Tahiraguhé. The choice of plots in each site was guided by the desire to study earthworm populations in the main agrosystems (palm, cocoa and rubber). In each land use, three sampling points were selected, sufficiently distant from each other to avoid auto-correlation, a common process within some soil macroinvertebrate components [20].

Earthworm diversity and abundance were estimated along three 20 m long transects, each perpendicular to the steepest slope. This exhaustive estimation method consists of sampling 10 m from the origin of the transect, three large monoliths (50 x 50 x 30 cm) spaced 5 m apart [9]. The sampling was done at the end of the main rainy season, a period of high activity of soil organisms.

2.2.2 EARTHWORM SAMPLING CONDUCT

A 50 cm square wooden quadrat was used to mark the location of the soil sample. The bedding bounded by the frame was removed and sorted for earthworm collection. The organisms were extracted using the direct hand sorting method adapted to tropical soils [9]. This method consists of digging a trench of 50 cm on each side and 30 cm deep around the quadrat in order to avoid possible leakage of mobile individuals. A large earth monolith of dimensions (50 x 50 x 30 cm) is thus isolated. The monolith is divided into three successive layers of 10 cm thickness which are placed in three separate buckets. The soil from each bucket is poured in small quantities into sorting trays. The earthworms are manually extracted from the clods and then stored in pillboxes containing 4% formaldehyde. The pellets are marked (site name, monolith type, transect number and stratum) and then sent to the laboratory for identification.

2.2.3 IDENTIFICATION OF EARTHWORM SPECIES

Identification was carried out in the laboratory of practical work n°2 of the Jean Lorougnon Guédé University. The collected worms were identified to species level using the determination keys [21; 22] and reference samples from the Natural History Museum in Budapest (Hungary). The identified individuals were then counted and weighed by species to determine their abundance and diversity.

2.2.4 ABUNDANCE AND DIVERSITY OF EARTHWORM POPULATIONS

Abundance was estimated by two parameters: density and biomass. Density represents the number of individuals per unit area ($Ind.m^{-2}$) while biomass represents the mass of individuals per unit area ($g.m^{-2}$). The density and biomass of earthworms were reduced to the square metre by multiplying the values by 4.

The diversity of earthworm populations was assessed through three parameters: (i) the average number of species, which is the number of species obtained per monolith, (ii) the Shannon Weaver diversity index (H), which measures the specific composition of a population based on the number of species and their relative abundance [23] using the following formula:

$\mathrm{H} = -\sum_{i}^{n} Pi.\log_2 Pi$ ($Pi = \frac{\mathrm{ni}}{\mathrm{N}}$ is the relative frequency of species i in the stand, N being the total number of species); (iii) equitability (E) shows the distribution of numbers between species:

$\mathrm{E} = \frac{H}{\log_2 S}$ (H is the Shannon index and S the average number of species).

Equitability varies from 0 to 1 and tends towards 0 when almost all the numbers are concentrated on one species. It takes the value 1 when all species have the same abundance.

2.3 STUDY OF THE PHYSICO-CHEMICAL PARAMETERS OF SOILS

2.3.1 SOIL SAMPLING METHOD

To characterise the soils under these crops, three soil pits were opened in a homogeneous area of 10,000 m^2 characterised by the best vegetation condition. Soil samples were taken from the full thickness of the A horizon in each pit. They were air-dried on a black tarpaulin. A 0.5 kg aliquot of each sample was taken, packed and labelled in a plastic bag for physico-chemical analysis in the laboratory.

2.3.2 PHYSICO-CHEMICAL ANALYSES

Physico-chemical analyses were carried out in the laboratory on the soil samples taken from each pit. The laboratory was the Laboratoire d'Analyse des Végétaux et des Sols (LAVESO) of the Ecole Supérieure d'Agronomie (ESA) located at the Institut National Polytechnique Félix Houphouët-Boigny (INPHB) in Yamoussoukro. The soil properties measured are summarised in Table 1, as well as their methods of determination:

Table 1. IMethod of determining the physico-chemical properties of soil in the laboratory

Soil properties	Methods of determination
Particle size	Limon Robinson pipette [24]
pH (Water)	Glass electrode pH meter [25]
Organic carbon (C)	Walkley and Black [26]
Organic matter	MO = 1.72 x C as it is a farm
Total nitrogen (Nt)	Modified Kjeldahl [25]
Assimilable phosphorus	Modified Olsen [26]

2.3.3 STATISTICAL ANALYSIS

The non-parametric Kruskal-Wallis test was used to compare the abundance and diversity of earthworms in the different agrosystems at the intra-site scale. Then, the Mann-Whitney test for pairwise comparison was performed at the 5% threshold when a difference was established. Anova 1 was used to compare the physico-chemical parameters. When the differences were significant, the means were separated according to the LSD (Least Significant Difference) method.

In addition, a hierarchical classification was carried out on the basis of the physico-chemical parameters of the soils using the ADE-4 software [27]. The dendrogram obtained by Ward's method based on the Euclidean distance made it possible to define typologies. We then proceed to partition the dendrogram and stop partitioning when the typology obtained offers a better interpretation of the results and when this level of division represents the partition threshold at which the indicator values of the species start to decrease considerably.

