From the Efficiency of Berlese Tullgren Funnel to the Spatiotemporal Variation of Two Uropodina Genera, Afrotrachytes Kontschán, 2006 and Trachyuropoda Berlese, 1888 (Acari, Mesostigmata) in Côte d'Ivoire

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Abstract

Due to their interaction with many other small Arthropods, Uropodina mites can be considered as good indicators of soil fauna of forest litter. In order, to better understand their distribution and phenology according to forest type four sites from primary forest to plantations were sampled in 2008 in Côte d'Ivoire: 1- the Lamto savannah (6°13' N, 5°02' W), 2- Oumé primary forest (6°31' N, 5°30' W), 3- Oumé teak plantation (6°31' N, 5°30' W) all situated in the Sudanese domain and finally, 4- the Taï primary forest (5°45' N, 7°07 W) located in the Guinean domain. After a preliminary study devoted to the efficiency of Berlese Tullgren funnel, the spatiotemporal variation of two Uropodina genera - *Afrotrachytes* Kontschán, 2006 and *Trachyuropoda* Berlese, 1888 - was assessed. We hypothesized that the abundance of Uropodina would be higher in primary forest and lower in savannah and monospecific plantation. Whatever the season, we expected that the abundance of Uropodina would decrease with soil depth and would vary along transect. On each site, 15 sampling points were allocated over a 14-m transect with 1m intervals between two consecutive points. For each sampling point, 9 cores (litter, 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35 and 35-40 cm) were taken with a steel corer (Ø 3.5 cm). Thus, a total of 1,080 soil cores were collected over two sampling periods from January to March 2008 (dry season) and August to October 2008 (rainy season). Soil physico-chemical parameters were also characterized. Mites were extracted using the Berlese-Tullgren funnels for one week after testing the extraction duration in a preliminary study. The bulbs lighting as soon as the soil cores were placed in Berlese Tullgren gave better results regarding the abundance of extracted mites. The results showed that the abundance of *Afrotrachytes* sp and *Trachyuropoda* sp was higher in rainy season, and varied significantly through the sites, whatever the season. The highest abundances of *Afrotrachytes* sp were observed in Oumé primary forest whereas those of *Trachyuropoda* sp were recorded in Oumé primary forest, and in Lamto savannah, whatever the season. Apart from the distribution of *Trachyuropoda* sp in dry season, the abundance of *Afrotrachytes* sp and *Trachyuropoda* sp was greater in the topsoil (litter and 0-5 cm) and decreased with soil depth. The abundances of *Afrotrachytes* sp and *Trachyuropoda* sp did not follow a normal distribution along the transects. The season-soil depth interaction affected significantly the abundance of *Trachyuropoda* sp whereas the bulk density (dry season and rainy season), soil depth (dry season), carbon / nitrogen ratio (dry season) impacted significantly the abundance of *Afrotrachytes* sp. This first study highlighted the spatiotemporal variation of Uropodina in Côte d'Ivoire. However, taking into account of the different dispersal agents in future studies would help us to better understand their abundance and distribution along different habitats, as well as their role as biological control agents.

Keywords: Uropodina, Abundance, Distribution, Abiotic Factors, Primary Forest, Savannah, Teak Plantation

Academic Discipline And Sub-Disciplines: Soil Ecology, Ecosystem, Biodiversity, Uropodina

Date of Publication: 2018-07-09

DOI: 10.24297/jab.v11i1.7470

ISSN: 2347-6893

Volume: 11 Issue: 1

Journal: Journal of Advances in Biology

Website: https://cirworld.com

Introduction

The Uropodina mites occur in forest soil and leaf litter (Kazemi and Abolghasemi, 2016). Forest soil and litter covering up the mineral soil are known to be an important source of biological diversity, and harbor a diversity of animals of varying sizes (Duyar and Makineci, 2016). The Uropodina mites (Mesostigmata) play a crucial role in soil food webs and are important as biological control agents (Wissuwa *et al.*, 2012). As a consequence of their position in the trophic structure of the ecosystem, the Mesostigmata are linked to the vegetation community type and the overall productivity of ecosystems only indirectly (Madej *et al.*, 2011; Kaczmarek *et al.*, 2012). Forest ecosystems are characterized by a high diversity of microhabitats, which can be used as habitats by the mites (Madej *et al.*, 2011). The free living Mesostigmata inhabit nests, soil, soil litter, decaying wood, compost, and other detrital substrates (Marchenko and Bogomolova, 2015). They are often phoretic of bark beetles or other animals which act as agents of their dispersal in many types of forest ecosystems worldwide (Gwiazdowicz *et al.*, 2011; Čejka and Holuša, 2014; Marchenko and Bogomolova, 2015; Zach *et al.*, 2016). The Mesostigmata play an important role in ecosystem interactions, such as the regulation of populations of other small soil invertebrates, and indirectly participate in the decomposition of the organic substrates and nitrogen cycle (Marchenko and Bogomolova, 2015). They can thus be considered as bioindicators and their abundance and diversity may reflect past disturbances of ecosystems. These small Arthopods communities also reflect the state of ecosystems functioning (Duyar and Makineci, 2016). The mite communities of forest ecosystems are characterized by a specific structural and functional composition, depending on forest type, its structure, and complexity (Madej *et al.*, 2011). In fact, seasonal changes in the plant community can directly or indirectly influence the soil invertebrate communities (Wu *et al.*, 2014). Mites abundance and distribution between habitats depended on vegetation cover of the vascular plants, while moss cover and soil pH had no significant influence (Salmane and Spuņģis, 2015). Abundance of Mesostigmatid mites is much higher on open site than on the closed one (Pérez-Velázquez *et al.*, 2011).

The Uropodina is one of the most diverse groups of the Mesostigmatid mites, superorder Parasitiformes (Kontschán *et al.*, 2013). They are small or medium sized (300-1200 µm), and mostly strongly sclerotised (Kontschán *et al.*, 2013). The classification of Uropodina, particularly at higher level is not yet stable (Kazemi and Abolghasemi, 2016). Indeed, the group was divided into four to five superfamilies depending on authors.

The Uropodina genus *Trachyuropoda* Berlese, 1888 is composed of several species (Kontschán, 2007), mainly, *Trachyuropoda festiva* Berlese, 1888, *Trachyuropoda bostocki* Michael, 1894 from the Netherlands, United Kingdom, Luxemburg, Austria, and Hungary; *Trachyuropoda myrmecophila* Wiśniewski and Hirschmann, 1992 from Poland, Slovakia, and Hungary; *Trachyuropoda hirschmanni* Pecina, 1980 from Europe; *Trachyuropoda troguloides* Canestrini and Fanzago, 1877 from West and Central Europe; and *Trachyuropoda wasmanniana* Berlese, 1903 from Europe. During the investigation of the unsorted soil samples of the Hungarian Natural History Museum, five new Trachyuropoda species were found from different regions of the Neotropics: from Costa-Rica *Trachyuropoda costaricana* n. sp.; from Ecuador *Trachyuropoda ecuadorica* n. sp. and *Trachyuropoda chimboensis* n. sp.; and from Saint Lucia *Trachyuropoda saintluciana* n. sp. and *Trachyuropoda pesici* n. sp. (Kontschán, 2011). The species *Trachyuropoda arculata* collected in the Galapagos Islands and both *Trachyuropoda bali* sp. nov. and *Trachyuropoda extremica* sp. nov. recorded in Colombia were described by Kontschán and Starý (2013).

