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Earthworms and soil-feeding termites (*Cubitermes subcrenulatus*) adopt a strategy of ecological niche by the sharing of space in the natural reserve of Lamto in Côte d'Ivoire

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Abstract: The ecosystems engineers are considered as a prime resource of agroecosystems because they regulate the soil biological process. Among them, earthworms and soil-feeding termites that have the same diet and similar roles on the soil structure have been the subject of this study. It focuses on the influence of *Cubitermes subcrenulatus* nests on the distribution of earthworm communities in the Lamto savannas (Côte d'Ivoire). In total, 15 living nests of *Cubitermes subcrenulatus* remote the one of the other of 200 m have been identified randomly in the forest block of "Yao Ble Boka". Around each of these nests (center of the circle), 9 monoliths of modified Tropical Soil Biology and Fertility (TSBF) type (50 cm x 50 cm x 30 cm) were arranged on three circles (C I, C II and C III) of respective radius, 0.75 m, 1.25 m and 1.75 m. In each of the monoliths, earthworms and *Cubitermes subcrenulatus* were sampled by direct manual sorting by layer of 10 cm (0-10 cm; 10-20 cm and 20-30 cm). Eight (08) species of earthworms were collected. It was noted that around the nests of *Cubitermes subcrenulatus*, the structure of the earthworm communities is characterized by preponderance and regular frequency endogeic earthworms compared to epigeic earthworms. Earthworms and termites related to these nests have a reverse spatial distribution which is done by only remoteness. These results show that around the nests of *Cubitermes subcrenulatus* (i) the structuring of the earthworms communities appears to be a function of the activities of the termites that reside there. (ii) The presence of nests does not does not result in behavioral change or preferential biotope to earthworms. This seems to foster a good dynamics of the organic matter in the soils located near the nests.

Keywords: Earthworms, *Cubitermes subcrenulatus*, Lamto, Côte d'Ivoire

INTRODUCTION

In many countries of Sub-Saharan Africa, sustainable management and the replenishment of strongly degraded soil constitute an enormous challenge for agriculture[1,2]. The use of chemical fertilizers for production optimization remains very costly for many producers. Thus, the adoption of an approach to move toward a sustainable agriculture that is in line with the potential of the soil and the social demands requires the development and introduction of technologies conservative of resources[3]. It is therefore appropriate to know and understand better the functioning of the soil through a good analysis of the place and the role of each of these components (physical, chemical, and biological). Alternatives found such as the adapted management of organic matter (crop residues, green manure of legumes, alley cropping) and mineral fertilization, still fail to maintain or increase the potential for soil productivity in the long term[4,5] because of the degradation of physico-chemical and biological properties of soil.

One of the fields of research to be explored will be the treatment of biological processes which maintain the soils fertility in a natural system and allow apparently poor soils to support high primary production[4,6]. Many authors agree that soil fauna are important actors in the functioning of the soil[7,8]. They consider that this fauna is composed of organisms that are not simple inhabitants of the soil, but are part of the soils[7, 9]. Among the fauna of the soil, the macrofauna is the resource which fills within ecosystems, essential functions for the maintenance of the quality of the soils[5,10]. The "ecosystem engineers", such as earthworms and termites are thus considered as the main representatives, given their abundance, geographical distribution and functional roles. These organisms influence the diversity of other organisms belonging to subordinates functional groups (litter transformers, microprocessors and microorganisms), thus regulating nutrients transformations[9, 11].

For earthworms and soil-feeding termites that use the same trophic resources in addition to their similar roles on the soil structure and the dynamics of organic matter[12], the relationships they establish between themselves implement biological processes that are responsible for the proper functioning of terrestrial environments. Yet, very few studies have been conducted on these relationships. It therefore seems appropriate to study the relationships that may exist between these two biological components in order to better understand the improvement of soil properties through a better apprehension of their role and ecosystem function. We have postulated that the nests of *Cubitermes subcrenulatus* having their hypogeic part containing a large number of termites, cause a change of habitat or biotope of earthworms living on their surroundings.

