

Mineral Fertilizers Influence the Macrofauna of Soils Under Cocoa Trees in the South-Western Côte d'Ivoire

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Abstract

A study on mineral fertilization of soils was carried out for two years in three cocoa farms in the Nawa region of south-western Côte d'Ivoire. The aim of this study was to evaluate the effects of mineral fertilizers on soil macrofauna. The experimental design was Fisher block with four treatment with three repetitions. The treatments were control without fertilizer (T0), NPK 0-23-19 fertilizer (T1), NPK 0-15-15 + 17 CaO + 5 MgO + 1 B₂O₃ + 0.5 Zn (T2) and NPK 4-10-10 + 19 CaO + 4 MgO + 0.8 B₂O₃ + 0.3 Zn (T3). Twelve soil monoliths were made per treatment and per site, to count the macrofauna of the soil. Each soil monolith was subdivided into three strata 0-10 cm, 10-20 cm and 20-30 cm. The organisms were counted and classified into functional groups. The abundance, species richness and diversity indices of Shannon-weaver and Piéluou were determined. The analysis of variance of the numbers of individuals in the macrofauna did not show a significant difference between the treatments on different strata of the monoliths during the second year of the trial. However, during the first year, all the treatments with fertilizer in the 0-10 cm stratum had a more abundant macrofauna than that of the control without fertilizer at Soubré and Mayo. Multivariate analyses (AFC) showed links between functional groups of organisms and treatments. Myriapods and earthworms were linked to the T2 and T3 treatments, microarthropods to T1 and other organisms to T0. As for macrofauna diversity, the highest value of species richness (7 species), Shannon-weaver (2) and Piéluou (1) indices were found in the fertilized treatments. Mineral fertilizers thus presented better conditions for the expansion of macrofauna. A reasoned application of mineral fertilizers creates a favourable living environment for certain soil organisms.

Keywords: cocoa trees, Côte d'Ivoire, macrofauna, mineral fertilizers, soils

1. Introduction

Falling cocoa yields due to declining crop soil fertility (Koko et al., 2009) are prompting producers to explore remedial measures. One such avenue is soil fertilization to improve yields. Mineral fertilization is the most widely adopted to correct the state of soil fertility in order to obtain better yields. The application of these inputs is not without consequences on the environment (Stadelmann et al., 2002). Thus, the soil fauna that has a very important role in soil fertility (Lavelle et al., 2006) is in some cases impacted by external inputs. A first cause of decline in species diversity at the landscape/territory/regional scale is thus land use change which may substitute spaces with species-poor communities for spaces with richer communities (either through intensification or abandonment). Moreover, in the case of agricultural intensification (significant fertilization with synthetic fertilizers, deep drainage, intensive mowing, mowing early in the year), spatial heterogeneity tends to diminish at all scales, from the plot to the regions to the landscape (Benton et al., 2003), leading to a decrease in diversity at the landscape scale. Thus, the source and/or composition of the fertilizer may have an influence on the distribution of soil fauna. Indeed, chemical fertilizers in particular are sometimes responsible for soil acidification (Boli et al., 2000; Bado, 2002) and a decrease in microbiological activities in fertilized soils

compared to unfertilized ones (Monkiedje et al., 2006). The change in the abiotic characteristics of the soil by the contribution of external elements influences the life of soil fauna, particularly that of the macrofauna. Among these external elements, phosphorus is the most limiting in tropical soils, especially in soils under cocoa trees. In Côte d'Ivoire, soils in cocoa-producing areas are markedly deficient in phosphorus and potassium (Kassin et al., 2016; N'guessan, 2017). Thus, the hypotheses of fertilizer formulation for the fertilization of these soils are based essentially on the correction of phosphorus and potassium and to a lesser extent on nitrogen. While for some, losses of organic carbon and decreases in organic matter content in cultivated soils are essentially due to the intensification of agriculture and associated cropping practices (Le Villio et al., 2006), and thus to the loss of soil biodiversity. Their increasing use is more than ever observed in cocoa production in Côte d'Ivoire (IFDC, 2015; Ruf, 2014). Indeed, they are blamed for degrading soil biodiversity. Thus, in order to remove any ambiguity on this character, a study is being conducted on the impact of these mineral fertilizers on the density and diversity of soil macrofauna.

2. Materials and Methods

2.1 Study Site

The study took place in Soubré, Méagui and Mayo in south-western Côte d'Ivoire (Figure 1). These three agro-ecological zones are located between 5°35'32" and 5°58'44" North and between 6°34'24" and 6°36'00" West. The climate is sub-equatorial, characterized by two rainy and two dry seasons. The average annual rainfall is relatively abundant, varying between 1,203 and 1,392 mm. The average monthly temperature is between 25.8 and 26.3 °C (Evi et al., 2007). Vegetation used to be dense forest, but has now given way to forest fragments. Soils according to the WRB (2006) classification are reworked or typical Ferralsols, Gley and pseudo-Gley Gleysols derived from alluvial deposits and tropical eutric cambisols (Birmingham, 2003; ICRAF, 2011; Perraud, 1971).

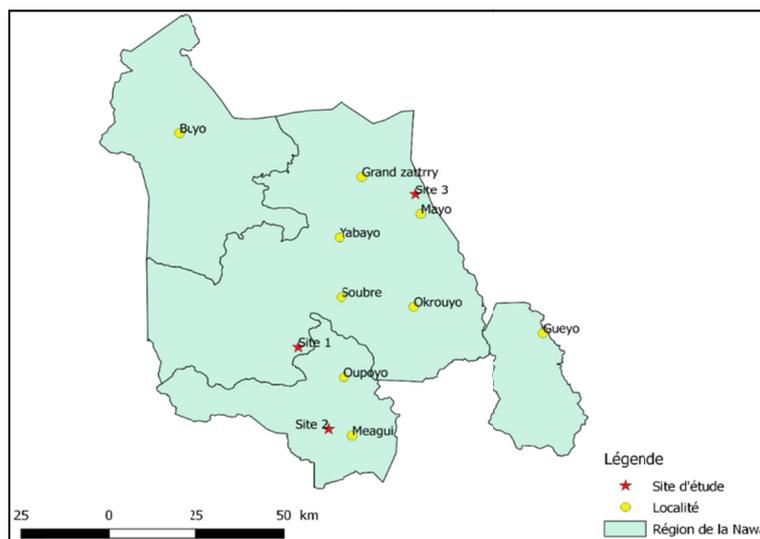


Figure 1. Map showing localities and study sites in the Nawa area

2.2 Methods

At each site, the trial was conducted according to a Fisher block experimental design, with four treatments and three replications. The different treatments were a control without fertilizer (T0), a fertilization with NPK 0-23-19 (T1), a fertilization with NPK 0-15-15 + 17 CaO + 5 MgO + 1 B₂O₃ + 0.5 Zn (T2) and a fertilization with NPK 4-10-10 + 19 CaO + 4 MgO + 0.8 B₂O₃ + 0.3 Zn (T3). The elementary plot had an area of 255 m² (25.5 m × 10 m). The blocks were 6 m apart and the treatments in the blocks were 5 m apart. The phosphorus in the T1 and T3 treatments came from triple superphosphate while that of the T2 treatment was derived from reactive phosphate. Fertilizer for T1 and T2 was applied at a dose of 400 g per foot per year and for T3 at a dose of 800 g per foot per year. These quantities of minerals were split into two doses. The first dose was given in April-May and the second in September-October. The fertilizers were spread on the soil in a crown pattern within 0.80 m of the collar of the cocoa trees and covered by the litter produced by the leaves of the cocoa trees to limit their loss by erosion. These fertilizers were applied in 2017, 2018 and 2019.

Soil macrofauna was determined in May-June of the years 2018 and 2019, using the TSBF “Tropical Soil Biology and Fertility” method (Anderson & Ingram, 1993). Each year, three soil monoliths per treatment were collected; one per elementary plot. Each soil monolith had a size of 25 cm × 25 cm × 30 cm. When a soil monolith is collected, it is divided into 0-10 cm, 10-20 cm and 20-30 cm strata. The soil monoliths were positioned at a distance of 80 cm from the collar of the fertilized cocoa trees. In each soil monolith stratum, manual harvesting of the macrofauna was carried out. The extracted organisms were preserved in 70 p.c. formaldehyde. The recorded individuals were then classified by morphotype or functional group and the abundance and species diversity (species richness, Shannon-Weaver index and Piéou equitability index) (L. Legendre & P. Legendre, 1984) were determined.