In fact, the characteristic earthworm species of each group are identified and their indicator values calculated by the IndVal method. The species retained by the method as indicators are those whose preference for these environments is significantly higher than suggested by a random distribution (Student's t test) and those whose indicator value is at least equal to 25 % [28].

3 RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 COMPOSITION OF EARTHWORM POPULATIONS

The earthworm populations collected in Tapeguhé, Zepreguhé and Tahiraguhé consist of 11, 8 and 10 species respectively. These worm species are divided into 5 genera *(Millsonia, Dichogaster, Hyperiodrilus, Stuhlmannia* and *Gordiodrilus)* and three families (Table 2). One species belonging to the genus *Dichogaster* could not be identified, and was therefore classified as a morpho-species. The species *Dichogaster saliens* and *Stuhlmannia palustis* are restricted to the Tapéguhé site, while *Dichogaster baeri* and *Dichogaster eburnea* are found only at the Tahiraguhé site. With the exception of the 4 earthworm species mentioned above, the others are common to at least two sites (Table 2).

Table 2. Occurrence of earthworm species per study site

Families	Species	Sites		
		Tap	Zep	Tah
Acanthodrilidae	*Millsonia lamtoiana* (*Omodeo & Vaillaud,* 1967)	1	0	1
	M. omodeoi (*Sims,* 1986)	1	1	1
	Dichogaster baeri (*Sciacchitano,* 1952)	0	0	1
	D. terraenigrae (*Omodeo & Vaillaud,* 1967)	1	1	1
	D. saliens (*Beddard,* 1893)	1	0	0
	D. erhrhardti (*Michaelsen,* 1898)	1	1	1
	D. papillosa (*Omodeo,* 1958)	1	1	1
	D. eburnea (*Csuzdi & Tondoh,* 2007)	0	0	1
	Dichogaster sp.	1	1	1
Eudrilidae	*Hyperiodrilus africanus* (*Beddard,* 1891)	1	1	1
	Stuhlmannia zielae (*Omodeo,* 1963)	1	1	0
	S. palustris (*Omodeo & Vaillaud,* 1967)	1	0	0
Ocnerodrilidae	*Gordiodrilus paski* (*Stephenson,* 1928)	1	1	1
3	13	11	8	10

Tap: Tapeguhe; Zep: Zepreguhe; Tah; Tahiraguhe; 1: presence; 0: absence

3.1.2 ABUNDANCE OF EARTHWORM POPULATIONS

ON THE TAPEGUHE SITE

The highest density of earthworms is observed in the palm grove (68.33 ± 4.42 Ind.m^{-2}). This was followed by rubber cultivation (51.33 ± 5.00 Ind.m^{-2}). The lowest density was collected in the cocoa plantation (21.33 ± 4.92 Ind.m^{-2}). The differences observed between the land use types were significant (Kruskall-Wallis, $P = 0.001$). Three species, *Hyperiodrilus africanus* (31.4%), *Stuhlmannia zielae* (28.4%) and *Dichogaster erhrhardti* (22.5%) shared most of the total density in the palm grove. While in the cocoa field, the overall density is held by *Dichogaster sp.* (25%), *D. terraenigrae* (21.9%), *Millsonia omodeoi* (18.8%) and *D. saliens* (15.6%). Three species namely *H. africanus* (46.8%), *Dichogaster sp* (13%) and *M. omodeoi* (10.4%) dominate under rubber cultivation. The pantropical species *H. africanus* establishes its population in the palm grove and the rubber plantation at the Tapeguhé site. Similar to density, the overall biomass of earthworms shows very strong differences between the environments considered (Kruskall-Wallis, $P < 0.001$). The rubber plantation hosts the highest biomass (65.98 ± 12.74 g.m^{-2}): It is followed in decreasing order by the palm plantation (18.21 ± 1.15 g.m^{-2}) and the cocoa plantation (12.57 ± 1.48 g.m^{-2}).

On The Zepreguhe Site

The overall density of earthworms varied significantly (Kruskall-Wallis, $P = 0.024$) between the 3 land use types at the Zepreguhé site. The highest density was found under the rubber plantation (50.00 ± 2.48 Ind.m^{-2}) while the cocoa plantation with a value of (31.33±4.06 Ind.m^{-2}) shows the lowest density of earthworms. The palm grove (38.00 ± 4.47 Ind.m^{-2}) has an intermediate density value. The species *Stuhlmannia zielae* (36.8%), *Hyperiodrilus africanus* (31.6%), and *Dichogaster papillosa* (22.8%) dominate the stands in density in the palm grove. Four species including *D. terraenigrae* (29.8%), *D. erhrhardti* (17%), *Millsonia omodeoi* (14.9%), *D. papillosa* (14.9%) and *H. africanus* (14.9%) shared the bulk of the density under the cocoa field. *H. africanus* (63%) and *D. terraenigrae* (29%) dominate under the rubber tree crop. At the Zepreguhé site, *H. africanus* dominated the populations in the three perennial crop plots. Overall earthworm biomass followed a similar pattern of variation to density under the different land use types (Kruskall-Wallis, $P < 0.001$). Biomass is highest under the rubber plantation (36.11 ± 5.05 g.m^{-2}), followed by the cocoa plantation (19.13 ± 2.37 g.m^{-2}). The lowest biomass is observed in the palm grove (9.06 ± 0.76 g.m^{-2}).