The Uropodina genus *Afrotrachytes* was established by Kontschán (2006a) on the basis of a newly described species, *Afrotrachytes seticaudatus* Kontschán, 2006 collected in Angola. In the same year, Kontschán (2006b) described a further new species of this genus, *Afrotrachytes longicaudatus* Kontschán, 2006 from Tanzania. Since 2009, the endemic status of *Afrotrachytes* in Africa is reconsidered because the description of two new species, *Afrotrachytes bercziki* sp. nov. and *Afrotrachytes mirabilis* sp. nov. was realized, respectively in South American, Ecuador and West African, Cameroon (Kontschán, 2009a).

In Côte d'Ivoire, except for the description of the Uropodina *Rotundabaloghia browni* spec. nov (Kontschán, 2009b), no Uropodina was described at the species level. However, this group abounds in the different local collections. Thus, before the description at the species level, the study aims to assess the spatiotemporal variation of two Uropodina genera, *Afrotrachytes* Kontschán, 2006 and *Trachyuropoda* Berlese, 1888. Specifically, the study will focus on three points (i) test the efficiency of Berlese Tullgren funnel, (ii) evaluate the

abundance of two Uropodina genera following the season, soil depth and transect, and (iii) establish the relationship between the two Uropodina genera and abiotic factors. We hypothesized that the abundance of Uropodina would be higher in primary forest and lower in savannah and monospecific plantation. Whatever the season, we expected that the abundance of Uropodina would decrease with soil depth and would vary along the transects.

Materials and Methods

Site description

This study was conducted in Côte d'Ivoire, where four sites, all located in arboreal areas, were sampled in 2008. The Lamto savannah (6°13' N, 5°02' W), Oumé primary forest (6°31' N, 5°30' W), and Oumé teak plantation (6°31' N, 5°30' W) are situated in the Sudanese domain whereas Taï primary forest (5°45' N, 7°07 W) is located in the Guinean domain. The climate of Lamto savannah (LTO) is intertropical humid (Le Roux, 2006). The annual rainfall is 1,211 mm and the average monthly temperature is 27°C. The vegetation of Lamto is a forest-savannah mosaic (Menaut and César, 1979) with five facies: (i) the gallery forests, (ii) herbaceous savannah dominated by Loudetia simplex, (iii) shrub savannahs dominated by Hyparrhenia diplanda and Andropogon sp., (iv) wooded savannah, and (v) shrub savannahs protected from fire. All facies were dominated by tall palm trees (*Borassus aethiopum*), pretty regularly distributed (Barot, 1999). The sampling site (shrub savannahs protected from fire) is now completely covered by the invasive Asteraceae *Chromolaena odorata*. Soils were ferralsols (FAO classification) with a very low organic matter and nitrogen content. The climate of Oumé primary forest (OPF) is subequatorial (Monnier, 1983). The annual rainfall is around 1,275 mm and the average monthly temperature is 26°C. The forest is a semi-deciduous type (Monnier, 1983). The vegetation is very dense and even luxuriant. The undergrowth is also dense with lianas and dead wood. Some tree species, such as *Griffonia simplicifolia* (Caesalpiliniaceae), *Marantochloa leucantha* (Marantaceae), *Anthiaris toxicaria* (Moraceae) are observed in OPF. Man-made activities are very weak and limited to some tracks. Soils were ferralitic (Assié *et al.*, 2008). The Oumé teak plantation (OTK) is also located in Oumé, near the previous forest and is composed of even-aged teaks (*Tectona grandis*) planted in 1994. The climate of Taï primary forest (TPF) is subequatorial type, humid all the year round (Kouadio, 2006). The annual rainfall during the field works was 1,853 mm and the average monthly temperature was about 25°C. The Taï primary forest is the largest remaining forest in West Africa and the last largest island of the original Upper Guinean forest that once reached from Ghana to Guinea-Bissau. The vegetation was dominated by *Eremospatha macrocarpa* and *Diospyros mannii*. Highly desaturated ferrallitic soils and hydromorphic soils cover almost all areas (Avenard *et al.*, 1971; Moreau, 1983).

Determination of the extraction conditions

In order to determine the bulbs lighting period of the Berlese Tullgren and the number of days required for the extraction of soil mites, a preliminary study was conducted in 2007 with soil cores from Oumé primary forest (OPF). In practice 18 soil cores were taken at the extreme layers (0-5 cm and 35-40 cm) during both dry and rainy season. The soil cores were replicated three times and were taken along a 17-m transect with 1m intervals between two consecutive points. A total of 108 soil cores were collected during each season and brought to the laboratory in plastic packets for mite extraction. Both, extractions with and without light, create different conditions within the soil cores (Barberena-Arias *et al.*, 2012). Following the soil cores heating and desiccation, a temperature and humidity gradient is created between the upper and lower surfaces of the soil cores (Barberena-Arias *et al.*, 2012). Bulbs lighting 24 hours or 48 hours after the soil cores were placed in Berlese Tullgren favors taking into account the environment of origin (André *et al.*, 2002). As this gradient moves downwards, mites are forced down into the collecting liquid (Coleman *et al.*, 2004). Thus, three treatments are considered for the extraction of soil mites:

Treatment 1: bulbs lighting 24 hours after the soil cores were placed in Berlese Tullgren.
Treatment 2: bulbs lighting 48 hours after the soil cores were placed in Berlese Tullgren.
Treatment 3: bulbs lighting as soon as the soil cores were placed in Berlese Tullgren.

Every day (24 hours), the number of mites extracted is determined after the withdrawal and sorting of the collection tubes. For the soil water content estimation, the soil cores are weighed before and after their passage to Berlese. The temperature in the Berlese was 39°C. The experiment lasted 10 days.

Consequence of site localization and vegetation cover on Uropodina

Soil sampling and mite identification

After the preliminary sampling, the design of mean study consisted of four sites: the Lamto savannah (LTO), Oumé primary forest (OPF), Oumé teak plantation (OTK), and the Taï primary forest (TPF). On each site, 15 sampling points were allocated over a 14-m transect with 1m intervals between two consecutive points. For each profile or sampling point, 9 cores (litter, 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35 and 35-40 cm) were taken with a steel corer (Ø 3.5 cm). Thus, a total of 1,080 soil cores were collected over two sampling periods from January to March 2008 (dry season) and August to October 2008 (rainy season). Mites were extracted using the Berlese-Tullgren funnels for one week after testing the extraction duration in a preliminary study. Soil mites were sorted in Petri dishes using a dissecting microscope and mounted in lactic acid medium under a light microscope with phase contrast. A particular interest was devoted to two Uropodina genera, *Afrotrachytes* Kontschán, 2006 and *Trachyuropoda* Berlese, 1888 (Fig. 1) due to their abundance and their key role in the ecosystem functioning. The identification was made at genus levels by using keys and illustrations provided in Kontschán (2006a,b), Kontschán (2007), Kontschán (2009a), Kontschán (2011), Kontschán and Starý (2013).