Specific diversity is defined according to the stationary (wildlife) data processing method proposed by Grall and Hily (2003).

Specific Richness was the total number of species in a stand.

The Shannon-Weaver H' index defined the diversity of species in relation to all the individuals in the stand. It is based on:

$$H' = - \sum_{i=1}^s p_i (\log_2 p_i) \quad (1)$$

where, H' : number of individuals of a given species, i ranging from 1 to S (S = total number of species); P_i : total number of individuals.

H' is minimal if all the individuals in the stand belong to the same species. H' is also minimal if each species is represented by a single individual, except one species that is represented by all other individuals in the stand. The index is maximal when all individuals are equally distributed over all species (Issouf et al., 2008; Pedel & Fabri, 2012).

The equitability index (J) of Piéou, represented the ratio of H' to the theoretical maximum index in the stand:

$$J = \frac{H'}{H_{max}} \quad (2)$$

where, $H_{max} = \log_2(S)$.

This index varies from 0 to 1, it is maximal when species have identical abundances in the stand and it is minimal when a single species dominates the entire stand. Insensitive to species richness, it is very useful for comparing potential dominance between stations or between sampling dates.

2.3 Soil and Litter Data Collection Produced

After fertilizer application, a sampling of the 0-20 cm soil horizon was carried out in June 2019 using an auger. Three composite samples were made by treatment and sent to the laboratory after air drying and sieving with a 2 mm mesh sieve. In addition to the sampling of the 0-20 cm horizon, the 0-10, 10-20 and 20-30 cm layers were sampled using a cylinder for bulk density with a volume of 554.2 cm³. These samples were used to determine the soil bulk density. As for the litter, using litter traps installed under the canopy of the cocoa trees, it was quantified. Three metal cages per treatment constituted these traps. Each cage measuring 1m x 1m x 1m with a removable grid installed at 0.5 m from the ground in this cage made it possible to collect the fall of cocoa tree leaves from June 2018 to November 2019.

2.4 Data Processing

A normality test was performed on all the data. Those found abnormal were transformed by the square root function ($\sqrt{x + 0.5}$) before being all subjected to an analysis of variance using the GLM procedure in SAS 9.4 software. The mean values were separated by the Student-Newman-Keul (SNK) method at a ≤ 0.05 . To see the impact of fertilizers on the macrofauna over time, a comparison of the macrofauna means was carried out between the two study periods. In order to establish links between treatments and groups of organisms, the data were subjected to multivariate analyses (PCA, AFC) by first forming taxonomic groups (earthworms, myriapods, microarthropods and other organisms encountered). This multivariate analysis was performed using the XLSTAT 2016 software. The Excel interface was used to enter the data and graph the shannon-weaver and Piéou diversity indices.

3. Results

3.1 Morpho-pedological and Physico-chemical Characteristics of Study Site Soils and Quantity of Litter

On the Soubré site, the soils were silty-sandy in the T0 treatment and silty-clay-sandy in the other treatments. As a result, a higher proportion of sand was determined in the soil of the T0 treatment. On the other hand, the other

treatments had the highest levels of fine elements. In terms of bulk density, no significant difference was observed between treatments. Stratum averages were 0-10 cm, 10-20 cm and 20-30 cm, 1.7, 1.8 and 1.8 respectively. In terms of chemical parameters, the levels of the variables pH(water), V, organic matter (OM), soil organic carbon (SOC), total nitrogen, assimilable phosphorus, exchangeable potassium, exchangeable calcium and exchangeable magnesium in the T0 treatment were lower than those recorded in soil samples taken in the fertilizer treatments. As for litter production, no significant differences were found between treatments (Table 1).

On the Méagui site, all treatments were installed on sandy-silt soils. Therefore, no difference was observed between soils at the level of each mineralogical fraction. However, in terms of bulk density, differences were observed in the 0-10 cm stratum, and the highest value (1.6) was obtained in the soil of the T1 treatment. In terms of chemical parameters, the levels of the variables pH(water), V, organic matter (OM), soil organic carbon (SOC), total nitrogen, assimilable phosphorus, exchangeable potassium, exchangeable calcium and exchangeable magnesium in the T0 treatment were lower than those recorded in soil samples taken in the fertilizer treatments. As for litter production, no significant differences were found between treatments (Table 2).

At the Mayo site, the T0 treatment was installed on a clay loamy-sandy textured soil, the T1 treatment on a silty-sandy textured soil, the T2 treatment on a silty-clay loamy-sandy textured soil and the T3 treatment on a silty-sandy textured soil. Therefore, a higher clay content was determined in the soil on which the T0 treatment was installed and a higher proportion of sand in the soils where the T1 and T3 treatments were installed. On the other hand, in terms of bulk density, no difference was observed between the soils of the treatments in all strata. In terms of chemical parameters, the levels of pH(water), V, total nitrogen, exchangeable potassium and exchangeable calcium in the T0 treatment were lower than those recorded in the soil samples taken in the fertilizer treatments. On the other hand, no significant differences were observed between the treatments in organic matter, soil organic carbon. As for litter production, during the year 2018 significant differences were observed between treatments. Treatments T1 and T2 produced more litter 271.6 g and 257.2 g respectively. In contrast, during the year 2019, litter production was statistically similar between all treatments (Table 3).

Table 1. Morpho-pedological and physico-chemical characteristics of soils and quantity of litter at the Soubré site

Treatment	T0	T1	T2	T3	Average	CV	Pr > F
Physical properties							
<i>Granulometry</i>							
Clay	9.9±1.1 b	27.9±1.0 a	27.8±1.5 a	25.8±1.6 a	22.8	10.43	<.0001
Limon	18.5±0.7 b	24.4±1.9 a	18.2±0.7 b	18.8±0.7 b	19.9	10.18	0.0164
Sand	71.6±1.4 a	47.8± 1.0 c	54.0±2.3 b	55.4±0.9 b	57.2	4.70	<.0001
Texture	LS	LAS	LAS	LAS	-	-	-
<i>Apparent density</i>							
0-10 cm	1.8±0.1 a	1.6±0.1 a	1.6±0.0 a	1.8±0.0 a	1.7	7.27	0.5175
10-20 cm	1.8±0.1 a	1.6± 0.4a	1.7±0.2 a	1.8±0.2 a	1.8	22.73	0.9327
20-30 cm	1.8± 0.3 a	1.9±0.0 a	1.64±0.3 a	2.0±0.0 a	1.8	18.98	0.7579
Chemical properties							
pH(water)	6.4± 0.1c	8.0±0.1 a	6.5±0.1 c	6.9±0.1 b	6.9	2.96	<.0001
V	38.3±4.4 c	72.4±0.4 a	58.4± 2.3 b	54.9±1.7 b	56.0	8.23	0.0001
MO (g kg ⁻¹)	24.0±5.0 c	49.8±7.0 a	37.8± 2.0 b	32.7± 0.0 bc	3.6	22.59	0.0272
SOC (g kg ⁻¹)	14.0±3.0 c	29.0±4.0 a	22.0± 1.0 b	19.0±0.0 bc	2.1	22.58	0.0271
N (g kg ⁻¹)	1.3±0.0 c	2.6±0.0 a	2.4±0.0 a	1.8±0.0 b	2.0	14.39	0.0002
C/N ratio	10.6±1.8 a	11.0±0.3 a	9.2±0.1 a	10.6±0.3 a	10.4	15.84	0.5567
Available P (mg kg ⁻¹)	0.0±0.0 b	118.0±14.0 a	0.0±0.0 b	0.0±0.0 b	29.5	41.13	<.0001
Available K (mg kg ⁻¹)	0.3±0.0 b	0.5±0.0 a	0.4±0.0 b	0.3±0.0 b	0.4	13.88	0.0049
Available Ca (mg kg ⁻¹)	3.8±0.5 c	17.7±0.1 a	9.3±0.6 b	8.5±0.2 b	9.8	8.34	<.0001
Available Mg (mg kg ⁻¹)	1.1±0.0 d	2.9±0.0 a	2.3±0.0 b	2.2±0.0 c	2.1	4.56	<.0001
Litter							
Litter (2018)	175.0±15.0 a	259.3±38.0 a	247.1±10.4 a	238.9±7.3 a	235.1	16.17	0.1781
Litter (2019)	222.7±15.0 a	306.6±23.9 a	277.2±36.6 a	236.1±53.1a	264.1	24.33	0.4689

Note. LS = Silt and Sand, LAS = Silt and Sand Clay.