On The Tahiraguhe Site

The rubber plantation (57 ± 4.70 Ind.m^{-2}) has the highest overall density of earthworms. It is followed by the palm plantation (36.67 ± 3.92 Ind.m^{-2}), then the cocoa plantation (26.0 ± 4.7 Ind.m^{-2}) which reveals the lowest overall density. This variation in density was highly significant between the three perennial crop plots at the Tahiraguhé site (Kruskall-Wallis test, $P = 0.003$). Three species, namely *Dichogaster erhrhardti* (50.9%), *D. terraenigrae* (29.1%) and *Hyperiodrilus africanus* (14.1%), shared most of the total density in the palm grove. While in the cocoa field, the overall density is dominated by *D. terraenigrae* (33.3%), *Millsonia omodeoi* (33.3%) *Dichogaster erhrhardti* (10.3%) and *Dichogaster sp* (10.3%) and *Hyperiodrilus africanus* (10.3%). The species *D. papillosa* (45.4%), *Hyperiodrilus africanus* (31.4%) and *Dichogaster terraenigrae* (17.4%) dominate under the rubber tree crop. The *Hyperiodrilus africanus* population described a pattern identical to that of Zépréguhe; individuals were sampled in all three perennial crop facies. Like density, overall earthworm biomass varied significantly across land use types (Kruskall-Wallis test, $P = 0.005$). Biomass is highest in the rubber plantation (29.86 ± 9.82 g.m^{-2}). It is followed by the cocoa plantation (14.75 ± 2.66 g.m^{-2}). The lowest biomass value is observed in the palm crop (7.65 ± 0.63 g.m^{-2}).

3.1.3 Diversity Of Earthworm Populations

On The Tapeguhe Site

However, the rubber plantation (6.17±0.31 species.m^{-2}) seems to harbour a high species richness of worms, followed by the palm plantation (5.67 ± 0.80 species.m^{-2}) and the cocoa plantation (4.33 ± 0.88 species.m^{-2}) (Table 3). The Shannon diversity index does not differ significantly from one type of land use to another at the Tapéguhé site, but equitability varies very significantly between plots. The equitability values are all above the 0.50 threshold. However, the trend towards equitable distribution of numbers between species is more pronounced in the cocoa plantation (0.97 ± 0.01) and in the oil palm plantation (0.89 ± 0.01) (Table 3).

On The Zepreguhe Site

The earthworm populations are richer, more diversified with a tendency towards equitable distribution of individuals (Anova 1, $P \leq 0.002$) under the cocoa farm; the average number of earthworm species is 5.33±0.33 species.m^{-2} for a Shannon index value of 2.28 ± 0.12. Equitability is in the order of 0.95 ± 0.05. The palm grove is in second place after the cocoa grove (Table 3).

On The Tahiraguhe Site

The specific richness of earthworms does not vary significantly (Anova 1, $P = 0.885$) between the 3 perennial crop plots. Nevertheless, the cocoa plantation seems to have a rich and diverse worm population (Table III). However, equitability varies significantly between plots (Anova 1, $P = 0.007$). The trend towards equitable distribution of numbers between species is more pronounced in cocoa (0.97 ± 0.01) and rubber (0.91 ± 0.02) plantations (Table 3).

Table 3. Abundance and diversity of earthworm populations

Site	Type of use	Density	Biomass	S	H	E
Tapeguhe	Palmeraie	68.33 ± 4.42a	18.21 ± 1.15ab	5.67±0.8a	2.16 ± 0.14a	0.89 ± 0.01ab
	Cocoa farm	21.33 ± 4.92b	12.57 ± 1.48b	4.33 ± 0.88a	1.91 ± 0.28a	0.97 ± 0.01a
	Hevea field	51.33 ± 5.0ab	65.98 ± 12.74a	6.17 ± 0.31a	2.2 ± 0.1a	0.84 ± 0.02b
	P-value	*0.001*	*< 0.001*	*0.221*	*0.699*	*< 0.001*
Zepreguhe	Palmerais	38.0 ± 4.47ab	9.06 ± 0.76c	3.83 ± 0.4ab	1.77 ± 0.12ab	0.94 ± 0.01a
	Cocoa farm	31.33 ± 4.06b	19.13 ±2.37b	5.33 ± 0.33a	2.28 ± 0.12a	0.95 ± 0.02a
	Hevea field	50.0 ± 2.48a	36.11 ± 5.03a	3.0 ± 0.0b	1.23 ± 0.01b	0.78 ± 0.01b
	P-value	*0.024*	*< 0.001*	*0.002*	*< 0.001*	*0.002*
Tahiraguhe	Palmeraie	36.67 ± 3.92ab	7.65 ± 0.63b	3.5 ± 0.34a	1.23 ± 0.21a	0.67 ± 0.06b
	Cocoa farm	26.0 ± 4.7b	14.75 ± 2.66ab	3.83 ± 0.65a	1.71 ± 0.25a	0.94 ± 0.02a
	Hevea field	57.0 ± 4.7a	29.86 ±9.82a	3.5 ± 0.34a	1.61 ± 0.09a	0.91 ± 0.02ab
	P-value	*0.003*	*0.005*	*0.885*	*0.171*	*0.007*

H: Shannon Index and E: Equitability. Values followed by different letters are significantly different at the 5% threshold (Anova 1).