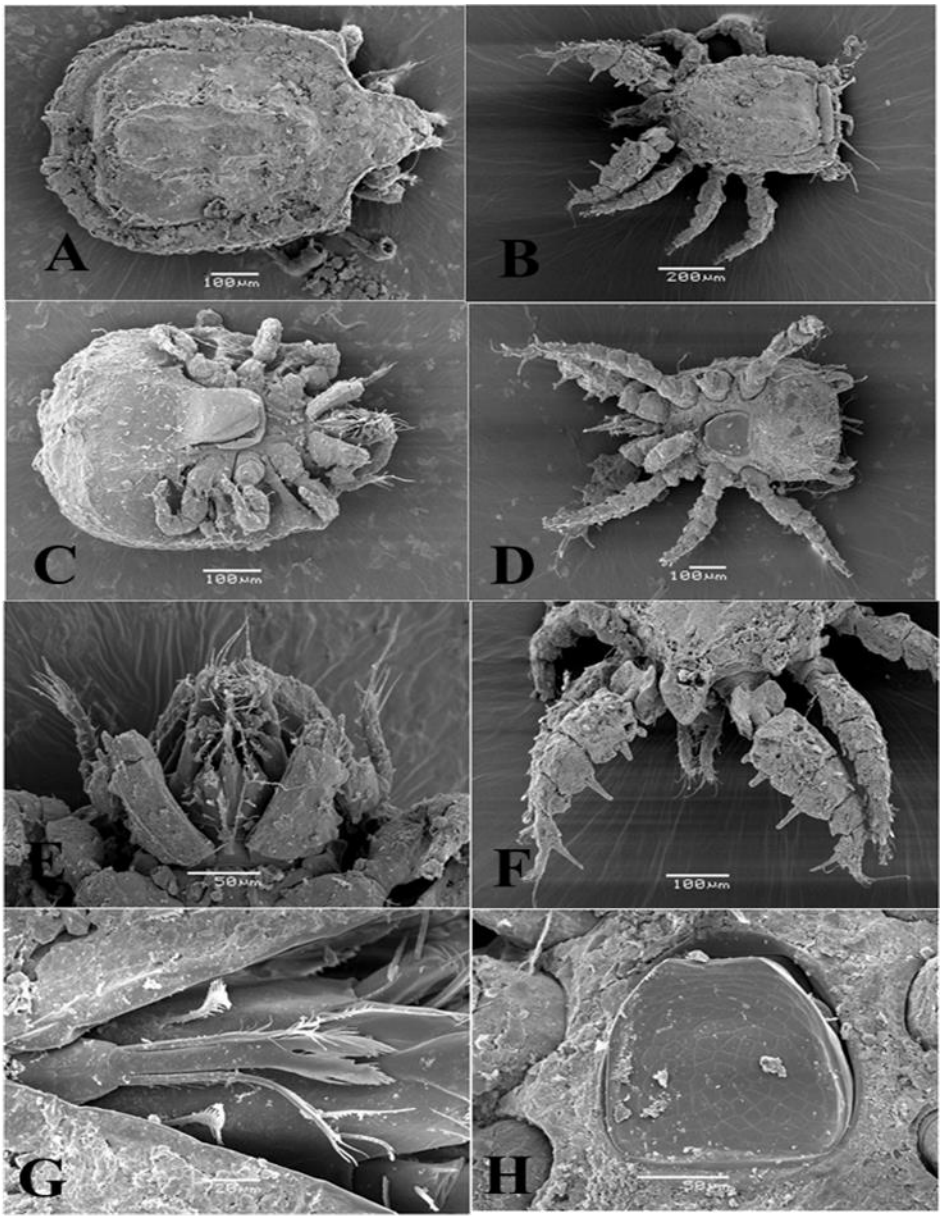

Figure 1: Uropodina genre: *Trachyuropoda* Berlese, 1888 (A-dorsal aspect, C-ventral aspect, E-anteroventral portion of propodosoma, G-detail of tritosternum); *Afrotrachytes* Kontschán, 2006 (B-dorsal aspect, D-ventral aspect, F-anterodorsal portion of propodosoma, H-epigynial shield)

Soil physico-chemical characteristics

Soil physico-chemical parameters were estimated from seven cores adjacent to the sampling point. Five cores were mixed together to measure the pH and other chemical analyses as recommended by Anderson and Ingram (1993). One core was reserved for the water content and the last one for the bulk density. At each sampling point, 8 layers (0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35 and 35-40 cm) were considered for the measurements of water content, bulk density and pH, whereas organic carbon, organic matter and total nitrogen were determined through the extreme depths (0-5 cm and 35-40 cm). The soil water content and bulk density of 960 cores sampled in both dry and rainy season were estimated after 48 h drying at 105°C (Baize, 1988; Duchaufour, 1991). The pH-H_2O (Baize, 1988; Duchaufour, 1991) was estimated with a pH meter (HANNA) after calibration. On each site, five sampling points were taken into account for organic carbon and total nitrogen measurements, whether a total of 80 composites soil cores (4 sites x 5 sampling points x 2 layers x 2 seasons). To measure organic carbon, the carbon was oxidized to CO2 by heating the soil to at least 900°C in a flow of oxygen-containing gas according to ISO Standard 10 694. Total Nitrogen was determined by dry combustion, according to ISO Standard 13 878. Soil organic matter (SOM) was estimated through the formula, organic carbon x 1.7 as made by Noti et al., (2003).

Statistical analysis

Soil physico-chemical characteristics were compared across the sites and following soil depth by using a one-way ANOVA test. The abundance of soil mites was expressed as the number of individuals per square meter, but the abundance of Uropodina genus was expressed as the number of individuals from soil cores per site. As data did not follow a normal distribution, the impact of sites on the abundance of *Afrotrachytes* sp and *Trachyuropoda* sp was estimated by using a Kruskal-Wallis test. Within each site, the abundance of *Afrotrachytes* sp and *Trachyuropoda* sp was compared by using the Mann-Whitney test. The abundance of soil mites extracted during preliminary study was compared using a Kruskal-Wallis test whereas the data of water content was evaluated by a one-way ANOVA test. Rank Spearman correlation was performed to study the relationship between the abundance of *Afrotrachytes* sp and *Trachyuropoda* sp and soil physico-chemical parameters. These tests were conducted on both the dry and rainy season and along transect and soil depth. The factorial Anova with general linear mixed (GLM) model was used to explore the effects of season-sites-soil depth interaction on the abundance of *Afrotrachytes* sp and *Trachyuropoda* sp and soil physico-chemical parameters. All tests were conducted using the software Statistica 7.1 (StatSoft, Tulsa, USA). As explained by André *et al.* (2002), we estimated the soil depth in which 50 or 90% of Uropodina were living (respectively the Soil $Depth_{50}$ and Soil $Depth_{90}$).

Results

Extraction conditions

Water content in soil cores

Whatever the season and the layers, soil water content did not vary significantly across the three treatments (Table 1). The water content decreased with the soil depth. Whatever the season, soil cores from the extreme layers 0-5 cm and 35-40 cm, and submitted respectively to the treatment 3 and 1 revealed the lowest values of water content.

Table 1: Water content (%) measured in soil cores during the experiment. Treatment 1: bulbs lighting 24 hours after the soil cores were placed in Berlese, Treatment 2: bulbs lighting 48 hours after the soil cores were placed in Berlese, Treatment 3: bulbs lighting as soon as the soil cores were placed in Berlese. N = 54, one-way ANOVA test, $p < 0.05$.