Table 2. Morpho-pedological and physico-chemical characteristics of soils and quantity of litter at the Méagui site

Treatment	T0	T1	T2	T3	Average	CV	Pr > F
Physical properties							
<i>Granulometry</i>							
Clay	5.7±0.3 b	5.2±0.6 b	9.0±0.5 a	9.6±0.4 a	7.3	12.05	0.0005
Limon	14.0±1.7 a	12.7±0.3 a	13.0±0.7 a	13.3±0.3 a	13.2	12.85	0.8106
Sand	80.4±1.4 a	82.1±0.6 a	78.0±1.3 a	77.1±0.8 a	79.4	79.40	0.0481
Texture	SL	SL	SL	SL	-	-	-
<i>Apparent density</i>							
0-10 cm	1.3±0.0 b	1.6±0.0 a	1.2±0.0 c	1.4±0.0 b	1.4	1.46	0.0002
10-20 cm	1.7±0.1 a	1.9±0.2 a	1.4±0.2 a	1.5±0.2 a	1.6	17.25	0.45
20-30 cm	1.8±0.0 a	1.9±0.1 a	1.7±0.2 a	1.8±0.1 a	1.8	12.49	0.8580
Chemical properties							
pH(water)	6.7±0.2 c	6.5±0.2 c	7.3±0.0 b	7.9±0.0 a	7.1	7.13	0.0016
V	25.1±0.6 c	22.6±0.7 c	61.2±2.4 a	51.4±1.6 b	40.10	6.70	<.0001
MO (g kg ⁻¹)	12.0±0.1 c	13.7±0.1 c	27.5±0.3 a	20.6±0.1 b	1.84	21.91	0.0058
SOC (g kg ⁻¹)	7.0±0.05 c	8.0±0.1 c	16.0±0.2 a	12.0±0.1 b	1.07	21.81	0.0056
N (g kg ⁻¹)	0.6±0.0 b	0.8±0.0 b	1.5±0.0 a	1.2±0.0 a	1.0	19.51	<.0001
C/N ratio	12.0±1.1 a	10.0±1.2 a	11.0±2.4 a	10.0±3.0 a	10.7	24.09	0.7486
Available P (mg kg ⁻¹)	6.0±0.5 c	133.0±17.0 a	52.0±3.7 b	105±12.7 a	74.0	25.33	0.0002
Available K (mg kg ⁻¹)	0.2±0.0 b	0.3±0.03 b	0.5±0.02 a	0.4±0.05 ab	0.3	20.82	0.0199
Available Ca (mg kg ⁻¹)	2.8±0.04 b	2.36±0.1b	7.81±0.3 a	7.43±0.2 a	5.10	7.82	<.0001
Available Mg (mg kg ⁻¹)	0.5±0.05b	0.6±0.05 b	1.0±0.09 a	1.1±0.07 a	0.8	15.22	0.0006
Litter							
Litter (2018)	296.8± 1.6a	524.1± 33.8a	487.8± 77.7a	372.8±13.5a	422.3	19.24	0.0829
Litter (2019)	227.7±15.1a	278.1± 27.0a	221.2± 57.8a	225.9±28.1a	235.3	28.35	0.7929

Note. SL = Sand loam.

Table 3. Morpho-pedological and physico-chemical characteristics of soils and quantity of litter at the mayo site

Treatment	T0	T1	T2	T3	Average	CV	Pr > F
Physical properties							
<i>Granulometry</i>							
Clay	31.2±1.0 a	20.3±0.6 c	25.9±0.9 b	19.5±0.0 c	24.6	6.00	0.0001
Limon	14.6±0.9 b	16.5 ±0.4 ab	18.2±0.6 a	16.7±0.2 ab	16.5	6.44	0.0212
Sand	54.2±0.5 b	63.2±0.3 a	55.9±1.0 b	63.4±0.5 a	59.1	1.97	<.0001
Texture	ALS	LSA	LAS	LS	-	-	-
<i>Apparent density</i>							
0-10 cm	1.8±0.0 a	1.4±0.1 a	1.1±0.1 a	1.6±0.4 a	1.5	21.86	0.3615
10-20 cm	2.09±0.1 a	1.6±0.2 a	1.6±0.0 a	1.8±0.0 a	1.8	11.91	0.2876
20-30 cm	1.8±0.1 a	1.7±0.2 a	1.4±0.0 a	1.7±0.2 a	1.7	16.24	0.5754
Chemical properties							
pH(water)	6.1±0.0 b	6.9±0.1 a	6.8±0.0 a	6.8±0.0 a	6.6	1.50	<.0001
V	26.4±0.2 b	44.1±0.6 a	43.6±0.8 a	46.8±1.3 a	40.2	3.731	<.0001
MO (g kg ⁻¹)	29.0±1.0 a	27.0±1.0 a	34.0±1.0 a	36.0±1.0 a	3.1	10.78	0.0446
SOC (g kg ⁻¹)	17.0±0.0 a	16.0±0.2 a	20.0±0.1 a	21.0±0.1 a	1.8	10.81	0.0452
N (g kg ⁻¹)	0.1±0.0 b	0.1±0.1 b	0.2±0.0 a	0.2±0.5 a	1.7	10.18	0.0007
C/N ratio	12.3±1.4 a	10.6±0.6 a	10.8±1.6 a	10.5±0.8 a	11.1	18.99	0.6955
Available P (mg kg ⁻¹)	27.0±9.5 a	36.0±1.0 a	0.0±0.0 b	0.0±0.0 b	15.7	52.74	0.0012
Available K (mg kg ⁻¹)	0.1±0.0 c	0.61±0.0a	0.24±0.0 b	0.24±0.0 b	0.3	13.20	<.0001
Available Ca (mg kg ⁻¹)	3.5±0.0 c	5.9±0.0 b	6.7±0.1 a	6.2±0.1 b	5.5	3.805	<.0001
Available Mg (mg kg ⁻¹)	0.8±0.0 a	1.3 ±0.2 a	1.5±0.0 b	2.0±0.1 a	1.4	14.48	0.0011
Litter							
Litter (2018)	193.0±43.0 b	271.6±10.9 a	257.2± 32.3 a	137.9±17.b	216.9	19.46	0.0212
Litter (2019)	363.4±62.5 a	481.0± 63.5 a	559.8± 11.8 a	526.6±93.8a	493.5	22.43	0.3251

Note. ALS = Clay loam-sand loam, LSA = Clay-sand loam, LS = Sand loam.

3.2 Species Identified at the Three Sites During the Trial

Twenty-two (22) species were recorded on the three study sites. These included 6 species of earthworms, 4 species of diplopods and chilopods, 4 species of microarthropods, 2 species of pterygotic insects and 2 species of mites. On the Soubré site, sixteen (16) species were counted. On the Méagui site, seventeen (17) species were encountered. Finally, on the site of Mayo, eighteen (18) species were identified. All the species of earthworms and diplopods mentioned in Table 1 were identified at the three sites. At the level, chilopods *Scolopendra cingulata*, *Cryptopidae* sp. and *Geophilus* ssl. were identified at the three sites. Among the microarthropods, only one species was identified at the three sites (Table 4).

Table 4. List of species found at the study sites

Taxonomic group	Species	Soubré	Méagui	Mayo
Earthworms	<i>Lumbricus terrestris</i>	+	+	+
	<i>Lumbricus rubellus</i>	+	+	+
	<i>Dichogasterpapillosa papillosa</i>	+	+	+
	<i>Hyperiodrilus africanus</i>	+	+	+
	<i>Stuhlmania zielae</i>	+	+	+
	<i>Millsonia omodeoi</i>	+	+	+
Diplopods	<i>Oxidus gracilis</i>	+	+	+
	<i>Anoplodesmus saussurii</i>	+	+	+
	<i>Tachypodoiulus niger</i>	+	+	+
	<i>Archispirostreptus gigas</i>	+	+	+
Chilopodes	<i>Scolopendra cingulata</i>	+	+	+
	<i>Cryptopidae</i> sp.	+	+	+
	<i>Geophilus</i> ssl.	+	+	+
	<i>Lithobius</i> ssl.	-	-	+
Microarthropods	<i>Tapinoma magnum</i>	-	+	-
	<i>Ancistrotere dimorphus</i>	-	+	-
	<i>Ancistrotermes guineensis</i>	+	+	+
	<i>Pseudacanthotermes militaris</i>	+	+	-
Pterygotic insects	<i>Anommatus duodecimstriatus</i>	-	-	+
	<i>Histeridae shipka</i>	+	-	-
Mites	<i>Pardosa lugubris</i>	+	-	-
	<i>Pholcus phalangioides</i>	+	-	-

Note. Presence = +, absence = -.

