Partie III

Résultats

Les différents résultats de cette recherche sont présentés sous des formats articles.

Article 1 (chapitre 4) : Soil mite densities from Ivory Coast

Article 2 (chapitre 5) : Soil mite diversity from Ivory Coast

Article 3 (chapitre 6) : Indicator species in soil mites (Acari) from Ivory Coast

Article 4 (chapitre 7) : Teak plantation vs. primary forest in Oumé, Ivory Coast.

De la densité des acariens du sol

Cette première partie traite de l'abondance des acariens du sol de la Côte d'Ivoire.

Généralement en zone tropicale, la distribution des acariens dans le sol est affectée par le type et la qualité du couvert végétale, le climat et certains facteurs mésologiques. Les activités anthropiques liées à certaines pratiques forestières contribueraient à modifier la composition de la faune acarologique du sol. Pour vérifier ces hypothèses, 4 sites d'études situées dans deux des trois régions écologiques de la Côte d'Ivoire ont été investigués. Un intérêt particulier a été accordé aux différents groupes majeurs (Oribatida, Gamasida, Actinédida et Acaridida). Les résultats révèlent que quelque soit la saison la densité des acariens diminuait de la litière vers les couches profondes avec un effet saison marqué superficiellement. Contrairement à toute attente la forêt de Taï abritait la plus faible densité. Les abondances issues de Lamto étaient sensiblement similaires aux résultats obtenus par F. Athias même si 50% des abondances étaient obervé dans les couches superficielles. La densité apparente et la teneur en eau du sol sont fortement corrélées à la densité des acariens.

Chapitre 4

Soil mite densities from Ivory Coast

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Abstract

Four sites, the Lamto savannah, the Oumé primary forest and Oumé teak plantation (Sudanese domain) and the Taï primary forest–(Guinean domain) were sampled twice (rainy vs. dry season) in Ivory Coast. During this study we investigated around two hypothesis: (1) soil mite densities varies with vegetation type and season; (2) soil mite densities are affected by soil physico-chemical parameters and decrease with depth. After a 1-week extraction in Berlese-Tullgren funnels, mite densities were higher during in the rainy than during in the dry season. Whatever the site and whatever the season, density generally decreased from the litter to the deep layers despite the appearance of a bimodal distribution in some sites. The seasonal effect was much marked in topsoils. Whatever the season, the same density succession was observed: Oumé forest - Lamto savannah - Oumé teaks - Taï forest. Major taxa Oribatida and Gamasida decreased with the depth in all sites whatever the season. Contrary to what is observed in temperate areas, the Soil Depth$_{50}$ indicated that the study of topsoils may be sufficient to describe the soil mite densities in the Tropics. However, all densities were very low compared to data from the Namib desert, Congo D. R. and temperate regions with the same extraction method. Nevertheless our data are higher than those observed by Badejo and his team in Nigeria Physico-chemical parameters such as water content and apparent density influenced the vertical mite distribution.

Key words: Acari, forest, physico-chemical parameters, savannah, season.

Introduction

Soils are complex open systems, natural bodies in which biosphere, lithosphere, atmosphere and hydrosphere come together (Ibáñez & Boixadera 2002). The implications of this complex three-dimensional milieu are of fundamental importance for a very diverse biota (Coleman *et al.* 2004). Soil biological diversity is sometimes linked to its functioning (Lavelle 1996, Andrén & Balandreau 1999, Fitter *et al.* 2005, Bardgett 2008). Generally, the soil fauna, especially mites, is considered to play a key role in the soil functioning. It contributes to the decomposition process and nutrient mineralization: mixture and fragmentation of soil particles, regulation of micro-organisms, etc (Seastedt 1984, Lavelle & Spain 1991, Coleman *et al.* 2004, Gobat *et al.* 2004, Bardgett 2005, Illig et al. 2010).

Despite few calls (Ghabbour 1984, André *et al.* 1992), the literature on soil microarthropods from tropical and equatorial Africa remains meager. In Africa, soil microarthropods abundance is highly variable depending on the vegetation, the habitat fragmentation and mesological factors (Badejo 1990, 1994, Noti *et al.* 1996, Badejo & Tian 1999, Badejo & Ola-Adams 2000, Noti *et al.* 2003) although all these studies are based on topsoil and disregard mineral soils. A strong exception is offered by the publications of Athias *et al.* (1975) and Athias (1975, 1976) who studied mites from Lamto. Her approach is however limited to the Lamto savannah in Ivory Coast.