	Rainy season		Dry season	
	0-5 cm	35-40 cm	0-5 cm	35-40 cm
Treatment 1	40.12 ± 2.45	11.51 ± 0.60	37.23 ± 2.20	9.92 ± 0.58
Treatment 2	44.17 ± 1.25	12.35 ± 0.80	38.23 ± 1.38	10.44 ± 0.60
Treatment 3	39.21 ± 1.72	12.27 ± 1.10	36.20 ± 1.84	10.08 ± 1.03
p value	0.645	0.768	0.738	0.884

Abundance of mites extracted

Whatever the season and the layers, the dynamic of soil mites extracted did not vary significantly (Kruskal-Wallis test, rainy season: 0-5 cm, $P = 0.659$, 35-40 cm, $P = 0.621$; dry season: 0-5 cm, $P = 0.874$, 35-40 cm, $P = 0.548$) across the three treatments (Fig. 2). The amounts of mites extracted were higher during the first day of the experiment and decreased over the following days. Whatever the season and the layers, the treatment 3 (rainy season, 0-5 cm: 166 individuals, 35-40 cm: 50 individuals; dry season, 0-5 cm: 98 individuals, 35-40 cm: 24 individuals extracted) favored a higher extraction of the soil mites compared to treatment 1 (rainy season, 0-5 cm: 56 individuals, 35-40 cm: 21 individuals; dry season, 0-5 cm: 68 individuals, 35-40 cm: 16 individuals extracted) and 2 (rainy season, 0-5 cm: 110 individuals, 35-40 cm: 29 individuals; dry season, 0-5 cm: 71 individuals, 35-40 cm: 11 individuals extracted). After 5-6 days of experiment no individual was observed in the collection tubes.

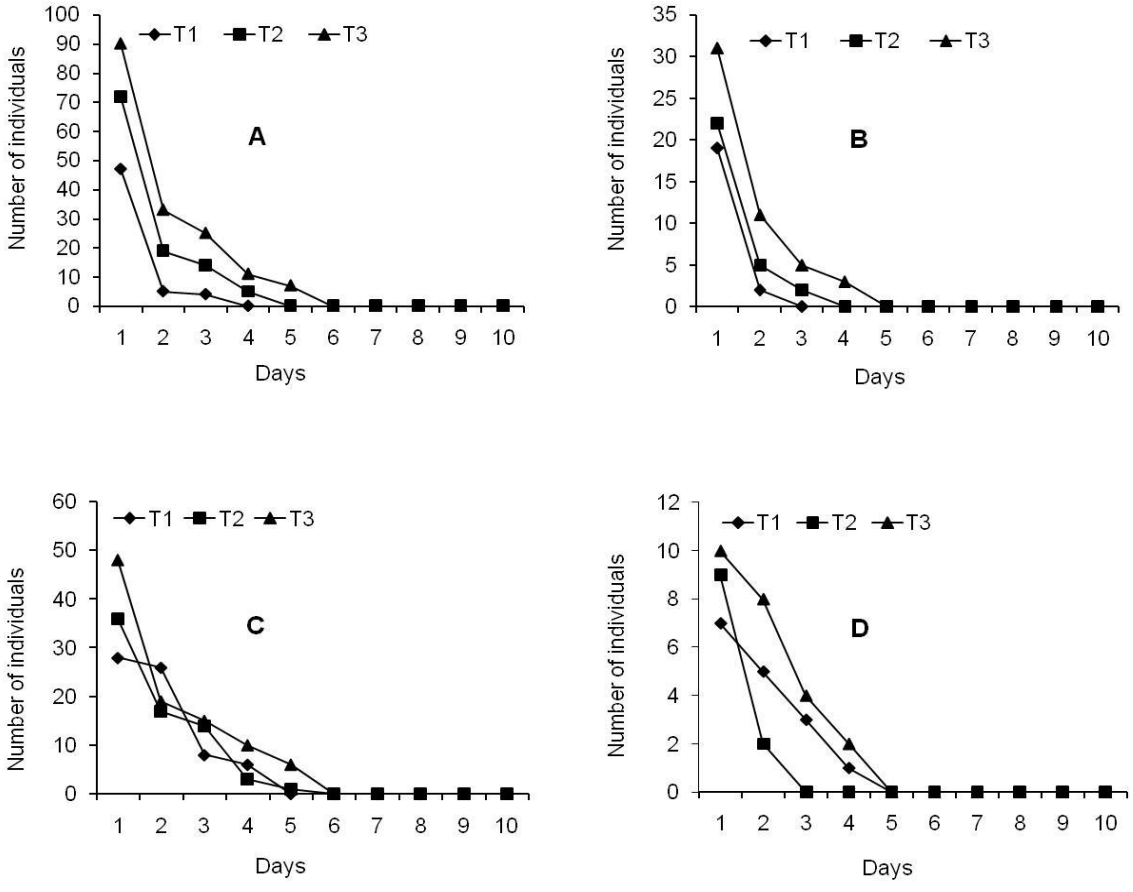

Figure 2: Dynamics of soil mites extracted from Berlese Tullgren. T1-treatment 1: bulbs lighting 24 hours after the soil cores were placed in Berlese, T2-treatment 2: bulbs lighting 48 hours after the soil cores were placed in Berlese, T3-treatment 3: bulbs lighting as soon as the soil cores were placed in Berlese. A-B: rainy season, C-D: dry season, A-C: 0-5 cm, B-D: 35-40 cm. N = 30, Kruskal-Wallis test, $p < 0.05$.

Consequence of site localization and vegetation cover on Uropodina

Total abundance

The density of soil mites varied across the different study sites. In rainy season, the densities represented 22046 ind.m^{-2}, 34386 ind.m^{-2}, 9082 ind.m^{-2}, 7141 ind.m^{-2}, respectively in Lamto savannah (LTO), Oumé primary forest (OPF), Oumé teak plantation (OTK), and the Taï primary forest (TPF). The densities of soil mites recorded in the dry season were lower than those of the rainy season, and were about 8527 ind.m^{-2}, 20451 ind.m^{-2}, 5754 ind.m^{-2}, 5269 ind.m^{-2}, respectively in Lamto savannah (LTO), Oumé primary forest (OPF), Oumé teak plantation (OTK), and the Taï primary forest (TPF).

Abundance of *Afrotrachytes* sp and *Trachyuropoda* sp

The abundance of *Afrotrachytes* sp (Kruskal-Wallis test, rainy season: $P = 0.0001$; dry season: $P = 0.0001$) and *Trachyuropoda* sp (Kruskal-Wallis test, rainy season: $P = 0.0001$; dry season: $P = 0.0001$) changed significantly through the sites (Fig. 3). Except for the Taï primary forest (Mann-Whitney test, rainy season: $P = 0.834$; dry season: $P = 0.916$), Lamto savannah (Mann-Whitney test, rainy season: $P = 0.989$; dry season: $P = 0.995$), and Oumé teak plantation (Mann-Whitney test, rainy season: $P = 0.525$; dry season: $P = 0.139$), the abundances of *Afrotrachytes* sp were significantly different compared to those of *Trachyuropoda* sp in Oumé primary forest (Mann-Whitney test, rainy season: $P = 0.001$; dry season: $P = 0.0002$). Whatever the season, the highest abundances of *Afrotrachytes* sp were observed in Oumé primary forest (rainy season: 148 ± 1.10 individuals; dry season: 76 ± 0.12 individuals) whereas those of *Trachyuropoda* sp were recorded in Oumé primary forest (rainy season: 31 ± 0.24 individuals; dry season: 16 ± 0.06 individuals), and in Lamto savannah (rainy season: 31 ± 0.24 individuals).