3.3 Abundance of Soil Fauna

3.3.1 Effect of Treatments on the Abundance of Soil Macrofauna

The analysis of variance did not show significant differences between treatments in the localities of Soubré, Méagui and Mayo for the abundance of soil fauna during the years 2018 and 2019. In the year 2018, the means were respectively 4.67, 6.42 and 2.58 organisms in Soubré, Méagui and Mayo. In 2019, the averages were 5.31 in Soubré, 4.47 in Méagui, and 1.50 in Mayo (Table 5).

Table 5. Comparison of average soil macrofauna abundance in treatments in 2018 and 2019

Treatment	Abundance (2018)			Abundance (2019)		
	Soubré	Méagui	Mayo	Soubré	Méagui	Mayo
T0	1.22±0.7 a	2.55±2.0 a	0.33±0.3 a	1.44±0.4 a	4.00±2.1 a	1.33±0.4 a
T1	5.44±2.7 a	13.89±11.2 a	5.00±1.9 a	9.11±4.4 a	3.44±1.6 a	1.00±0.4 a
T2	4.78±2.4 a	4.78±1.6 a	2.22±0.9 a	3.78±0.8 a	3.67±0.6 a	1.11±0.4 a
T3	7.22±3.6 a	4.44±1.8 a	2.78±1.3 a	6.89±2.7 a	6.78±3.2 a	2.55±1.5 a
Average	4.67	6.42	2.58	5.31	4.47	1.50
CV (%)	84.52	99.25	62.41	55.38	59.80	53.81
Pr > F	0.5103	0.6945	0.0833	0.0998	0.8018	0.7476

Note. The averages followed by the same letters in each column are not significantly different at $\alpha \leq 0.05$.

3.3.2 Effects of Treatments on the Abundance of Soil Macrofauna According to Strata

Significant differences between treatments were observed at the Soubré and Mayo sites in the 0-10 cm soil stratum during 2018. At the Soubré site, treatment T3 had the highest level of organism (21) and control T0 had the lowest value (3.3), while intermediate values were observed in treatments T1 and T2. In Mayo, the highest value was obtained by T1 (12.6 organisms) and the lowest by T0 (1.00 organisms). On the other hand, in the 0-10 cm stratum in Méagui and in the underlying strata (10-20 cm and 20-30 cm), the analysis of variance did not show a significant difference between treatments in all localities (Table 6).

However, in the year 2019, there were no significant differences between treatments in different localities across all strata (Table 7). However, from 0-10 cm the averages were 3.6 in Soubré, 6.0 in Méagui and 3.1 in Mayo. From 10-20 cm, the means were 10.0 in Soubré, 5.7 in Méagui, and 2.1 in Mayo. Finally, for the 20-30 cm stratum, the means were 2.1 in Soubré, 1.5 in Méagui and 0.1 in Mayo.

Table 6. Comparison of average soil macrofauna abundance in treatments in 2018 depending on thickness

Treatment	0-10 cm			10-20 cm			20-30 cm		
	Soubré	Méagui	Mayo	Soubré	Méagui	Mayo	Soubré	Méagui	Mayo
T0	3.3±1.7 b	7.3±5.8 a	1.0±1.0 b	0.3±0.3 a	0.3±0.3 a	0.0±0 a	0.0±0 a	0.0±0 a	0.0±0 a
T1	14.6±5.1 ab	7.3±4.0 a	12.6±0.6 a	1.3±0.3 a	34.3±34 a	0.6±0.6 a	0.3±0.3 a	0.0±0 a	1.6±1.2 a
T2	14.0±3.0 ab	5.3±1.3 a	5.0±2.0 ab	0.3±0.3 a	8.6±3.2 a	1.3±0.3 a	0.0±0 a	0.3±0.3 a	0.3±0.3 a
T3	21.0±4.5 a	11.6±1.6 a	7.0±3.0 ab	0.6±0.6 a	1.3±0.3 a	1.0±0.5 a	0.0±0 a	0.3±0.3 a	0.3±0.3 a
Average	13.25	7.91	6.41	0.67	11.17	0.75	0.08	0.16	0.58
CV (%)	26.33	47.88	28.89	33.63	124.93	33.17	19.917	26.63	43.54
Pr > F	0.0298	0.6693	0.0136	0.3654	0.5642	0.2245	0.4411	0.5957	0.3309

Note. The averages followed by the same letters in each column are not significantly different at $\alpha \leq 0.05$.

Table 7. Comparison of average soil macrofauna abundance in treatments in 2019 depending on thickness

Treatment	0-10 cm			10-20 cm			20-30 cm		
	Soubré	Méagui	Mayo	Soubré	Méagui	Mayo	Soubré	Méagui	Mayo
T0	1.0±0.5 a	7.6±6.6 a	2.0±1.1 a	2.6±0.3 a	3.0±1.0 a	1.6±0.3 a	0.6±0.6 a	1.3±0.3 a	0.3±0.3 a
T1	3.6±0.8 a	5.3±4.3 a	1.6±0.8 a	19.3±12.1 a	4.3±2.3 a	1.3±0.6 a	4.3±3.3 a	0.6±0.6 a	0.0±0.0 a
T2	5.0±1.7 a	2.0±0.5 a	2.6±0.6 a	4.6±1.2 a	6.0±0.5 a	0.6±0.3 a	1.6±0.3 a	3.0±0.5 a	0.0±0.0 a
T3	5.0±2.8 a	9.3±6.8 a	6.3±3.9 a	13.6±6.6 a	9.6±7.6 a	1.0±1.0 a	2.0±0.5 a	1.3±1.3 a	0.3±0.3 a
Average	3.67	6.08	3.17	10.08	5.75	1.17	2.17	1.58	0.17
CV (%)	41.35	73.66	46.88	49.14	49.59	37.36	19.917	37.86	26.66
Pr > F	0.3728	0.8238	0.4775	0.2523	0.7685	0.6850	0.4411	0.2675	0.5957

Note. The averages followed by the same letters in each column are not significantly different at $\alpha \leq 0.05$.

3.3.3 Effect of Fertilizers on Soil Macrofauna Abundance as a Function of Test Duration

In Soubré, the analysis showed significant differences between the two study periods (2018, 2019) in all treatments. For the T0 treatment, the difference was found in the 10-20 cm stratum, with more organisms (2.6) in 2019. For the T1 treatment, the differences were observed in the 0-10 and 10-20 cm strata. In the 0-10 cm stratum, macrofauna was more abundant in 2018 with 14 organisms. For the T2 treatment, differences were observed in the 10-20 cm and 20-30 cm strata. In both strata, abundance was highest in 2019 with 4.6 organisms in the 10-20 cm and 1.6 organisms in the 20-30 cm stratum. Finally, for the T3 treatment, in the 0-10 cm stratum, the highest value was obtained in 2018 with 21 organisms; in the other two strata, the highest values were obtained in 2019 (Table 8).

In Méagui, the analysis showed significant differences between the two study periods (2018, 2019) in the T0, T1 and T2 treatments (Table 9). For the T0 treatment, the differences were observed in the 10-20 and 20-30 cm strata. In these two strata, the highest values were found in 2019 with 3 and 1.6 organisms respectively. For the T1 treatment, the difference was observed in the 10-20 cm stratum, with. Thus, a higher abundance (34.3 organisms) in 2018. For T2, the difference was observed in the 20-30 cm stratum, with a high abundance (3,000 organisms) in 2019. On the other hand, in the T3 treatment, at the level of all strata, no significant difference was observed between the two periods.