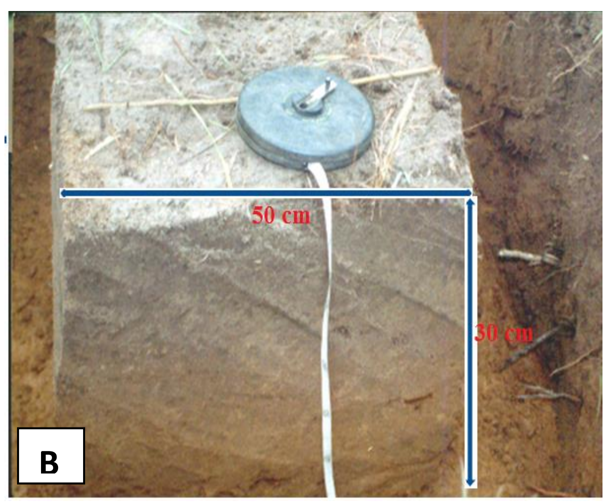
MATERIEL AND METHODS

The study site: This study was conducted in the natural reserve of Lamto in Côte d'Ivoire (6°13 N, 52°02 W) located at 160 km on the northwest of Abidjan. The Lamto reserve is located in a transition zone between the semi-deciduous moist forest in the south and the Sudanian Savanna in the north. With an area of 2700 ha, it consists of a mosaic of forests and savannas. The Lamto reserve is characterized by bimodal rainfall with two wet seasons: from April to July and from September to October. The average annual temperature from 2006 to 2016 was 28.4 ° C. Most soils are based on granitic bedrock. These soils are then slightly acidic and classified as ferralsols (FAO Classification) and consist of 75% sand

Sampling Device for the collection of earthworms and termites: In the "Yao ble Boka" forest block, 15 live nests (termite mounds) of *Cubitermes subcrenulatus* **(Figure 1A)**, have been identified so that they are 200 m apart to avoid the spatial influence of a nest on the other. Around each of the nests, 09 monoliths of the modified Tropical Soil Biology and Fertility (TSBF) type (50 cm x 50 cm x 30 cm) **(Figure 1B)** were dug so that they were arranged on three circles radius, with the nest (termite mounds) as the center of the circle, according to the following experimental design **(Figure 2)**:

- on the first circle of radius 0.75 m (CI), three monoliths were arranged so that by referring to the needle of a clock, the first is at 12 o'clock, the second at 4 o'clock and the third at 8 o'clock;
- on the second circle of radius 1.25 m (C II), three other monoliths placed each between two previous ones were arranged so that the first is at 2 o'clock, the second at 6 o'clock and the third at 10 o'clock;
- on the third circle of radius 1.75 m (C III), three monoliths also placed each between two monoliths of the preceding circle were arranged so that the first is at 12 o'clock, the second at 4 o'clock and the third at 8 o'clock.

(A) Nest of *Cubitermes subcrenulatus*



(B) Monoliths of type TSBF amended

Figure 1: Components of the sampling device

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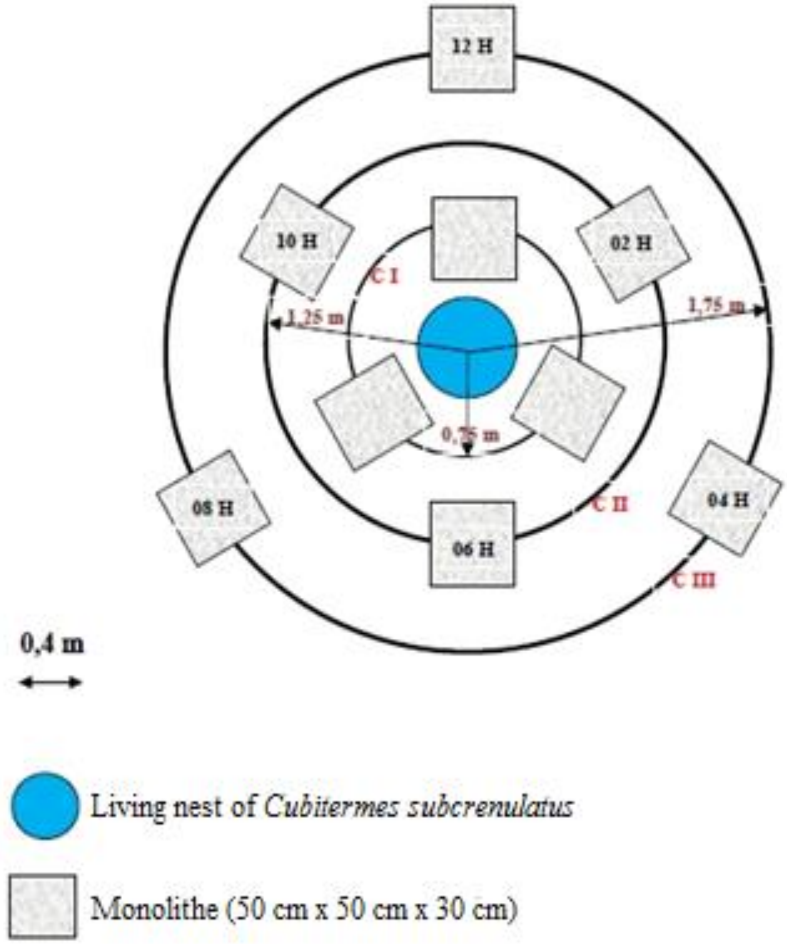