3.1.4 Physico-Chemical Properties Of Soils

On The Tapeguhe Site

At the Tapéguhé site, the quantities of organic matter, organic carbon, nitrogen, C/N ratio and phosphorus do not vary significantly (Anova 1, $P > 0.05$) between the types of land use, although the organic status of the soil under cocoa production seems high. The C/N ratio remained ≥ 13 regardless of the type of land use. As for assimilable phosphorus, its value in the palm grove appears to be higher. The soils are acidic (pH_{water} from 6.30 to 6.63). Their texture is silty-clay-sandy (cocoa and rubber plantation) to sandy (palm grove) (Table 4).

On The Zepreguhe Site

Texture also varies in the same direction as at the Tapeguhé site (silty-clay-sandy: cocoa and rubber plantation, to sandy: palm grove). The soils are slightly more acidic in the palm grove (pH_{water} of 6.00 ± 0.12) (Anova 1, $P < 0.05$). With the exception of the higher C/N ratio in the palm grove (16.33 ± 0.88) and the lower C/N ratio in the cocoa plantation (13.00 ± 0.58) and the rubber plantation (13.00 ± 0.58), organic matter, organic carbon and total nitrogen did not vary significantly between the three agrosystems. Assimilable phosphorus was higher in the palm grove (40.87 ± 1.74 $g.kg^{-1}$) and lower in the cocoa (14.90 ± 6.13 $g.kg^{-1}$) and rubber plantation (2.87 ± 1.58 $g.kg^{-1}$) (Table 4).

Tahiraguhe Website

At the Tahiraguhé site, the soil is neutral in the cocoa farm (7.2 ± 0.3) while in the palm farm (5.53 ± 0.03) and in the rubber plantation the soils are acidic (6.17 ± 0.12). The texture is sandy in the palm and rubber plantation, while in the cocoa plantation it is silty-sandy. Assimilable phosphorus does not vary significantly between soil use types (Anova 1, $P > 0.05$), its value is higher in the cocoa and rubber plantation and low in the palm plantation. Organic matter (3.04 ± 0.1 %), organic carbon (1.77 ± 0.09 %) and total nitrogen (0.17 ±0.03 %) are higher in the cocoa farm, while the C/N ratio (15.33 ± 0.088 %) is high in the rubber plantation (Table 4).

Table 4. Physico-chemical properties of different types of land use

Physico-chemical parameters	Sites											
	Tapeguhe				Zepreguhe				Tahiraguhe			
	Palmeraie	Cocoa farm	Hevea field	*P*	Palmeraie	Cocoa farm	Hevea field	*P*	Palmeraie	Cocoa farm	Hevea field	*P*
MO (%)	1.78 ± 0.56a	2.12 ± 0.32a	1.66 ± 0.15a	0.69	1.49±0.21a	2.06 ± 0.46a	2.06 ± 0.1a	0.34	1.89 ± 0.43a	3.04 ± 0.1b	1.55 ± 0.3a	0.03
CO (%)	1.03 ± 0.33a	1.23 ± 0.19a	0.97 ± 0.09a	0.69	0.87 ± 0.12a	1.20 ± 0.06a	1.20 ± 0.06a	0.34	1.1 ± 0.25a	1.77 ± 0.09b	0.9 ± 0.17a	0.03
Nt (%)	0.07 ± 0.03a	0.13 ± 0.03a	0.10 ± 0a	0.29	0.07 ± 0.03a	0.13 ± 0.03a	0.10 ± 0a	0.29	0.10 ± 0a	0.17 ± 0.03a	0.1 0± 0a	0.07
C/N ratio	14.67 ± 1.2a	13.00 ± 1a	14.00 ± 0a	0.46	16.33 ± 0.88	13.00 ± 0.58	13.00 ± 0.58	0.02	14.67 ± 1.2a	12.67 ± 0.67a	15.33 ± 0.88a	0.19
P ($g.kg^{-1}$)	17.37 ± 6.43a	13.00 ± 6.5a	5.47 ± 2.7a	0.36	40.87 ± 1.74b	14.90 ± 6.13a	2.87 ± 1.58a	0.001	8.6 ± 7.34a	24.57 ± 15.57a	17.5 ± 11.8a	0.66
pH_{water}	6.30 ± 0.36a	6.37 ± 0.22a	6.63 ± 0.24a	0.68	6.00 ± 0.12a	6.57 ± 0.07b	6.17 ± 0.07a	0.009	5.53 ± 0.03a	7.2 ± 0.3b	6.17 ± 0.12a	0.00
Clay (%)	6.33 ± 2.96b	25.67 ± 1.67a	23.67 ± 3.53a	0.005	2.33 ± 0.33a	13.00 ± 2.65ab	21.33 ± 5.17b	0.02	5.0 ± 1.0a	22.33 ± 2.33b	5.67 ± 0.88a	0.00
Silt (%)	16.33 ± 2.67a	22.33 ± 1.2a	13.67 ± 1.2a	0.14	12.33 ± 1.2a	19.33 ± 2.19a	20 ± 2.08a	0.05	14.67 ± 0.67a	22.67 ± 2.33b	18 ± 0.58ab	0.022
Sand (%)	77.33 ± 5.24b	52.00 ± 0.58a	56.67 ± 2.6a	0.00	85.33 ± 0.88b	67.61 ± 4.7a	58.67 ± 6.89a	0.02	80.33 ± 1.45a	55.33 ± 1.45b	76.33 ± 0.88a	< 0.001

OM: organic matter; OC: organic carbon, Nt: total nitrogen; P: Phosphore assimilable. Values followed by different letters are significantly different at the 5% level (Anova 1).