Finally, in Mayo, significant differences between the two periods (2018, 2019) were observed in the T1 and T0 treatments (Table 10). For the T1 treatment, the difference was observed in the 0-10 cm stratum, with a high presence of organisms (12.6) in 2018. For the T0 treatment, the difference was observed in the 10-20 cm stratum, with a high presence of organisms (1.6) in 2019.

Table 8. Comparison of the average abundance of soil macrofauna between the two periods sampling by stratum at the Soubré site

Treatment	T0			T1			T2			T3		
	0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30
2018	3.3 a	0.3 b	0.0 a	14.6 a	1.3 b	0.3 a	14.0 a	0.3 b	0.0 b	21.0 a	0.6 b	0.0 b
2019	1.0 a	2.6 a	0.6 a	3.6 b	19.3 a	4.3 a	5.0 b	4.6 a	1.6 a	5.0 b	13.6 a	2.0 a
Average	2.16	1.50	0.33	9.16	10.33	2.33	9.50	2.50	0.83	13.00	7.16	1.00
CV (%)	50.56	18.24	41.84	28.29	63.64	71.46	23.37	24.33	13.41	32.36	47.86	20.19
Pr > F	0.367	0.010	0.373	0.047	0.012	0.278	0.042	0.011	0.003	0.047	0.045	0.010

Note. The averages followed by the same letters in each column are not significantly different at $\alpha \leq 0.05$.

Table 9. Comparison of the average abundance of soil macrofauna between the two periods sampling by stratum at the Méagui site

Treatment	T0			T1			T2			T3		
	0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30
Year 1	7.3 a	0.3 b	0.0 b	7.3 a	34.3 a	0.0 a	5.3 a	8.6 a	0.3 b	11.6 a	1.3 a	0.3 a
Year 2	7.6 a	3.0 a	1.3 a	5.3 a	4.3 b	0.6 a	2.0 a	6.0 a	3.0 a	9.3 a	9.6 a	1.3 a
Average	7.50	1.66	0.66	6.33	19.33	0.33	3.66	7.33	1.66	10.50	5.50	0.83
CV (%)	85.42	27.75	14.19	70.86	131.65	41.84	20.11	30.62	20.81	41.98	71.70	59.74
Pr > F	0.989	0.035	0.005	0.750	0.030	0.373	0.063	0.649	0.013	0.545	0.312	0.583

Note. The averages followed by the same letters in each column are not significantly different at $\alpha \leq 0.05$.

Table 10. Comparison of the average abundance of soil fauna between the two periods stratum sampling at the Mayo site

Treatment	T0			T1			T2			T3		
	0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30
Year 1	1.0 a	0.0 b	0.0 a	12.6 a	0.6 a	1.6 a	5.0 a	1.3 a	0.3 a	7.0 a	1.0 a	0.3 a
Year 2	2.0 a	1.6 a	0.3 a	1.6 b	1.3 a	0.0 a	2.6 a	0.6 a	0.0 a	6.3 a	1.0 a	0.3 a
Average	1.50	0.83	0.16	7.16	1.000	0.83	3.83	1.00	0.16	6.66	1.00	0.33
CV (%)	54.04	13.41	26.63	17.65	44.105	49.16	28.88	21.41	26.63	45.42	50.10	33.97
Pr > F	0.543	0.003	0.373	0.003	0.5185	0.194	0.351	0.236	0.3739	0.804	0.877	1.000

Note. The averages followed by the same letters in each column are not significantly different at $\alpha \leq 0.05$.

3.4 Relationship Between Soil Macrofauna Taxonomic Groups and Treatments

All the information is carried by the F1 and F2 axes with an inertia of 89.66%. Regarding the graphical representation of the variables on the F1 and F2 axis, the taxonomic group of earthworms and the other unidentified organisms grouped under the term “others”, contribute to the formation of the F1 axis respectively to the extent of 35.26% and 37.6% with square cosines of 0.77 and 0.82. The F2 axis was formed by the taxonomic groups of myriapods and microarthropods respectively to the extent of 57.63% and 41.88% with square cosines of 0.82 and 0.59. Concerning the coordinates, on the F1 axis, an opposition was observed between the group formed by earthworms, myriapods and that formed by microarthropods and other organisms recorded. And along axis F2, an opposition was observed between the group formed by myriapods and earthworms and that formed by microarthropods and others.

As for the observations, the control treatment was very well correlated to the F1 axis with a cosine square equal to 1. Treatments T1 and T2 were correlated to the F2 axis with square cosines of 0.813 and 0.626 respectively.

With respect to the F1 axis, the T1, T2 and T3 treatments were opposed to the T0 treatment. The T2 and T3 treatments were opposed to the T1 treatment on the F2 axis (Figure 2).

With regard to correspondence factor analysis (CFA) (Figure 3), all the information was carried by the F1 (79.96%) and F2 (18.18%) axes with an inertia of 98.14%. It made it possible to constitute three entities, that of the treatment T1 and the microarthropods, that of the others and the control and finally the last group consisting of the couples (myriapods, earthworms) and (T2, T3).

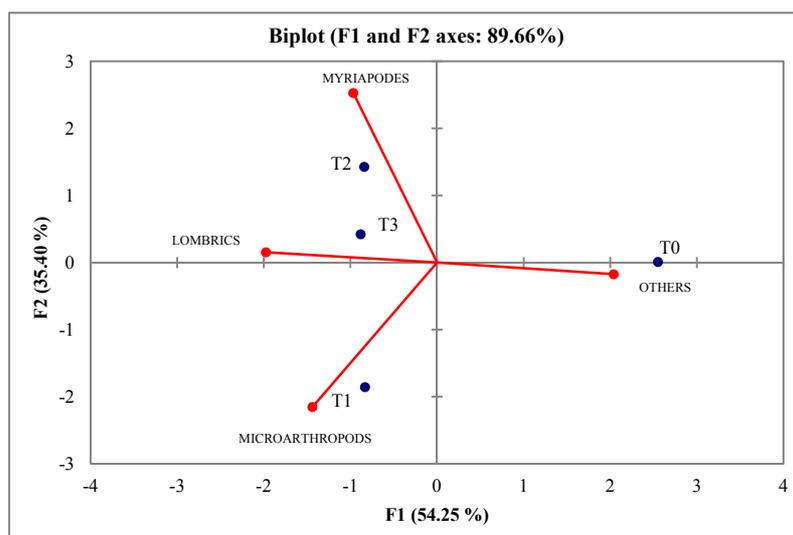


Figure 2. PCR of treatments and taxonomic groups on the F1 and F2 axes

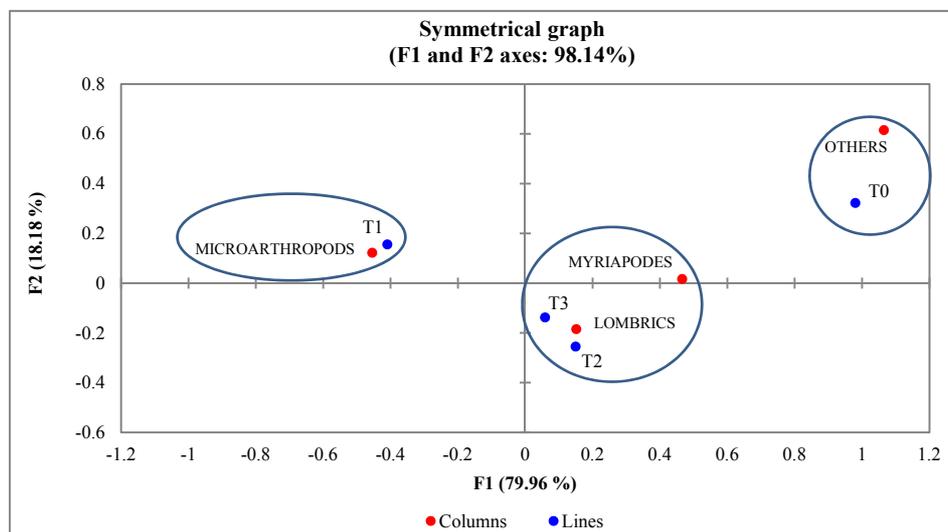


Figure 3. CFAs of treatments and taxonomic groups on the F1 and F2 axes

3.5 Specific Richness and Diversity of Soil Macrofauna

3.5.1 Specific Richness

In Soubré, the results showed that during the years 2018 and 2019, the specific richness was greater in the T1, T2 and T3 treatments compared to the control (T0). From 0 to 20 cm depth, treatments T1 and T3 respectively with 6 and 7 species had the highest species richness (Figure 4).