C I = circle of radius 0.75 m; **CII** = circle of radius 1.25 m; **C III** = circle of radius 1.75 m.

Figure 2: Schematic of the sampling device

Sampling of earthworms, and termites: Each dug monolith was manually excavated in a stratified manner (0-10 cm, 10-20 cm and 20-30 cm) to collect all earthworm individuals[13]. The earthworms collected were preserved in jars duly labeled containing formaldehyde 4%. Then, the jars were transported to the laboratory where species identification was performed using the determination keys of Cszudi and Tondoh[14], based on the morphology (shape, size, segments length) and the pigmentation of individuals.

In addition, the sampling method used for the collection of earthworms is not very suitable for the collection of termites because of their social structure and their high mobility; the densities of termites were estimated around the different sampled nests.

Data analysis: For each sampled nest, the data were grouped by distance (circle) and by stratum for statistical reasons (increase number of replications). The structure of earthworm communities around nests of *Cubitermes subcrenulatus* was determined using an ordination method: Correspondence Analysis (CA). This technique was used to analyze the data, because the data collected in community ecology and environmental ecology are mostly multivariate, i.e. each unit of statistical sampling is characterized by many of the attributes. These data are complex and subject to sampling error, and redundancy andnoises[15]. The ordination was performed using the ade4 software package R.

Furthermore, the distribution of mean densities of earthworms collected around live nests was represented using the function of Buble gstat package of the program R. This function made it possible to make maps on which the earthworm densities obtained by distance (C I; C II; C III) and by stratum (0-10 cm; 10-20 cm and 20-30 cm) are materialized by circles or patch. Comparisons of mean densities of earthworms between the different distances and between the different strata sampled around living nests were made using the non-parametric Kruskal-Wallis test using the STATISTICA 7.1 software.

RESULTS AND DISCUSSION

Structure of the earthworm communities around the nests of *Cubitermes subcrenulatus*: Around nests of *Cubitermes subcrenulatus* sampled, 8 species of earthworms were collected. These are *Agastrodrilus multivesiculatus*, *Chuniodrilus palustris*, *Chuniodrilus zielae*, *Dichogaster agilis*, *Hyperiodrilus africanus*, *Millsonia lamtoiana*, *Millsonia omodei and Stuhlmania prolifera*. Among these earthworms, 6 species belong to the ecological category of endogeic and 2 species belong to the ecological category of epigeic **(Table 1)**.The Correspondence Analysis (CA) used to highlight the community structure of these earthworms showed that the first 4 axes explain 84, 87% of the total variance of the matrix of earthworms **(Table 2)**.This indicates that the main variability of the earthworm communities around the nests of *Cubitermes subcrenulatus*has been measured. The distribution of these earthworms would be largely influenced by the activities of termites strongly related to these nests and also to stochastic conditions. In fact, the interpretation of the percentage of variance measured takes account the fact that the percentage never reaches 100%, because part of this variance may be due to "noises" of data interpreted as being the result of a random fluctuation of the species[15]. The structure of the data is summarized, according to this author, in the first main axes while the other would be explained by the noise. An ordination that explains only a small percentage may nevertheless contain much of the ecological information.