This second study in Ivory Coast is original as soil mite densities were estimated in topsoil and mineral soils in different types of vegetation. The choice of these sites can be explain by their situation in a distinct ecological zones. Most sites have protection status (primary forest, savannah). In contrast the teak plantation were more disturbunce.

The following hypotheses were specifically explored:

(1) mite densities are higher when the vegetation, including the soil is old and undisturbed

(2) major dominant groups are low when the site is disturbed, (3) soil mite densities varies with vegetation type and season, (4) soil mite densities are affected by soil physico-chemical parameters and decrease with depth.

Material and methods

Study areas

Four sites, all located in arboreal areas of Ivory Coast, were sampled in 2008. The first site (Lamto) is a transition zone between forest and savannah, the second and third sites (Oumé) are located in Sudanese domain and the last one (Taï) pertains to the Guinean domain.

Lamto savannah (LAS).— The first site is the 2500-ha Lamto reserve (Coordinates: 6°13' N, 5°02' W; altitude: 125 m asl). The Ecology Station is located 153 km north-west of Abidjan, its history with ecological studies is provided by Vuattoux *et al.* (2006). The climate, reviewed by Le Roux (2006), is characterized by a mean annual temperature of 27°C and a mean yearly rainfall of 1211 mm (data from Lamto Geophysical Station). The dry season occurs in December and January

Broadly defined, the savannah is perceived as a continuous layer of graminoids (grasses and sedges) and a discontinuous layer of trees and shrubs (Solbrig *et al.* 1996). In Lamto, all faciès were dominated by tall palm trees (*Borassus aethiopum*), pretty regularly distributed (Barot 1999). Sampling was conducted in an unburned area already prospected by Athias *et al.* (1975) and Athias (1975, 1976) and now dominated by *Chromolaena odorata* (Asteraceae) (Fig. 1A).

Soils were ferralsols (FAO classification) with a very low organic matter and nitrogen content (1% and 0.5% respectively) (Delmas 1967, Riou 1974, Mordelet *et al.* 1996).

Oumé primary forest (OPF) .— The second site is located in Oumé, mid-west Ivory Coast, precisely in the village of Goulikao (6°31’ N, 5°30’ W) at

200 m asl (Fig. 1B). Man-made activities are very weak and limited to some tracks. Average temperature and relative humidity are 26°C and 85%, respectively (Avenard *et al.* 1971, Bongoua 2002). The rainfall pattern is of bimodal type, with two dry seasons and one rainy season. Yearly average rainfall is around 1 275 mm, with peaks reaching 2 015 mm and 1 386 mm, in June and in September, respectively. The climate regime is subequatorial, with a mesophile-type vegetation, or a semi-deciduous forest from the Guinean domain (Monnier 1983). Vegetation is very dense and even luxuriant (Fig. 1B). The understory is also dense with lianas and dead wood. *Griffonia simplicifolia* (Caesalpiliniaceae), *Marantochloa leucantha* (Marantaceae), *Anthiaris toxicaria* (Moraceae) are some trees found in OFP. Ferralitic soils are regularly distributed and cover all areas (Angui *et al* . 2005, Assié *et al.* 2008) .

Oumé teak plantation (OTK).— The third site is also located in Oumé, near the previous forest. It is composed of even-aged teaks (*Tectona grandis*) planted in 1994. Most conspicuous is the absence of understory and herbaceous stratum; the ground is bare (Fig. 1C).

Taï primary forest (TPF*)*.— The Taï National Park is the largest remaining forest (450 000 ha) in West Africa and the last large island of the original Upper Guinean forest that once reached from Ghana to Guinea-Bissau. Sampling was carried out at about 200 m North of the central research station (approximate coordinates: 5°45’ N 7°07 W, altitude 150-200 m asl)

The climate is of sub-equatorial type, humid all the year round (Kouadio 2006, OIPR 2006). The yearly average rainfall over the period 1993-2002 was 1 853 mm, with a mean annual temperature of 25.35°C.

The Taï National Park is dominated by *Eremospatha macrocarpa* and *Diospyros mannii* forests. The flora was estimated to 1 231 species (Adou *et al.* 2005). The Tai forest, although not layered, is definitely structured and the light penetration to the undergrowth is weak (Alexandre 1982a, b) (Fig. 1D).

Highly desaturated ferrallitic soils and hydromorphic soils cover almost all areas (Avenard *et al.* 1971, Moreau 1983).