3.1.5 ECOLOGICAL PREFERENCES OF EARTHWORMS: INDVAL ANALYSIS

This study was based on the hierarchical classification of all 9 agrosystems that served as a basis for the determination of the typologies (Figure 1). The partition of the agrosystems was stopped at level 3 because at this stage of partition the indicator values of the earthworm species start to decrease. Two edaphic parameters, texture and pH, are the most appropriate for the hierarchical classification of agrosystems. Thus level 1 does not define a partition but groups all agrosystems. Level 2 defines, on the one hand, the group of palm plantations with sandy textured soils and which associate the species *Hyperiodrilus africanus* (IndVal : 77.26 % ; t-test : $P < 0.01$), and on the other hand, the group composed of cocoa and rubber plantations characterised by a silty-sandy texture and preferred by the species *Dichogaster baeri* (IndVal : 81.92 % ; t-test : $P < 0.01$) The third level of partition gives three groups of agrosystems, namely group 1 composed of Tapeguhé and Zepreguhé palm plantations with a sandy texture and associating the species *Stuhlmannia zielae* (IndVal :99,72% ; t-test : $P < 0{,}01$) and *Gordiodrilus paski* (IndVal : 100 % ; t-test : $P < 0.01$); group 3 consisting of the Tahiraguhé palm grove with sandy texture and acidic soil is preferred by the species *Hyperiodrilus africanus* (IndVal :73.79 % ; t-test : $P < 0.01$), and group 2 composed of cocoa and rubber plantations with a silty-sandy texture, is preferred by the species *Dichogaster baeri* (IndVal : 63 % ; t-test : $P < 0.01$) (Table V).

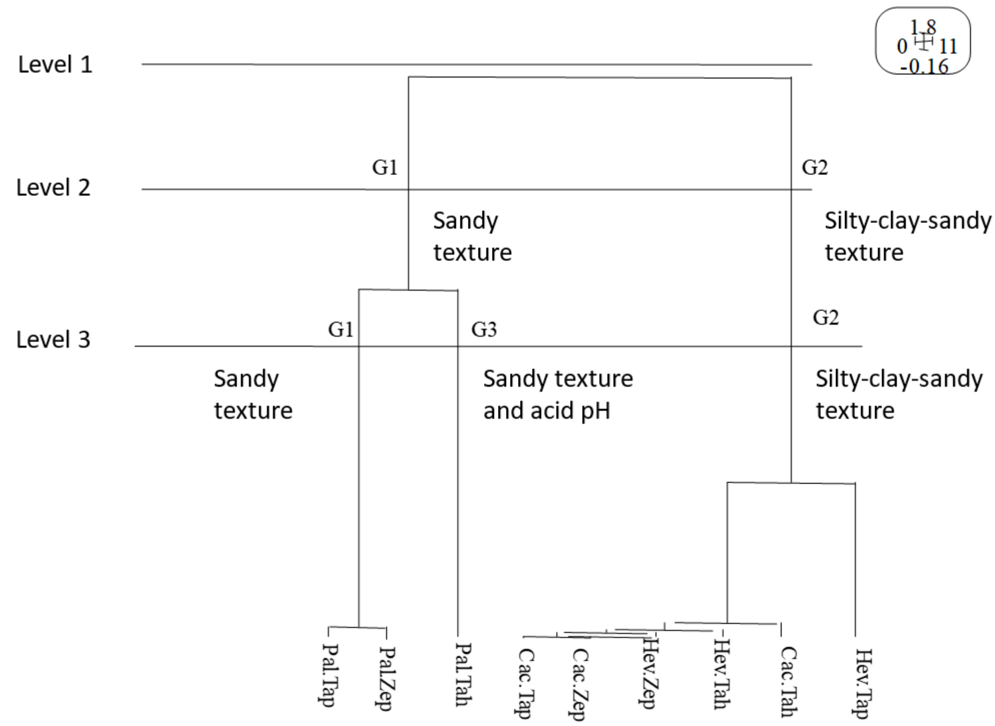

Fig. 1. Hierarchical classification of the 9 agrosystems on the basis of physico-chemical parameters

Pal: Palmeraie; Cac: Cocoa farm; Hev: Hevea field; Tap: Tapeguhe; Zep: Zepreguhe; Tah: Tahiraguhe; G1: Group 1; G2: Group 2 and G3: Group 3

Table 5. Species associated with the different typologies identified by the hierarchical classification

Scores	Typologies	Indications	Species and indicator values (%)
1	All agrosystems	-	-
2	Group 1: Palm groves	Soil with sandy texture	*Hyperiodrilus africanus* (77,26)
	Group 2: Cocoa and rubber plantations	Soil with a silty-clay-sandy texture	*Dichogaster baeri* (81,92)
3	Group 1: Tapéguhé and Zépréguhé palm groves	Sandy textured soil	*Stuhlmannia zielae* (99.72) and *Gordiodrilus paski* (100)
	Group 3: Tahiraguhé palm grove	Soil with sandy texture and acidic pH	*Hyperiodrilus africanus* (73,79)
	Group 2: Cocoa and rubber plantations	Soil with a silty-clay-sandy texture	*Dichogaster baeri* (63)

3.2 Discussion

In general, the practice of growing perennial crops induces a large variation in earthworm ensity and biomass compared to the diversity of the stand in each agricultural production site. Worms are sentially more abundant in rubber plantations while populations are low in cocoa farms despite the high organic matter levels in these agrosystems. This pattern under cocoa farms could be attributed to agricultural practices such as the treatment of cocoa plants with insecticides and fungicides; plant protection products known to have a harmful effect on earthworm populations [29].