Vertical distribution

If soil depths are considered, the abundance of *Afrotrachytes* sp (Kruskal-Wallis test, rainy season: $P = 0.033$; dry season: $P = 0.0001$) and *Trachyuropoda* sp (Kruskal-Wallis test, dry season: $P = 0.0001$) varied significantly across the sites, except for the abundance of *Trachyuropoda* sp (Kruskal-Wallis test, $P = 0.155$) in rainy season. Apart from the distribution of *Trachyuropoda* sp in dry season, the abundance of *Afrotrachytes* sp and *Trachyuropoda* sp decreased with soil depth (Fig. 4). The highest abundances of both Uropodina were recorded in the topsoil (litter and 0-5 cm). In the rainy season, the Soil $Depth_{50}$ and Soil $Depth_{90}$ represented respectively for the *Afrotrachytes* sp (OPF: 8.41 vs.18.41 cm, TPF: 1.75 vs. 6 cm, LTO: 8.36 vs. 13.36 cm, and OTK: 1.915 vs. 16.33 cm) and *Trachyuropoda* sp (OPF: 8.41 vs. 13.41 cm, TPF: 1.75 vs. 6 cm, LTO: 8.36 vs. 18.36 cm, and OTK: 6.33 vs. 6.33 cm). In the dry season, they represented respectively for the *Afrotrachytes* sp (OPF: 11.8 vs. 41.8 cm, TPF: 3.165 vs. 38.83 cm, LTO: 3.26 vs. 14.02 cm, and OTK: 10.23 vs. 30.23 cm) and *Trachyuropoda* sp (OPF: 21.8 vs. 36.8 cm, TPF: 8.83 vs. 8.83 cm, LTO: 9.02 vs. 9.02 cm, and OTK: 10.23 vs. 10.23 cm). The abundance of *Trachyuropoda* sp varied significantly with the season-soil depth interaction (Table 2).

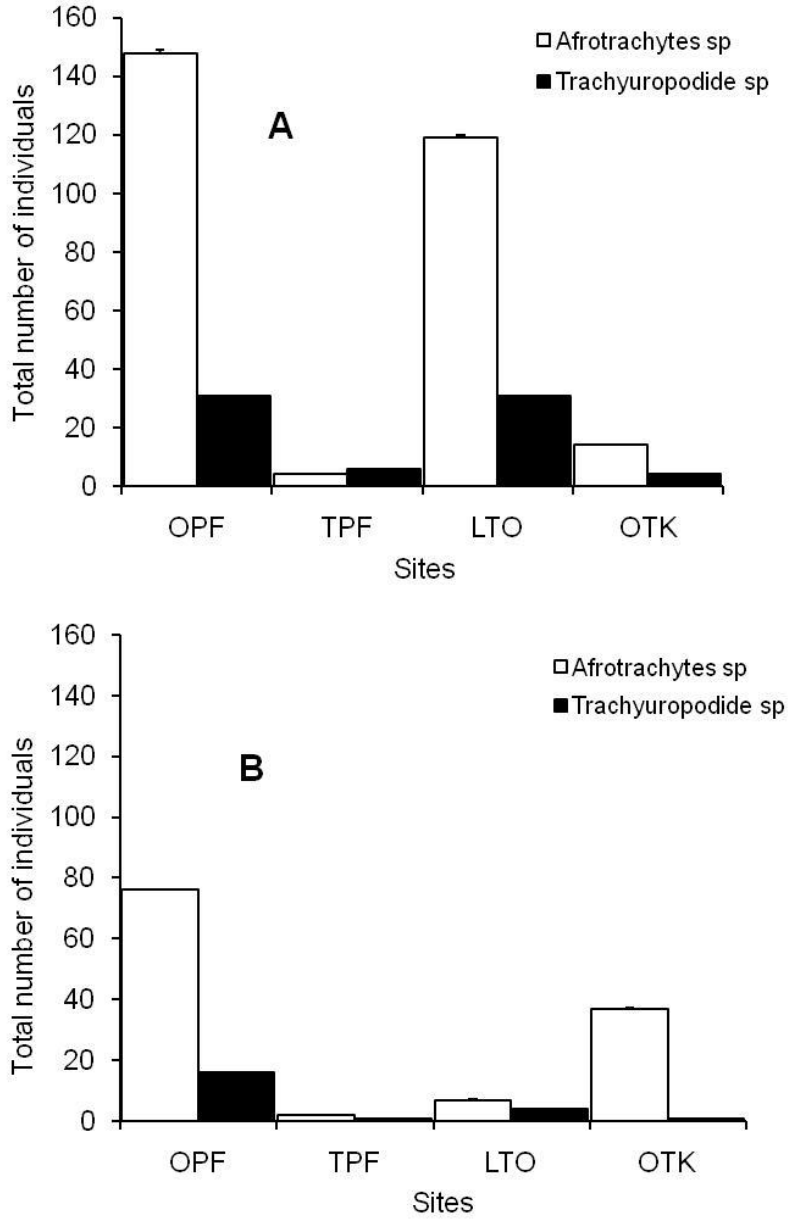

Figure 3: Abundance of *Afrotrachytes* sp and *Trachyuropoda* sp across the four sites. OPF-Oumé primary forest, TPF-Taï primary forest, LTO-Lamto savannah, OTK-Oumé teak plantation. A: rainy season, B: dry season. Entire biological profile (0-40 cm, including litter thickness) was considered. N = 540, Kruskal-Wallis test, $p < 0.05$.