Table 1: Diversity of earthworms collected around nests of *Cubitermes subcrenulatus*

Earthworm species	Earthworm family	Earthworm categories
Agastrodrilus multivesiculatus	Megascolecidae	Endogeic oligohumic
Chuniodrilus palustris	Eudrilidae	Endogeic polyhumic
Chuniodrilus zielae	Eudrilidae	Endogeic polyhumic
Dichogaster argilis	Megascolecidae	Epigeic detritivore
Hyperiodrilus africanus	Eudrilidae	Endogeic polyhumic
Millsonia lamtoiana	Megascolecidae	Epigeic oligohumic
Millsonia omodeoi	Megascolecidae	Endogeic mesohumic
Stuhlmannia prolifera	Megascolecidae	Endogeic polyhumic

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Table 2: Results of correspondence analysis of the earthworm communities

	Axis 1	Axis 2	Axis 3	Axis 4
Eigen values	0.322	0.302	0.255	0.122
Percentage variance of earthworms data	27.311	25.608	21.615	10.334
Cumulative percentage variance of earthworms data	27.31	52.92	74.53	**84.87**
Total inertia		1.179		

The ordination of species in the reduced space formed by the first 2 axis of the correspondence analysis (CA) which bear the bulk of the information on the structure of the earthworm communities (27.31% for axis 1 and 25.60% for axis 2), showed that they are structured in two large groups **(Figure 3)**. The first group characterized by species of earthworms with activities strongly related to the presence of nests (strong link with the two main axes) is mainly composed of earthworms belonging to the ecological category of endogeic (*Agastrodrilus multivesiculatus, Chuniodrilus palustris, Chuniodrilus zielae, Hyperiodrilus africanus, Millsonia omodei and Stuhlmania prolifera*). These earthworms are the common species, so the most abundant and the most frequent around the nests. They are mostly composed of endogenous species that feed on soil mixed with organic matter[16,17]. In fact, these species of earthworms live in the deeper layers and dig horizontal and vertical galleries[18]. They would help as well the termites to multiply their networks of galleries and explore the deep horizons in order to harvest the food and collect the clay needed for the construction of their nests[19,20]. In addition, their abundance and the good distribution around nests could be justified by their excellent capacity for adaptation that is a change of behavior in response to the environmental constraints such as the search for food[17,21,22]. According to Bouché[22], filiform earthworms belonging to the family of Eudrilidae, follow the gradient of water infiltration in the deep layers of the soil by filtering organic particles. The second group characterized by the earthworms having activities independent of the presence of nests (weak link with the main axes) is essentially composed of species of earthworms belonging to the ecological category of epigeic (*Dichogaster agilis, Millsonia lamtoiana*). These species of earthworms are the rare species around nests. They are mainly composed of epigeic, which live on the surface in clumps of organic matter and dig little or no galleries in the soil[18]. The low abundance of these earthworms could be justified by the fact that they exploit the superficial horizons which also constitute a zone of strong activity of the Cubitermes[20].

According to Pelosi *et al.*[23], these earthworms species are quite rare in the environments where they are directly exposed to the environmental constraints, such as the competition. In total, these results indicate that the structure of the earthworm communities around the nests of *Cubitermes subcrenulatus* is influenced by the activities of the termites.