Indeed, work by [30] in the southern region of Cameroon found that worm populations decreased as the intensity of application of the fungicide Ridomil^{R} increased in a 35-year-old cocoa farm. The lower abundance could be explained by the lack of availability of food resources for these groups due to plantation maintenance [31] and the frequent use of herbicides for plantation maintenance [32].

Studies also show a direct effect of herbicides through toxicity, resulting in high mortality and declining populations of some macro-invertebrate groups in intensive agricultural systems [33; 32]. This practice acts indirectly on macro-arthropod communities by suppressing weeds covering the soil. This suppression can lead to an alteration of microclimatic conditions (increase in temperature and decrease in humidity) and also to a suppression of resources and organic matter inputs, leading to a decrease in the abundance of species, especially detritivores [34; 32].

Gains in abundance under rubber plantations would be governed by, among other things, the reduced use of plant protection products, which would decouple the beneficial effect of soil cover by litter, which would regulate soil temperature and moisture (creation of a mild microclimate) and constitute a source of diversification of microhabitats for soil fauna [35].

At the scale of the three agricultural production sites, 13 species of earthworms were sampled with 11, 8 and 10 species, respectively at the Tapeguhé, Zepreguhé and Tahiraguhe sites. Six species, namely *Millsonia omodeoi, Dichogaster erhrhardti, Dichogaster terraenigrae, Dichogaster papillosa, Stuhlmannia zielae* and *Hyperiodrilus africanus,* dominated the earthworm population by far in all three sites. However, four were found to be indicative of agrosystem groups obtained from the hierarchical classification of plots on the basis of soil physico-chemical properties. These include *Hyperiodrilus africanus, Stuhlmannia zielae, Dichogaster baeri* and *Gordiodrilus paski*. Our results thus reveal that earthworm abundance can be an appropriate indicator of the physico-chemical status of soils.

Indeed, depending on the functional aptitudes of each species, worms are excellent bioindicators of the quality of the ecosystems in which they live, as they are sensitive to the edaphic environment [36]. Individuals of the species *Hyperiodrilus africanus, Stuhlmannia zielae* and *Gordiodrilus paski* are indicators of soils under palm groves, characterised by a sandy texture. The establishment of Hyperiodrilus africanus in palm groves may reflect its ability to withstand high rates of anthropisation and its lower sensitivity to soil acidity. Similar results on the acidophilic suitability of the earthworms *Dichogaster candida* and *D. cornuta* were demonstrated by Guei *et al*. (2019) on Mount Nimba in highland grassland soils characterised by high iron toxicity, which causes their acidity.

Furthermore, the detritivorous species *Dichogaster baeri* has a preference for cocoa and rubber plantations with soils that are silty, clayey and sandy in texture but also characterised by high levels of organic matter. The simultaneous presence of organic matter, silt and clay in these soils will contribute to the formation of the clay-humus complex, which will give the soil a good structure, particularly the lumpy structure. Thus, the association of the species Dichogaster baeri with these agrosystems may underlie the indication of soils with a good clay-humus complex. *Dichogaster baeri* is less generalist than *Hyperiodrilus africanus, Gordiodrilus paski* and *Stuhlmannia zielae* and has an abundance of between 2.6 and 8.4 %, giving it specialist status. The knowledge of specialist species is an asset for the orientation of soil biodiversity conservation policy and the promotion of sustainable agriculture [37], because their elimination leads to the disappearance of the irreplaceable ecological services they provide [38], which could lead to an imbalance in the environment.

4 CONCLUSION

The present study aimed to identify response groups within earthworm populations to changes in edaphic parameters in nine perennial crop agrosystems. The results show that worms are predominantly more abundant in rubber plantations while populations are low in cocoa plantations despite the high organic matter levels in these agrosystems. Rubber plantations provide favourable conditions for the establishment of earthworm populations and can thus play an important role in the conservation of these organisms. The stand at the three agricultural production sites shows a richness of 13 earthworm species. Six species dominated the stand, of which *Hyperiodrilus africanus, Stuhlmannia zielae, Dichogaster baeri* and *Gordiodrilus paski were found to* be indicative of agrosystem groups.

REFERENCES

[1] Y. T. Brou: Climat, mutations socio-économiques et paysages en Côte d'Ivoire. Mémoire de synthèse des activités scientifiques. Habilitation à Diriger des Recherches, Université des Sciences et Technologies de Lille, France, pp 212, 2008.

[2] K. Traoré, «Couverture forestière de la Côte d'Ivoire: une analyse critique de la situation de gestion des forêts (classée, parc et réserve),» *The International Journal of Social Sciences and Humanities Invention,* Vol. 5, No. 2, pp 4387 - 4397.