In Méagui, the results showed that in 2018, the specific richness was approximately equal between treatments in all strata. However, in 2019, the highest species richness (6 species) was obtained in T1 (Figure 5).

Finally, in Mayo, the results revealed that in 2018, the T0 and T3 treatments obtained the highest values in species richness (4 species). In 2019, the second year of testing, the highest values of species richness were recorded by T1, T2 and T3 with 4 species (Figure 6).

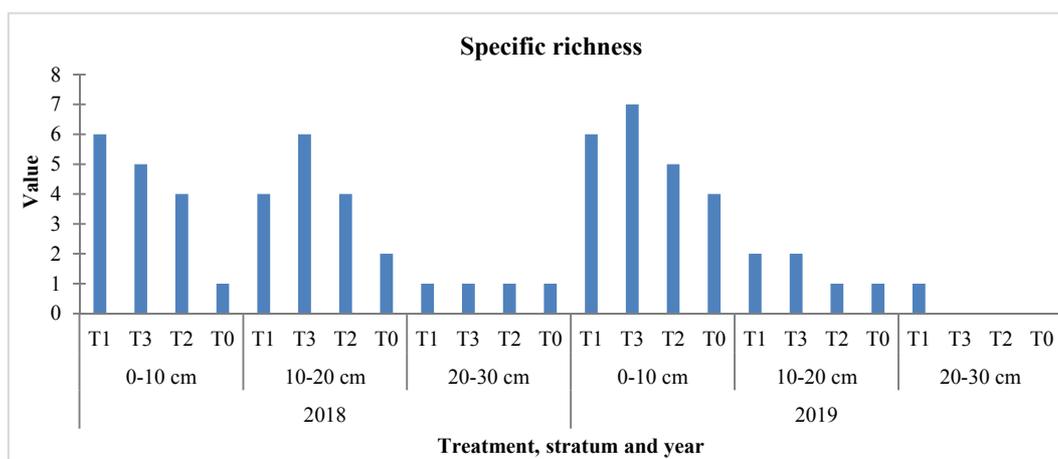


Figure 4. Value of Soubré-specific wealth according to treatment, stratum and year

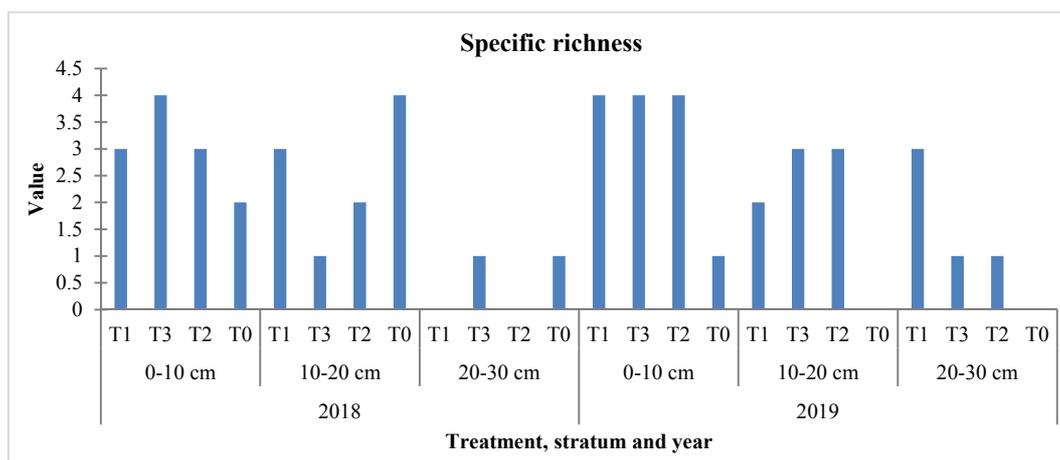


Figure 5. Value of Méagui-specific wealth by treatment, stratum and year

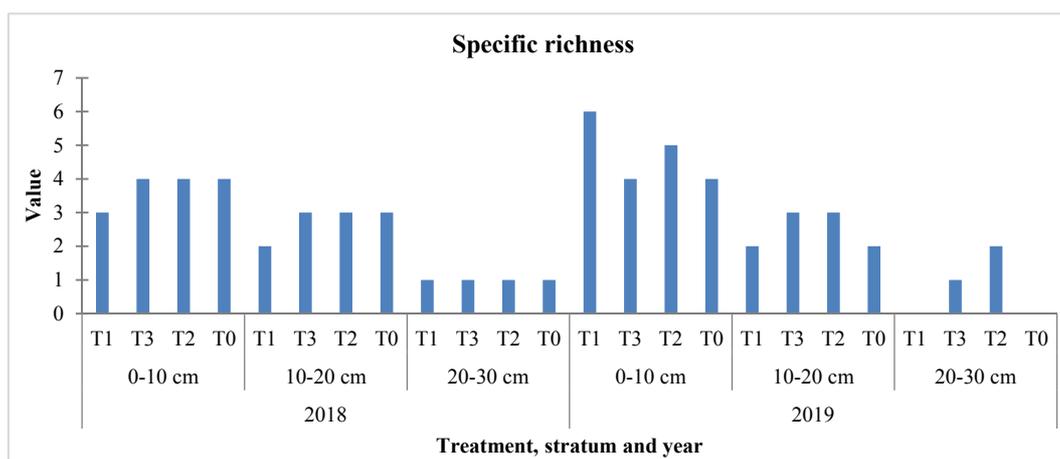


Figure 6. Value of Mayo-specific wealth by treatment, stratum, and year

3.5.2 Shannon-Weaver Diversity and Equitability Indices

In Soubré during 2018, treatments T1 (2.41) and T3 (2.02) obtained the highest Shannon-Weaver diversity indices in the 0-10 cm and 10-20 cm strata respectively, while T0 had the lowest value (0). In contrast, in 2019, the T0 treatment with 1.72 recorded the highest value. From 2018 to 2019, there was a decrease in the diversity index in all treatments except the T0 treatment at the 0-10 cm stratum. In contrast, at the 20-30cm stratum, all treatments had a zero diversity index during the trial (Figure 7).

Concerning the equitability index of Piélou, in year 1, treatments T1 (0.933) and T2 (0.844) had the highest values in the 0-10 cm stratum and T0 recorded a zero value. In the 10-20 cm stratum, treatment T0 (0.811) had the highest index, while T1 had the lowest.

In 2019, Q3 (1), Q0 (0.86) and Q1 (0.81) treatments had the highest indices across all strata. However, from 2018 to 2019, treatments T1, T2 and T3 had a decrease in the equitability index in the 0-10 cm stratum, while in the 10-20 cm horizon, T1 and T3 had an increase in this index. For the 20-30 cm stratum, the equitability index was zero for all treatments (Figure 8).

In Méagui, in 2018, the highest Shannon-Weaver diversity index (> 1.5) was found in the T2 treatment (1.91). The lowest values of this index were found in all treatments in the 20-30 cm stratum. In 2019, the highest value of the index was obtained in treatment T2 (1.66). From 2018 to 2019, diversity increased in the T1 treatment at the 0-10 cm horizon, in the T2 treatment in the 10-20 cm stratum and in the T3, T2 and T0 treatments in the 20-30 cm stratum (Figure 9).

As for Piélou's equitability index, in 2018, the highest values were obtained in treatments T1 (0.99) and T2 (0.96). In 2019, treatments T0 (1), T3 (0.94) had the highest values. From the first to the second year, the index increased in the T0, T2 and T3 treatments in the 20-30 cm stratum (Figure 10).

Finally in Mayo, in 2018, the highest Shannon-Weaver diversity indices (> 1.5) were recorded by the T0 (1.92) and T1 (1.52) treatments. In 2019, T2 (1.89), Q1 (1.59) and Q3 (1.58) treatments had the highest values. From 2018 to 2019, Q1 and Q2 treatments had an increase in diversity at the 0-10 cm horizon. This trend was noted in T3 and T2 treatments at the 10-20 cm stratum. Finally, in the 20-30 cm stratum, an increase in diversity was observed in the T1 treatment (Figure 11).