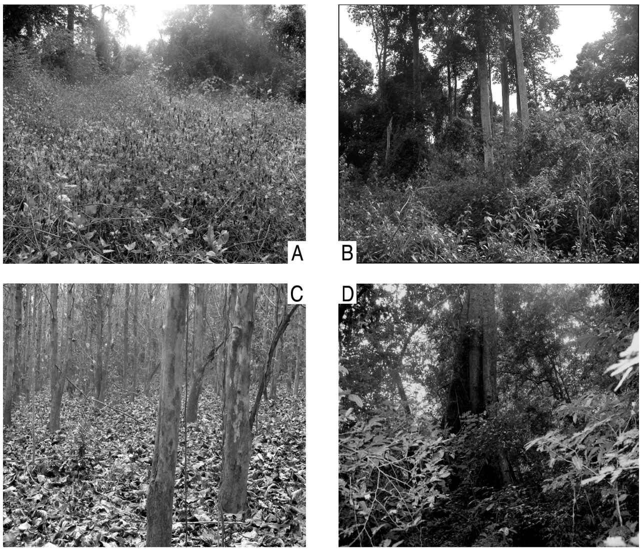

Figure 1. The four sampling sites. LAS with *Chromolaena odorata* in foreground (A); discontinuous woody stratum in OPF (B); no herbaceous stratum and no understory in OTK (C); weak light penetration in TPF (D); (Photo N'Dri 2008, in a dry season).

Sampling method

Mite data were obtained from 1 080 soil cores, *i.e.* 8 series of 15 sets scattered over a 14-m transect, homogeneous from a floristic point of view. Each set determined a "biological" profile representing the mite vertical distribution and was composed of 9 cores, 1 from litter (organic layer; variable height) and 8 from mineral soil taken at regular depths below the litter (0-5 cm ; 5-10 cm ; 10-15 cm ; 15-20 cm ; 20-25 cm ; 25-30 cm ; 30-35 cm ; 35-40 cm). Series of 15 sets (the litter sample and eight 48-cm^3 samples) were repeated in the 4 sites and 2 seasons (dry season in January to

March 2008; rainy season from August to October 2008 for most sites, December 2008 for TPF).

A steel corer (∅ 3.5 cm) was used to take samples vertically. It was not possible to take samples more deeply as the corer met rocky materials.

Microarthropods extraction

Animals were extracted using the Berlese–Tullgren funnels. After preliminary samples, light bulbs (25 W), 15 cm above the intact samples, were lit immediately after the beginning of the extraction process. Extraction lasted 1 week (after 7 days, no animal was captured in preliminary samples). The mean top temperature in the extraction cabinet did not exceed 39°C.

Mite identification

Microarthropods were sorted in Petri dish using a dissecting microscope. Mites were mounted in lactic acid or in Hoyer medium for identification under a light microscope with phase contrast. Contrary to common practice, all stases (developmental stages) were identified. In most cases, mites were recognized to the species level. However, most species could not be identified accurately, because only immature individuals were found or because relevant taxonomic data were lacking. Despite this, the immature abundance represent 1.65% of mite and was very low to affect considerably the mite density. At the species level, there is virtually no major key available for African species. Keys to oribatid genera was offered by Balogh & Balogh (1992). At the family level, keys by Krantz (1978), Dindal (1990) and Krantz & Walter (2009) were consulted. Major taxa (Oribatida, Acaridida) are defined in the traditional sense used in soil zoology and available in Krantz (1978) and Dindal (1990), not in the more recent sense found in Krantz & Walter (2009).

Physico-chemical Parameters

In organic soils, the sample depth corresponds to the mean litter height (variable depending on the site and season); in mineral soils, it corresponds to the mean layer depth plus the mean litter height.

Other physico-chemical parameters were estimated from seven cores adjacent to the sample itself, five cores are mixed together to measure the pH and chemical analyses as recommended by Anderson & Ingram (1993), one core is reserved for the water content and the last one for the apparent density. Soil water content and apparent density of the 960 mineral soil samples were estimated after 48 h drying at 105°C (Baize 1988, Duchaufour 1991, Harmand & Njiti 1998).

The pH (water) (Baize 1988, Duchaufour 1991) was estimated with a pHmeter (Hanna) after calibration at the "Laboratoire d'Écologie du sol" of the "Université d'Abobo Adjamé" in Abidjan (Ivory Coast). Other chemical analyses for extreme depths (0-5 cm and 35-40 cm) were conducted by the "Centre Provincial de l'Agriculture et de la Ruralité" located in La Hulpe (Belgium). Organic and total carbon were measured through ISO norm 10 694. Total nitrogen was measured through ISO norm 13 878. Soil organic matter (SOM) was estimated through the formula C_{org} x 1.7 as made by Noti *et al.* (2003).