[3] Ruf F. Les cycles du cacao en Côte d'Ivoire: la mise en cause d'un modèle. In le modèle ivoirien en questions. Crises, ajustements, recompositions. *Karthala-ORSTOM,* Paris, France, pp 249-264, 2009.

[4] Chatelain, C., Dao H., Gautier L. and Spichiger R., Forest cover change in Côte d'Ivoire and Upper Guinea. In: *Poorter, L., Bonger, F., Kouamé, F.N., Hawthorne, W.D.* (eds). Biodiversity of West Africa forest. An Ecological Atlas of Woody Plant Species. CABI, Wallingford, pp 15 - 31, 2004.

[5] M. Koumba, H. K. Mipounga, A. A. Koumba, C. R. Z. Koumba, B. R. Mboye, J. F. Liwouwou, J. D. Mbega and J. F. Mavoungou, «Diversité familiale des macro-invertébrés et qualité des cours d'eaux du Parc National de Moukalaba Doudou (Sud-Ouest du Gabon) ». *Entomologie Faunistique,* 70: 107 - 120, 2017.

[6] M. Henry, M. Belem, R. D'Annuzio, M. Bernoux, Les stocks de carbone des sols d'Afrique de l'Ouest. *In*: Carbone des sols en Afrique. Impacts des usages des sols et des pratiques agricoles. Rome/Marseille, pp 35 - 41, 2020.

[7] H. R. P. Phillips, E. M. Bach, M. L.C. Bart, J. M. Bernnett, R. Beugnon, M. J. I. Briones, G. G. Brown and N. Eisenhauer, «Global data on earthworn abundance, biomass, diversity and corresponding environmental property,» *Scientific Data,* Vol. 8, pp 1 - 36, 2021.

[8] A. Turbé, A. De Toni, P. Benito, P. Lavelle, N. Ruiz, W. H. Van der Putten, E. Labouze and S. Mudgal: Soil biodiversity: functions, threats and tools for policy makers. Bio Intelligence Service, IRD, and NIOO, Report for European Commission (DG Environment), pp 250, 2010.

[9] A. M. Guei, J. K. N'Dri, F. G. Zro Bi, S. Bakayoko and J.E. Tondoh, «Relationships between soil morpho-chemical parameters and earthworm community attributes in tropical agroecosystems in the center-west region of Ivory Coast, Africa». *Tropical Ecology,* Vol. 60, 209 - 218, 2019.

[10] S. J. Fonte, A. Y. Y. Kong, Chris van Kessel, P. F. Hendrix and J. Six, «Influence of earthworm activity on aggregate-associated carbon and nitrogen dynamics differs with agroecosystem management». *Soil Biology and Biochemistry,* Vol. 39, 1014 – 1022, 2007.

[11] H.N. Hong, C. Rumpen T. H. Des-Tureau, G. Bardoux, D. Billou, T. T. Duc and P. Jouquet. «How do earthworms influence organic matter quantity and quality in tropical soils?» *Soil Biology and Biochemistry,* Vol. 43, pp 223 - 230, 2011.

[12] P. Lavelle, J. Mathieu, A. Spain, G. Brown, C. Fragoso, E. Lapied, A. De Aquino, I. Barois, E. Barrios, M. E. Barros, J. C. Bedano, E. Blanchart, M. Caulfild, Y. Changueza, Y. Dai, T. Dacaens, A. Dominguez, Y. Dominguez, A. Feijoo and C. Zhang, «Soil macroinvertebrate communities: A world-wide assessment. *Global Ecology and Biologeography,»* Vol 00, pp 1 - 16, 2022.

[13] P. Lavelle, T. Decaëns, M. Aubert, S. Barot, M. Blouin, F. Bureau, P. Margerie, P. Mora, J. P. and J P. Rossi, «Soil invertebrates and ecosystem services,» *European Journal of Soil Biology,* Vol. 42, pp 3 - 15, 2006.

[14] A. Swati and S. Hait, «Fate and bioavailability of heavy metals during vermicomposting of various organic wastes,» A *review, Process Safety and Environnment Protection,* India, (D0I: 10.1016/j. psep.2017.03. 031), 2017.

[15] Y. Capowiez, T Decaens, M. Hedde, C. Marsden, P. Joupet, F. D. Marchan, J. Nahamani, C. Pelosi and Bottinelli, «Faut-il continuer à utiliser les catégories écologiques de vers de terre définies par Marcel Bouché il y'a 5 ans ? une vision historique et critique». *Etude Gestion des Sols,* Vol. 29, pp 51- 58, 2022.

[16] ICEF et ENSEA (2002). L'économie locale du département de Daloa. Rapport d'étude, Programme ECOLOC, Vol. 1, p 144, 2002.

[17] R. Ligban, D Goné, B. Kamagaté, M. B. Saley & J. Biémi, «Processus ydrogéochimiques et origine des sources naturelles dans le degré carré de Daloa». *Journal of Biology and Chemical Science,* vol. 3, no. 1, pp 38 - 47, 2009.

[18] J. M. Avenard & A. Deluz, «Milieu naturel de Côte d'Ivoire». *Etudes rurales,* no 48, pp. 185-186, 1972.

[19] B. Dabin, N. Leneuf, G. Riou, Carte pédologique de la Côte d'Ivoire au 1/2.000.000. Notice explicative. ORSTOM, p 39, 1960.