As for Piélou's equitability index, treatments T1 (0.96), T2 (0.96) and T0 (0.96) had the highest values in 2018, while in 2019 the highest values were obtained by T1 (1), T3 (1) and T2 (0.94) (Figure 12).

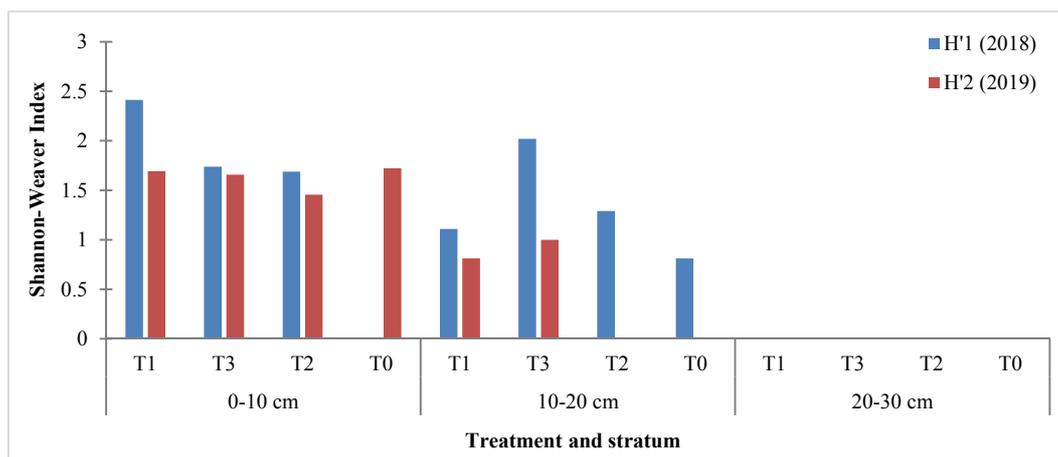


Figure 7. Shannon-Weaver to Soubré diversity index value by treatment, horizon, and year

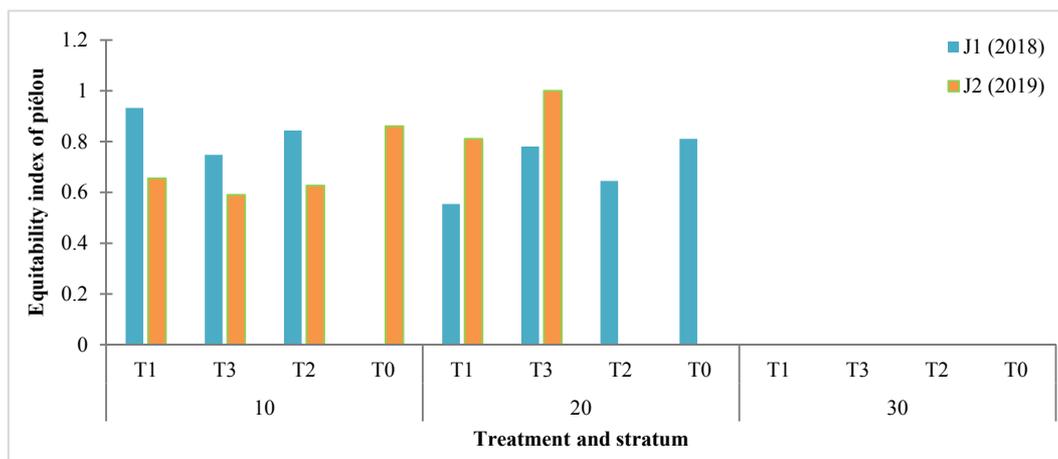


Figure 8. Equitability index value from Piélou to Soubré according to treatment, horizon and year

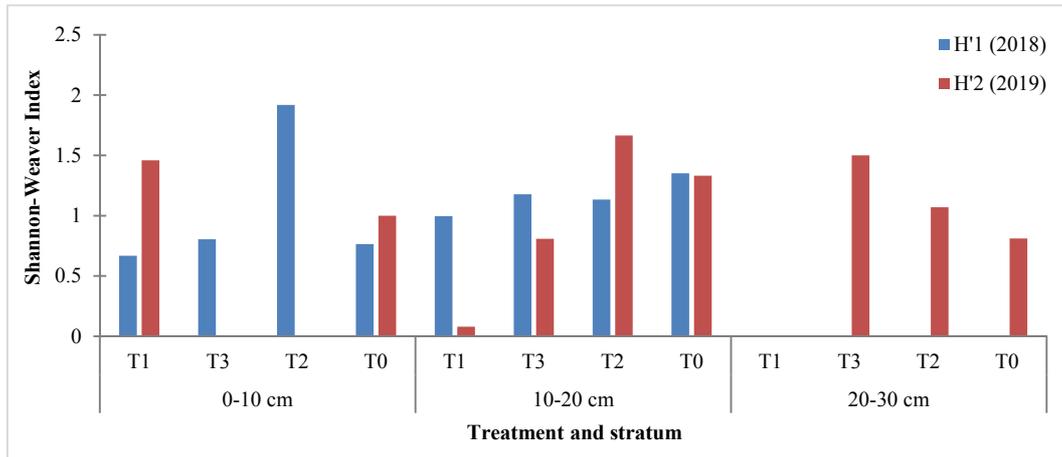


Figure 9. Value of the Shannon-Weaver diversity index in Méagui, by treatment and horizon