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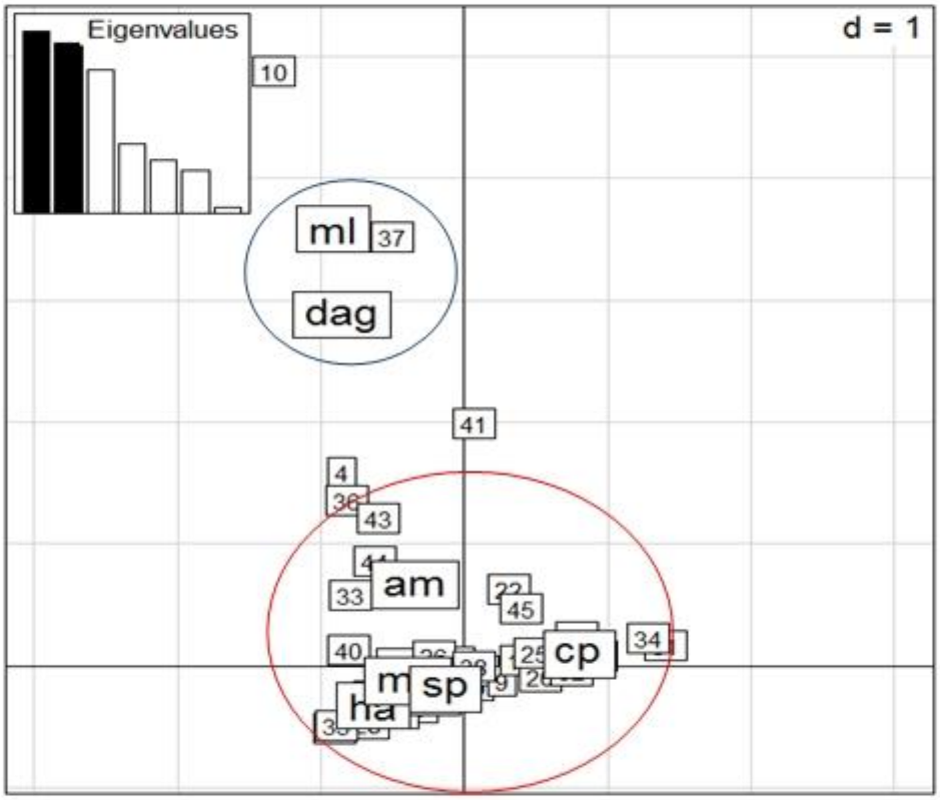
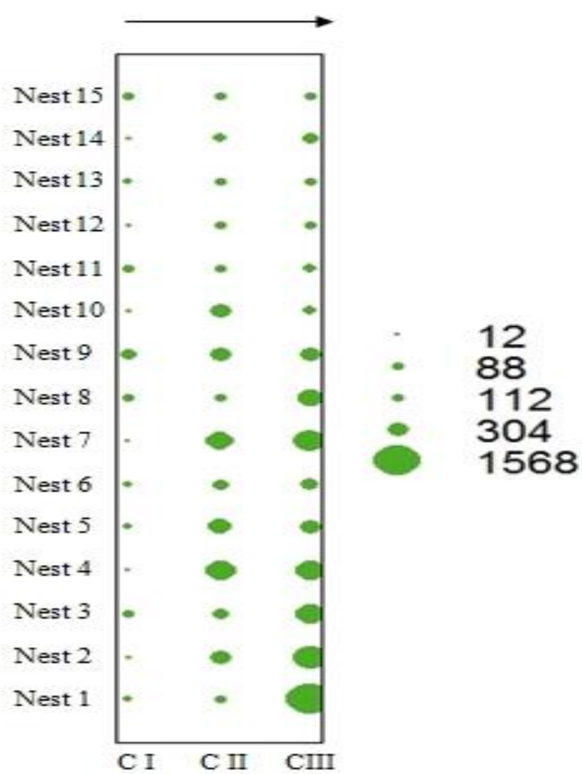


am: *Agastrodrillus multivesiculatus*; **cp:** *Chuniodrilus palustris*; **cz:** *Chuniodriluszielae*; **dag:** *Dichogaster agilis*; **ha:** *Hyperiodrilus africanus*; **ml :** *Millsonia lamtoiana*; **mo :** *Millsonia omodeoi*; **sp :** *Stuhlmania prolifera.*

Figure 3: Correspondence analysis of the earthworm communities

Spatial interaction between earthworms and *Cubitermes subcrenulatus* around nests: For the different monoliths sampled according to the distance to the nests the distribution map of the mean densities of earthworms showed that the highest densities of earthworms (large circles) are observed at the sampling points furthest from the nests (C II and C III). By contrast, in the immediate vicinity of the nests (C I), low densities of earthworms (small circles and points) have been noted **(Figure 4**). Pairwise comparison of mean earthworm densities using Kruskal-Wallis test revealed significant differences ($P < 0.05$) between mean earthworm densities in the vicinity of immediate nests (CI) and those of distant distances (C II and C III) **(Table 3)**. For the strata exploited by the earthworms around the nests, the mean density distribution map showed that the highest densities of earthworms (large circles) are observed at the level of the most distant strata (10-20 cm and 20-30 cm). On the other hand, at the level of the superficial layer (0-10 cm), low densities of earthworms (small circles and points) were noted **(Figure 5)**. Pairwise comparison of mean earthworm densities using the Kruskal-Wallis test revealed significant differences ($P < 0.05$) between mean earthworm densities of the layer superficial (0-10 cm) and those of deep layers (10-20 cm and 20-30 cm) **(Table 4)**. As for termites, in general, their mean densities are higher in the immediate vicinity of the nest (density higher than 40 ind.m^{-2}) and at the level of the 0-10 cm and 10-20 cm strata of the CI (densities between 40 and 20 ind.m^{-2}). By contrast, at the most distant distances and strata, the mean earthworm densities are either low (less than, 20 ind.m^{-2}) or null **(Table 5)**. These results indicate that there is an inverse distribution between the densities of earthworms and those of termites by remoteness of nests. This reverse distribution would be a niche differentiation adopted by these functional groups for the exercise of their activity and the collection of the organic matter that they transform through a symbiotic relationship that they establish with specialized bacteria contained in their digestive tubes. This transformation led to the production of structures organo-mineral resources (turricules, termite mounds)[12,24]. According to Maldague[20], the collection of the organic matter by termites of the genus Cubitermes is made from galleries located in the vicinity of the nest (20 to 25 cm) and mainly in the superficial horizon (0-15 cm) of the soil, where organic matters are incorporated. Earthworms would be forced to carry out their activities and collect organic matter at distances other than those exploited by termites, in order to avoid any competition. In addition, this mode of soil occupation adopted by earthworms and *Cubitermes subcrenulatus* would positively influence the dynamics of soil organic matter in the vicinity of nests, making them suitable for agricultural activity[25,26].