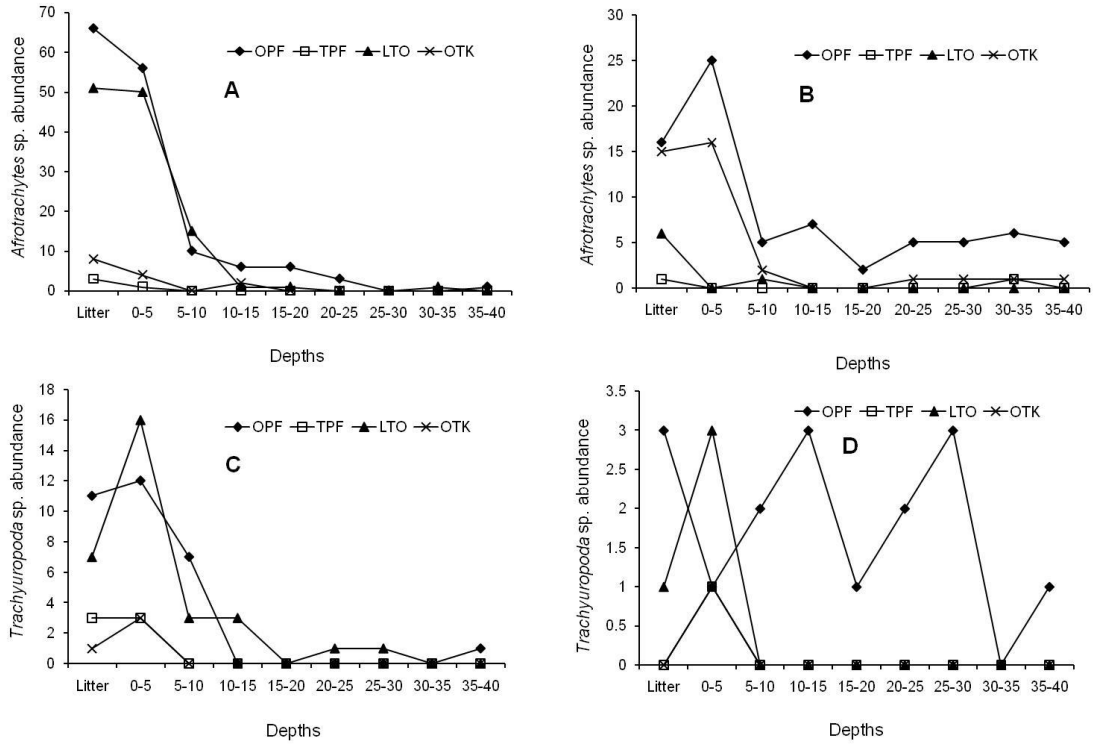

Figure 4: Abundance (number of individuals) of *Afrotrachytes* sp and *Trachyuropoda* sp following the soil depth. OPF-Oumé primary forest, TPF-Taï primary forest, LTO-Lamto savannah, OTK-Oumé teak plantation. A-C: rainy season, B-D: dry season. N = 36, Kruskal-Wallis test, $p < 0.05$.

Table 2: Anova table of general linear mixed (GLM) effect models on the abundance of *Afrotrachytes* sp and *Trachyuropoda* sp across the season, sites, and soil depth. F-values and the corresponding *p*-values are displayed.

		Afrotrachytes sp		*Trachyuropoda* sp	
	df	F	*p*	F	*p*
Season	1	1.33	0.2564	4.26	0.0470*
Sites	3	3.73	0.0208*	3.85	0.0183*
Depth	3	6.94	0.0009***	9.16	0.0001***
Season × Sites	3	1.29	0.2914	1.34	0.2773
Season × Depth	3	2.17	0.1106	5.83	0.0026**
Sites × Depth	9	1.42	0.22	1.35	0.2488
Season × Sites × Depth	9	1.25	0.2964	1.38	0.2356

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

Repartition along the transect

The abundance of *Afrotrachytes* sp (Kruskal-Wallis test, rainy season: $P = 0.00001$; dry season: $P = 0.0003$) and *Trachyuropoda* sp (Kruskal-Wallis test, rainy season: $P = 0.0005$; dry season: $P = 0.001$) varied significantly through the sites, if we considered the sampling transect. Except for Taï primary forest (Mann-Whitney test, rainy season: $P = 0.933$; dry season: $P = 0.755$), Lamto savannah (Mann-Whitney test, rainy season: $P = 0.648$; dry season: $P = 0.868$) and Oumé teak plantation (Mann-Whitney test, rainy season: $P = 0.164$), the abundances of *Afrotrachytes* sp were significantly different compared to those of *Trachyuropoda* sp respectively in Oumé primary forest (Mann-Whitney test, rainy season: $P = 0.0001$; dry season: $P = 0.0042$), and in Oumé teak plantation (Mann-Whitney test, dry season: $P = 0.021$). The abundances of *Afrotrachytes* sp and *Trachyuropoda* sp did not follow a normal distribution along the transect (Fig. 5). However, some abundance maximum could be observed, mainly in both Oumé primary forest (*Afrotrachytes* sp: 17 individuals; *Trachyuropoda* sp: 3 individuals) and Oumé teak plantation (*Afrotrachytes* sp: 12 individuals) during the dry season, and in Lamto savannah (*Afrotrachytes* sp: 53 individuals; *Trachyuropoda* sp: 10 individuals) during the rainy season.

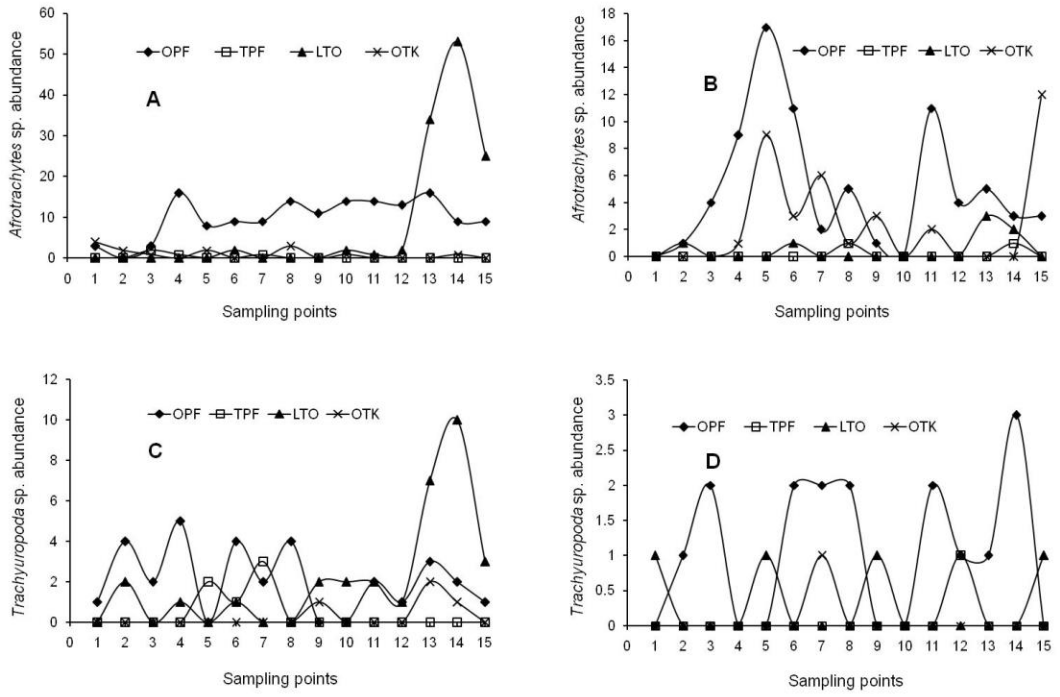

Figure 5: Abundance (number of individuals) of *Afrotrachytes* sp and *Trachyuropoda* sp following the sampling transect. OPF-Oumé primary forest, TPF-Taï primary forest, LTO-Lamto savannah, OTK-Oumé teak plantation. A-C: rainy season, B-D: dry season. N = 60, Kruskal-Wallis test, $p < 0.05$.

Soil physico-chemical characteristics

Whatever the site and the season, the bulk density increased significantly (N = 120, P < 0.05) from the 0-5 to 35-40 cm layers. Contrary to bulk density, the water content decreased significantly with soil depth in the two seasons (N = 120, P < 0.05), except in Lamto savannah (LTO) in the dry season (P = 0.928). Taï primary forest (TPF) soils were acidic and the pH values differed significantly from those (alkaline pH) observed in other sites (N = 120, P < 0.05). The deeper the layer, the greeter's the pH in Taï primary forest (TPF). If we consider the entire profile (0-40 cm), the soil pH-H_2O (dry season and rainy season) and the water content (dry season) varied significantly across the study sites (Table 3). In rainy season, the highest values of bulk density (1.12 ±

0.03 g.cm^{-3}), water content (18.21 ± 0.78%) and pH-H_2O (7.49 ± 0.04) were recorded, respectively, in Taï primary forest (TPF), Oumé teak plantation (OTK), and Oumé primary forest (OPF). In dry season, the maximum values of bulk density (1.22 ± 0.05 g.cm^{-3}), water content (19.48 ± 1.40%) and pH-H_2O (7.32 ± 0.03) were observed, respectively, in Oumé primary forest (OPF), Taï primary forest (TPF), and Oumé teak plantation (OTK). Whatever the season and the extreme layers, soil organic carbon, total nitrogen, C/N ratio and the soil organic matter differed significantly across the four sites. Except for C/N ratio, the other chemical parameters were higher in the topsoil (0-5 cm) and lower in the bottom (35-40 cm). The greater amounts of organic carbon and total nitrogen from 0-5 cm layer were observed in Oumé primary forest (OPF) whereas those from 35-40 cm layer were recorded in Taï primary forest (TPF). The environmental factors such as season, sites, and soil depth impact the soil physico-chemical parameters as presented in Table 4.