[20] J. P. Rossi, «The spatiotemporal pattern of a tropical earthworm species assemblage and its relationship with soil structure,» *Pedobiologia,* Vol. 47, pp 497 - 503, 2003.

[21] P. Lavelle, «Les vers de terre de la savane de Lamto (Côte d'Ivoire): Peuplements, Population et Fonctions dans l'écosystème,» *Publication du Laboratoire Zoologique,* ENS, Vol. 12, pp 301, 1978.

[22] C. Cszudi and E. J. Tondoh, «New and little-known earthowrm species from the Ivory Coast (Oligochaeta: Acanthodrilidae: *Benhamiinia-Eudrilidae*)», *Journal of Natural History,* Vol. 41, pp 2551 - 2556, 2007.

[23] Legendre L and Legendre P. Ecologie numérique tome 1: Le traitement multiple des données écologiques. 2eme edition 1984: Masson, Paris France, pp 50, 1984.

[24] Douzals J. P.: Mesures physiques de la variabilité des sols en agriculture de précision. Ingénieries-EAT, IRSTEA édition 2000, Dijon, France, pp 45 - 52, 2000.

[25] M. Diack and M. Loum, «Caractérisation par approche géostatistique de la variabilité des propriétés du sol de la ferme agropastorale de l'Université Gaston Berger (UGB) de SaintLouis, dans le bas delta du fleuve Sénégal». *Revue de Géographie du Laboratoire Leïdi,* Vol. 12 pp 15, 2014.

[26] Hilhorst M. A. and Balendonck J.: A pore water conductivity sensor to facilitate noninvasive soil water content measurements. In*:* Precision Agriculture 1999, J.V. Staffort (ed.). Proceedings of the 2nd European Conference in Precision Agriculture. Society of Chemical Industry, Odense, Denmark, pp 211 - 220, 1999.

[27] J. Thioulouse, D. Chessel, S. Dolédec and J. M. Olivier, «ADE-4: à multivariate analysis Tomography: preliminary study,» *European Journal of Soil Biology,* Vol. 38, pp 329 - 336, 1997.

[28] M. Dufrêne and P. Legendre, «Species assemblages and indicator species: the need for a flexible asymetrical approach», *Ecological Monographs,* Vol. 67, pp 345 - 366, 1997.

[29] M. E. Cook and A. A. J. Swait, «Effects of some fungicide treatments on earthworm populations and leaf removal in apple orchards,» *Journal of Horticulture Sciences,* Vol. 50, 495 - 499, 1975.

[30] L. Norgrove, C. Csuzdi, F. Forzi, M. Canet and J. Gounes, «Shifts in soil faunal community structure in shaded cacao agroforests and consequences for ecosystem function in Central Africa,» *Tropical Ecology*. Vol. 50, pp 71 - 78, 2009.

[31] M. Traore. Impact des pratiques agricoles (rotation, fertilisation et labour) sur la dynamique de la microfaune et la macrofaune du sol sous culture de sorgho et de niébé au Centre Ouest du Burkina Faso. Thèse de Doctorat. Université Polytechnique de Bobo-Dioulasso. Institut du Développement Rural (Bobo-Dioulasso: Burkina Faso), pp 15 - 120, 2012.

[32] M. El Jaouhari, G. Damour, C. Mauriol and M. Coulis, «Effets des pratiques agricoles sur les macro-arthropodes du sol dans les bananeraies de Martinique», *Etude et Gestion des Sols,* Vol. 29, pp 77 - 91, 2022.

[33] M. G. Paoletti and M. Hassall, «Woodlice (Isopoda: *Oniscidea*): their potential for assessing sustainability and use as bioindicators,» *Agriculture, Ecosystems & Environment,* 1999 Vol. 74, pp 157 - 165, 1999.

[34] C.W.G. De Menezes and M.A. Soares, «Impactos do controle de plantas daninhas e da aplicação de herbicidas em inimigos naturais», *Revista Brasileira de Herbicidas,* Vol. 15, pp 2 -7, 2016.

[35] E. J. Tondoh, K. Dimobe, A. M. Guéi, L. Adohe, L. Baidal, J. K. N'Dri and G. Forkuor, «Soil Health Changes Over a 25-Year Chronosequence from Forest to Plantation in Rubber Tree (*Hevea brasiliensis*) Landscapes in Southern Côte d'Ivoire: Do Earthworms Play Role?» *Frontiers in Environmental Science,* Vol. 7, pp 19 – 73, 2019.

[36] N. Ruiz, M. Jérôme, C. Léonide, R. Christine, H. Gérard, I. Etienne and L. Patrick. «IBQS: A synthetic index of soil quality based on soil macro-invertebrates communities» *Soil Biology and Biochemistry,* Vol. 43, 2032 - 2045, 2011.

[37] J. Nahmani, P. Lavelle and J.P. Rossi, «Does changing the taxonomical resolution alter the value of soil macroinvertebrates as bioindicators of metal pollution ?» *Soil Biology and Biochemistry,* Vol. 38, pp 385 - 396, 2006.

[38] T. H. Larsen, N.M. Williams and C. Kremen, «Extinction order and altered community structure rapidly disrupt ecosystem functioning,» *Ecology Letters,* Vol. 8, pp 538 - 547, 2005.