C I= circle of radius 0.75 m; **CII** = circle of radius 1.25 m; **C III** = circle of radius 1.75 m.

Figure 4: Map of the distribution of densities of earthworms (number of individuals/m^2) by monolith according to the distance to the nest of *Cubitermes subcrenulatus*

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Table 3: Results of the Kruskal-Wallis test (p values) for the distribution of densities of earthworms

Circle \ Circle	C I	C II	C III
C I	-		
C II	**0.015614****	-	
C III	**0.000009****	0.181707	-

****:** significant difference ($p < 0.05$); **CI** = circle of radius 0.75 m**;** **CII** = circle of radius 1.25 m; **C III** = circle of radius 1.75 m.

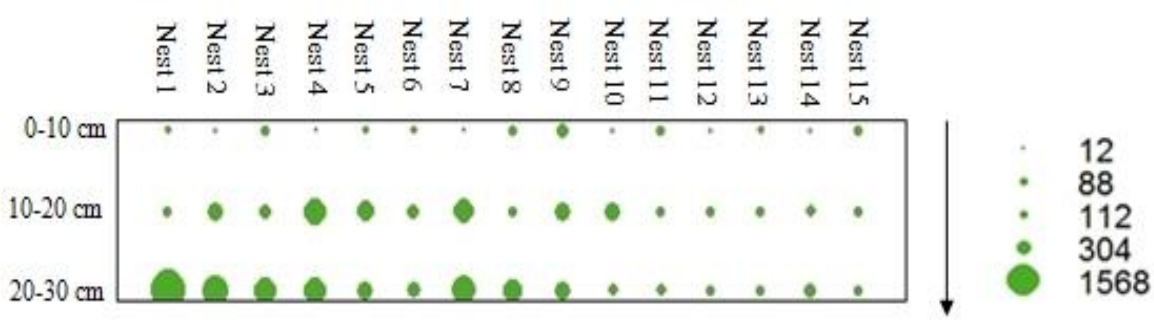

Figure 5: Map of the distribution of densities of earthworms (number of individuals/m^2) by layer exploited around nests of *Cubitermes subcrenulatus*

Table 4: Results of the Kruskal-Wallis test (p values) for the distribution of densities of earthworms

Stratum \ Stratum	0-10 cm	10-20 cm	20-30 cm
0-10 cm	-		
10-20 cm	**0.001531****	-	
20-30 cm	**0.000032****	1.000000	-

****:** Significant difference ($p < 0.05$).

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Table 5: Spatial distribution of *Cubitermes subcrenulatus* around nests

Circle / Stratum	C I	C II	C III
0-10 cm	+++	++	+
10-20 cm	++	+	-
20-30 cm	+	+	-

C I = circle of radius 0.75 m; **CII =** circle of radius 1.25 m; **C III =** circle of radius 1.75 m; +++ = high densities (greater than 40 ind.m^{-2}); ++ = medium densities high: (between 40 and 20 ind.m^{-2}); + = lower densities (less than 20 ind.m^{-2}); - = densities almost zero.

CONCLUSION

The nests of termites *Cubitermes subcrenulatus* exert an influence on the structure of the communities of earthworms. This structure is characterized by predominance and large distribution of endogeic earthworms compared to epigeic earthworms. The presence of *Cubitermes subcrenulatus* nests does not bring about a behavioral change (ecological category) to the earthworms: the sharing of niche is only done by the remoteness. This mode of distribution seems to be related to the fact that these two groups of organisms have in common the same diet (soil-feeding).

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