Table 3: Mean and SE values of soil physico-chemical characteristics measured along the four sites. LTO-Lamto savannah, OPF-Oumé primary forest, OTK-Oumé teak plantation, TPF-Taï primary forest. SOC-Soil organic carbon, TN-Total nitrogen, C/N-Carbon nitrogen ratio, SOM-Soil organic matter, BD-Bulk density, WC-Water content, pH-H_2O-Potential of Hydrogen-Water. Extreme layers 0-5 cm and 35-40 cm N = 20, Entire profile 0-40 cm N = 60, one-way ANOVA test, $p < 0.05$. More details are given in N'Dri and André (2011).

	LTO	OPF	OTK	TPF	*p* value
Rainy season					
0-5 cm					
SOC (g.kg^{-1})	11.80 ± 1.59	36.80 ± 6.30	16.60 ± 0.87	17.80 ± 1.39	0.0004***
TN (%)	0.11 ± 0.02	0.37 ± 0.06	0.18 ± 0.01	0.14 ± 0.01	0.0001***
C/N	10.99 ± 0.11	9.92 ± 0.33	9.50 ± 0.28	12.49 ± 0.40	0.0001***
SOM (g.kg^{-1})	20.06 ± 2.71	62.56 ± 10.70	28.22 ± 1.48	30.26 ± 2.37	0.0004***
35-40 cm					
SOC (g.kg^{-1})	5.30 ± 0.00	5.30 ± 0.00	5.44 ± 0.14	6.00 ± 0.00	0.0001***
TN (%)	0.03 ± 0.00	0.04 ± 0.00	0.04 ± 0.01	0.05 ± 0.00	0.0010***
C/N	17.67 ± 0.00	13.60 ± 1.14	12.95 ± 1.35	12.00 ± 0.00	0.0010***
SOM (g.kg^{-1})	9.01 ± 0.00	9.01 ± 0.00	9.25 ± 0.24	10.20 ± 0.00	0.0001***
Entire profile 0-40 cm					
BD (g.cm^{-3})	0.90 ± 0.03	1.04 ± 0.04	1.05 ± 0.04	1.12 ± 0.03	0.2918
WC (%)	14.63 ± 0.47	15.29 ± 0.59	18.21 ± 0.78	14.81 ± 0.83	0.4517
pH-H_2O	6.48 ± 0.04	7.49 ± 0.04	7.34 ± 0.06	5.88 ± 0.03	0.0010***
Dry season					
0-5 cm					
SOC (g.kg^{-1})	9.60 ± 0.68	26.60 ± 2.69	16.80 ± 1.39	23.60 ± 2.77	0.0001***
TN (%)	0.09 ± 0.01	0.27 ± 0.03	0.18 ± 0.02	0.19 ± 0.02	0.0001***
C/N	10.64 ± 0.26	9.69 ± 0.23	9.35 ± 0.05	12.49 ± 0.51	0.0001***
SOM (g.kg^{-1})	16.32 ± 1.15	45.22 ± 4.58	28.56 ± 2.37	40.12 ± 4.71	0.0001***
35-40 cm					
SOC (g.kg^{-1})	5.30 ± 0.00	6.18 ± 0.72	5.44 ± 0.14	7.20 ± 0.97	0.1460
TN (%)	0.03 ± 0.00	0.06 ± 0.01	0.05 ± 0.01	0.07 ± 0.01	0.0580
C/N	15.90 ± 1.08	10.93 ± 1.00	12.31 ± 0.94	10.85 ± 0.68	0.0040**

SOM ($g.kg^{-1}$)	9.01 ± 0.00	10.51 ± 1.22	9.25 ± 0.24	12.24 ± 1.65	0.1460
Entire profile 0-40 cm					
BD ($g.cm^{-3}$)	1.04 ± 0.05	1.22 ± 0.05	1.03 ± 0.05	1.06 ± 0.04	0.3472
WC (%)	8.08 ± 1.36	7.03 ± 0.75	12.51 ± 0.99	19.48 ± 1.40	0.0001***
pH-H_2O	6.52 ± 0.06	7.20 ± 0.05	7.32 ± 0.03	6.01 ± 0.04	0.0001***

$^{**}P < 0.01$, $^{***}P < 0.001$

Table 4: Anova table of general linear mixed (GLM) effect models on soil physico-chemical characteristics across the season, sites, and soil depth. F-values and the corresponding *p*-values are displayed. SOC-Soil organic carbon, TN-Total nitrogen, SOM-Soil organic matter, BD-Bulk density, WC-Water content, pH-H_2O-Potential of Hydrogen-Water.

$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$

		Entire profile (0-40 cm)		
		BD	WC	pH-H_2O
	df	F	F	F
Season	1	5.86*	67.33***	4.70*
Sites	3	7.38***	38.05***	1644.7***
Depth	3	77.58***	60.99***	18.1***
Season × Sites	3	5.18**	36.74***	28.2***
Season × Depth	3	0.10	4.87**	2.10
Sites × Depth	9	2.09	3.03**	26.7***
Season × Sites × Depth	9	0.40	2.32*	1.30
		Extreme layers (0-5 and 35-40 cm)		
		SOC	TN	SOM
	df	F	F	F
Season	1	0.29	0.09	0.09
Sites	3	20.69***	26.82***	26.82***
Depth	1	202.03***	229.33***	229.33***
Season × Sites	3	2.84*	2.24	2.24
Season × Depth	1	1.12	2.12	2.12
Sites × Depth	3	18.78***	21.37***	21.37***
Season × Sites × Depth	3	2.73	2.61	2.61

Relationship between the abundance of *Afrotrachytes* sp and *Trachyuropoda* sp and soil characteristics.

At the landscape scale, the abundance of *Afrotrachytes* sp was correlated significantly to the bulk density (rainy season: R = -0.70, P = 0.0005; dry season: R = -0.55, P = 0.0102), soil depth (dry season: R = 0.44, P = 0.0498) and C/N ratio (dry season: R = -0.51, P = 0.0215) in the topsoil (Table 5).

Table 5: Rank Spearman correlation performed at the landscape scale and between the abundances of *Afrotrachytes* sp and *Trachyuropoda* sp and soil physico-chemical characteristics. SOC-Soil organic carbon, TN-Total nitrogen, C/N-Carbon nitrogen ratio, SD-Soil depth, BD-Bulk density, WC-Water content, pH-H_2O-Potential of Hydrogen-Water.