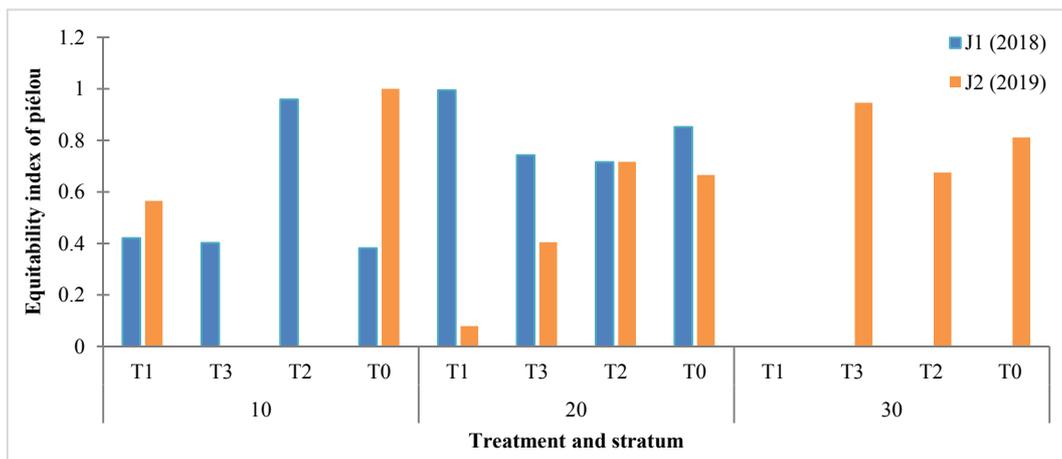


Figure 10. Pielou to Méagui equitability index value by treatment and horizon

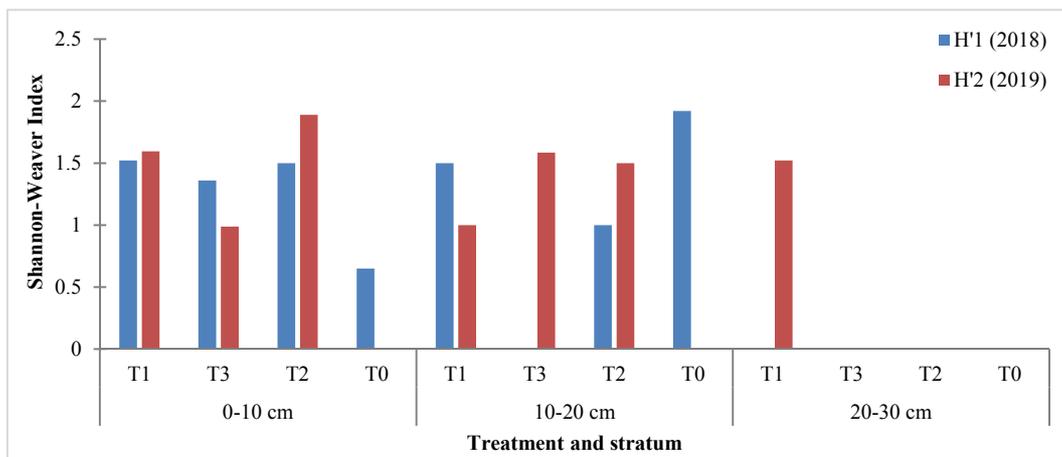


Figure 11. Shannon-Weaver diversity index value in Mayo by treatment and horizon

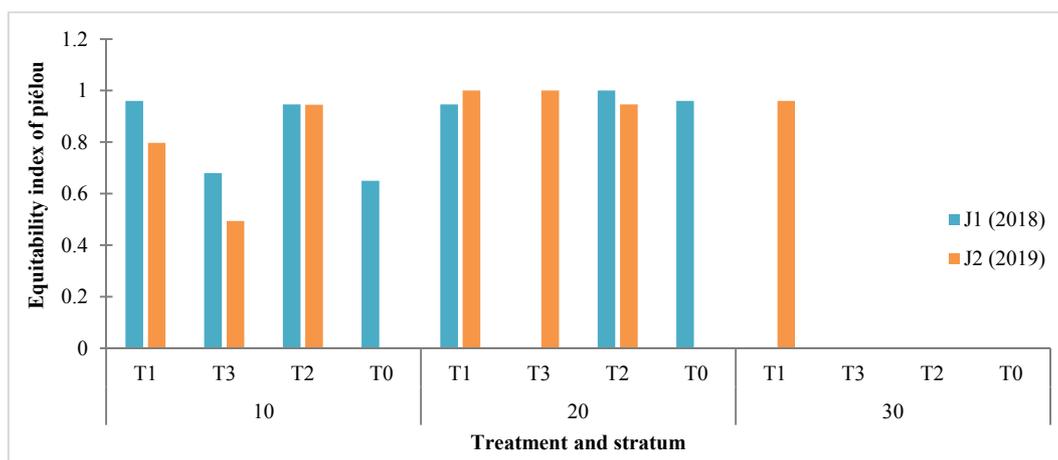


Figure 12. Piélou to Mayo equitability index value by treatment and horizon

4. Discussion

Comparison of the average abundance between treatments on the 0-30 cm layer showed no significant difference in all localities overall. However, differences appeared between treatments at the 0-10 cm layer. This difference shows a higher abundance of organism populations in the mineral fertilizer treatments. This result shows that these fertilizers improve organism populations. These phosphate fertilizers were applied to supplement the phosphate status of the soil, but their dissolution also provides other nutrients including potassium, calcium and magnesium. These exchangeable cations saturate the leaves with colloids and increase the saturation rate, which in turn raises the pH. Thus, a favourable living environment for the development of soil fauna is created. Soils that received fertilizer had higher saturation rates than the control without fertilizer. In the same order, the pH levels in the fertilized soils were close to neutral (6.5 to 8 in Soubré, 6.5 to 7.9 in Méagui and 6.8 to 6.9 in Mayo). Knowing that most soil organisms proliferate in less acidic environments that tend towards neutrality (pH(water) = 7) (Ponge, 2004), a higher abundance of soil macrofauna in fertilized environments is justified. Because, according to this author, environments with a strong biological activity present pHs close to neutrality. In addition to acidity, the choice of litter leaves, size, hardness, mineral content (calcium in particular) and carbohydrate and protein richness for feeding soil organisms play a major role (Benton et al., 2003). The application of moderately or highly reactive natural phosphates in strongly leached acidic tropical soils has a potential trigger effect on plant growth and the resulting crop yield. The products and residues from these crops have a better food quality (higher content of phosphorus, calcium, magnesium than unfertilized plants). The incorporation of such organic residues increases the biological activity in the soil, resulting in an improvement of the physical and chemical properties of the soil (FAO, 2004). Two others, and not the least important factors that determine soil life are soil organic matter (SOM) and soil organic carbon. They enable the maintenance of soil biological activity and the productivity of ecosystems (Chenu, 2009). Indeed, they are the energy source of most soil organisms with the exception of certain protozoa with chlorophyll chromatophores that are autotrophic. Fertilized soils have higher MOS (32.7 to 49.8 g kg⁻¹ in Soubré, 13.7 to 27.5 g kg⁻¹ in Méagui and 27.0 to 36.0 g kg⁻¹ in Mayo) and COS contents than the soils of the control without fertilizer. Thus, a larger population of macrofauna resides there. In addition to the nutrient conditions that positively impact the abundance of soil fauna (Guéi and Tondoh 2012; Moço et al., 2010), habitat is another determining factor. Even if litter production does not show a significant difference, it is sufficient to create an environment conducive to the life of soil macrofauna. Indeed, the production of abundant litter and fine dead wood covering the soil creates moisture conditions favourable to the development of soil fauna (Bertrand et al., 2015). The existence of favourable nutrition and housing conditions will positively impact the abundance of soil organisms in fertilized environments. This would explain the greater diversity of soil organisms observed in fertilized cocoa farms, given the higher species richness, Shannon-Weaver index and Piélou equitability index observed in these environments. This litter being of quality would attract soil organisms such as phytophages, saprophages, geophages, scavengers. However, there is greater diversity in the surface horizons than in the underlying horizons. Indeed, the deep horizons are less rich in organic matter and in particular in organic carbon. Also, it should be noted that the surface horizons are less dense than the deep horizons, making them easier to move. Thus, organisms migrate easily from the depths to the surface in search of food. The low values of the Shannon-Weaver index noted in the treatments without fertilizers indicate that there are preponderant species.

This is best appreciated with the Equitability Index, which highlights ecosystem imbalance and poor species distribution, given its values below 0.6 in most sampling levels for non-fertilizer treatments. Moço et al. (2010) found that density and richness in total soil invertebrate and litterfall numbers varied significantly between sites, and in particular faunal richness was higher in cocoa-based agroforestry systems where leaf litter was more abundant, suggesting that the vegetation structure responsible for the development of a litter layer is a key factor in explaining the observed variations in soil invertebrate populations.

These fertilizers used do not modify the abiotic and biotic parameters of the soil that could significantly influence the abundance of organisms. This is because it is recognized that these animals are extremely sensitive to variations in the microclimate and can disappear when the changes in state, which are likely to occur in a man-managed ecosystem, are bad. Better still, here, these fertilizers have created environments that tend towards a climax for soil organisms. This translates into greater diversity in the environments fertilized by mineral fertilizers. Moreover, the results of Principal Component Analysis (PCA) and Correspondence Factor Analysis (CFA) reveal affinities between taxonomic groups and different treatments. Myriapods and earthworms are more encountered in T2 (NPK 0-15-15 + 17 CaO + 5 MgO + 1 B₂O₃ + 0.5 Zn) and T3 (4-10-10 + 19 CaO + 4 MgO + 0.8 B₂O₃ + 0.3 Zn) treatments while microarthropods have a preference for 0-23-19 (T1) fertilizers and other organisms have a filiation with the treatment without fertilizer. These environments favour the settlement of certain taxonomic groups to the detriment of others. This would be due to the nutritive potential of the soils (quality and quantity). Indeed, Arpin et al. (1980) had evoked this aspect to show the presence or absence and the location of such species or groups in a complex game that limits a global representation. Moreover, different species participating in the same functions react differently to the limiting factors (André, 2006). They are therefore not all affected by a disturbance in the environment (presence of toxic substances, change in water regime, change in physico-chemical conditions).

5. Conclusion

The application of phosphate and potassium fertilizers on soils under cocoa trees in order to determine their impact on the soil macrofauna reveals a positive effect on the latter. The abundance of macrofauna was greater in environments with fertilizers than in environments without fertilizers. This was the case for the 0-10 cm strata at the Soubré and Mayo sites in the first year. Also, it should be noted that the specific richness in the fertilized areas is much higher than in the unfertilized areas. The highest values were observed in the fertilized plots. The Shannon-Weaver diversity index study showed values above 2 in plots fertilized with phosphate and potassium mineral fertilizers. As for the equitability index of Piélou, it showed a greater imbalance of organisms in cocoa farms without fertilizer. Finally, treatments with mineral fertilizers showed a greater affinity for myriapods, earthworms and microarthropods, unlike the treatment without fertilizer, which was richer in organisms grouped under the term “others”.

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