	Afrotrachytes sp.				*Trachyuropoda* sp.		
Rainy season	*N*	*R*	*P*		*N*	*R*	*P*
BD ($g.cm^{-3}$)	20	-0.70	0.0005	***	20	-0.39	0.0867
WC (%)	20	0.38	0.0954		20	-0.23	0.3100
pH-H_2O	20	0.30	0.1869		20	-0.07	0.7501
SD	20	0.31	0.1738		20	0.34	0.1364
SOC ($g.kg^{-1}$)	20	0.42	0.0596		20	-0.02	0.9143
TN ($g.kg^{-1}$)	20	0.40	0.0749		20	-0.02	0.9141
C/N	20	-0.20	0.3878		20	-0.14	0.5513
	Afrotrachytes sp.				*Trachyuropoda* sp.		
Dry season	*N*	*R*	*P*		*N*	*R*	*P*
BD ($g.cm^{-3}$)	20	-0.55	0.0102	*	20	-0.40	0.0799
WC (%)	20	-0.08	0.7090		20	0.30	0.1932
pH-H_2O	20	0.38	0.0915		20	-0.21	0.3536
SD	20	0.44	0.0498	*	20	-0.35	0.1241
SOC ($g.kg^{-1}$)	20	0.19	0.4104		20	-0.10	0.6456
TN ($g.kg^{-1}$)	20	0.27	0.2470		20	-0.13	0.5738
C/N	20	-0.51	0.0215	*	20	0.23	0.3268

$^{*}p < 0.05$, $^{***}p < 0.001$

Discussion

The Mesostigmata are a diverse and widespread group of invertebrates which include around 11000 described species (Marchenko and Bogomolova, 2015). More than 2000 species make up the group of Uropodina (Kontschán *et al.*, 2013). Beyond their great diversity, the study highlighted that abundance of the soil mites and both Uropodina genera was higher in the rainy season. The abundance of soil mites depends on soil moisture and season (Huhta and Hänninen, 2001; Salmane and Spuņģis, 2015). Indeed, there was a significant seasonal effect on the abundance of *Trachyuropoda* sp at the scale of the four study sites. If we consider each study site, the seasonal effect is significantly marked with *Afrotrachytes* sp in Oumé primary forest (Litter: p = 0.001; 0-5 cm: p = 0.024), and with *Trachyuropoda* sp in Lamto savannah (Litter: p = 0.012; 0-5 cm: p = 0.029). Seasonal changes in the plant community can directly or indirectly influence the soil invertebrate communities (Wu *et al.*, 2014). Whatever the season, the abundance of *Afrotrachytes* sp and *Trachyuropoda* sp significantly varied through the different sites, indicating that the Uropodina structuring was strongly impacted by abiotic factors, which was more pronounced in the Oumé primary forest. The great vegetation cover and the diversity of plant species favor the emergence of microhabitats in Oumé primary forest (Madej *et al.*, 2011). The structural features of microhabitats can influence the life cycle of arthropods (Duyar and Makineci, 2016). This heterogeneity provides a high potential for niche partitioning and habitat specialization, thereby facilitating species coexistence and promoting biodiversity (Wu *et al.*, 2014). The investigation made by Napierała and

Błoszyk (2013) pointed out that Uropodina communities inhabiting merocenoses are often predominated by one or two species, which constitute more than 50 % of the entire community. The numerous occurrence of *Afrotrachytes* sp and *Trachyuropoda* sp in the soil of Oumé primary forest and *Trachyuropoda* sp in Lamto savannah can be a good indicator not of the type of habitat, but the processes that habitat undergoes. In Lamto, all facies were dominated by tall palm trees (*Borassus aethiopum*), and sampling was conducted in an unburned area dominated by *Chromolaena odorata* (Asteraceae). The abundance of mites in fallow systems (dominated by the invasive shrub *Chromolaena odorata*) might be due to population growth, characterized by spatial heterogeneity and vegetation regrowth where factors such as the quality and quantity of litter and the age of fallow crops play a key role (Koné *et al.*, 2012).

In contrast to our expectation, the lowest abundance of Uropodina was observed in Taï primary forest. Probably, the soil cores were taken away from the stumps. The coarse woody debris (CWD) is an important component of forest ecosystems (Kamczyc *et al.*, 2017). It is characterized by higher abundance and diversity of mesostigmatid mites than (nearby) soil/litter (Kamczyc *et al.*, 2014). In fact, with increasing distance to CWD (stumps), the total number of mite species in the soil/litter matrix decreases (Kamczyc *et al.*, 2014). The lack of a clear relationship between Taï primary forest and Uropodina is probably related to their activity and ability to migrate (Kaczmarek *et al.*, 2012). Another reason is that the abundance and diversity of soil mites are not necessarily linked to the diversity of plant species, because individual plants have also been shown to have large effects on soil biological communities in strongly nutrient limited situations (Bardgett, 2005). The work of De Deyn *et al.* (2004) in experimental condition indicated that plant traits that affect the resource quality were more important than plant diversity. These assertions might explain the higher abundance of *Afrotrachytes* sp in Oumé teak plantation compared to Taï primary forest.

The highest abundance of both Uropodina was recorded in the topsoil, as presented with the Soil $Depth_{50}$. Indeed, on the four sites, 50% of *Afrotrachytes* sp and *Trachyuropoda* sp was observed in 1.75-8.41 cm soil depth during the rainy season. In the dry season, a water stress period, the Uropodina sink further into the soil to escape desiccation, which results into a deeper Soil $Depth_{50}$ for *Afrotrachytes* sp (3.16-11.8 cm) and *Trachyuropoda* sp (8.83-21.8 cm) compared to those estimated in the rainy season. The study also reveals that the Uropodina present a random distribution along the transects.

The abundance of the two Uropodina genera, *Afrotrachytes* Kontschán, 2006 and *Trachyuropoda* Berlese, 1888 could be impacted by the extraction method. The absolute efficiency of the Berlese-Tullgren funnels would vary, depending on the authors, from 26% (Forsslund, 1948) to 7% (André *et al.*, 2002) and the Berlese-Tullgren funnels are also selective with respect to their efficiency for certain taxa. Particularly, the ratio of immature mites is especially low (less than 2%) and the rate of Actinedida varies from 2 to 6% (N'Dri and André, 2011). Certainly, the Berlese Tullgren has a low yield compared to flotation methods (André and Noti, 1993); however it would be suitable for tropical soils and less dangerous to use. The preliminary study revealed that bulbs lighting as soon as the soil cores were placed in Berlese Tullgren gave better results regarding the abundance of extracted mites. Unlike immature mites and Actinedida, the Uropodina are mostly strongly sclerotised (Kontschán *et al.* 2013) and therefore able to resist to the desiccation of soil cores in the Berlese. Despite their very low mobility (Berthet, 1964), the gradual decrease of moisture in the soil cores following an increase in heat due to a rise in temperature in the Berlese will promote the downhill of sclerotised mites, because generally characterized by a positive geotropism (Nef, 1960,1971).

This first study on the spatiotemporal variation of Uropodina from Côte d'Ivoire shows that abiotic factors such as season, soil depth, bulk density, C/N ratio, and habitat type influence the abundance and the distribution of Uropodina. However, taking into account of the different dispersal agents in future studies would help us to better understand their abundance and distribution along different habitats, as well as their role as biological control agents.

Acknowledgments

A Big thank you goes out to Prof Jérôme E. Tondoh who suggested the research project. We thank N'Goran Yao for fieldwork assistance. Thank to Marcel K. Kouassi for the English text correction. Financial support from FEM/UNEP funded project CSM-BGBD, FRS/UCL, GTI/IRScNB, ABIC/MRAC is gratefully acknowledged.

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