Data analysis

Mite abundances, *i.e.* the number of individuals/sample, were transformed into density. As soils are three-dimensional bodies of the earth's crust with properties than can vary over different spatial and temporal scales in every direction (Ibáñez & Boixadera 2002, Castrignanò *et al.* 2004, Blum 2006), densities were expressed in number of mites/dm^3 (as in Table 1). Nevertheless, soils are generally investigated only in horizontal dimensions and densities and comparisons with previous studies were often made in mites/m^2 (as in Table 4).

The SE (Standard Error) associated with mite densities were high. Therefore, non parametric (Mann-Whitney) tests were used to compare mite densities in the different layers, as one deeper into the soil. Comparisons between sites and seasons were stopped whenever tests were not significant. As explained by André *et al.* (2002), we estimated graphically the soil depth in which 50 or 90% of animals were living (respectively the Soil $Depth_{50}$ and Soil $Depth_{90}$, abbreviated as SD_{50} and SD_{90}).

Soil physico-chemical means were compared using a one-way ANOVA test. Rank Pearson correlation was preferred to study the relationship between mite density and soil physico-chemical parameters. All tests were conducted using Statistica 7.1 software package (Statsoft, Tulsa, USA).

Results

Mites density

In all sites and seasons, the mite density generally decreased from the litter to the deep layers (Fig. 2) and was higher in organic than in mineral soils (Table 1). The highest densities were observed in OPF, especially in the rainy season (233 ± 116 mites/dm^3 in the litter, 233 ± 183 mites/dm^3 in the 0-5 cm layer). No mites were captured in the deepest layers of TPF, and also in the 10-15 cm layer in dry season of TPF. Generally, the lowest densities were found in OTK and TPF, and in the dry season rather than in the rainy season (except in TPF where the climate is humid all the year round).

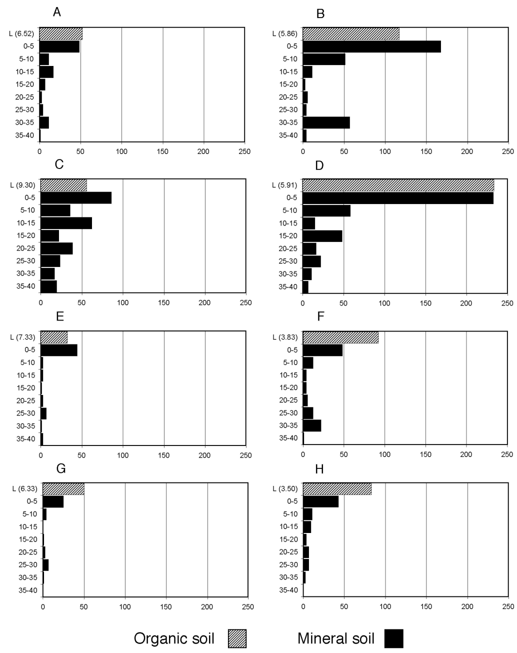

Figure 2. Mite density (individuals/dm^3) in the litter (L followed by the average height in cm) and mineral soil (depths of layers) in the four sites and during the two seasons. LAS: (A, B); OPF: (C, D); OTK: (E, F); TPF: (G, H); dry season: (A, C, E, G); rainy season: (B, D, F, H).

Whatever the season, the same global density succession OPF-LAS-OTK-TPF was observed (Table 1). The SE values associated with mean densities were high as cited above and not illustrated in Fig. 2. Tests comparing profile densities between seasons were not significant (Table 2). However, seasons significantly affected the mite densities observed in litter (OPF and OTK) and in the 0-5 cm layer (LAS and OPF). Deeper, the season effect was not significant.

TABLE 1. *Mite density (mean individuals/dm^3 ± SE) in litter (N = 15), mineral soils (0-40 cm, N = 120), and all samples (N = 135, global density) in the four sites and two seasons.*

	LAS	OFP	OTK	TPF
Dry season				
Litter	52 ± 50	56 ± 42	32 ± 38	50 ± 65
0-40 cm	13 ± 27	38 ± 51	8 ± 27	5 ± 16
Global density	18 ± 32	42 ± 51	12 ± 30	11 ± 30
Rainy season				
Litter	117 ± 154	233 ± 116	92 ± 73	83 ± 96
0-40 cm	38 ± 117	51 ± 103	14 ± 28	11 ± 26
Global density	48 ± 123	75 ± 119	21 ± 43	16 ± 46

TABLE 2. *Seasonal effect on mite density (individuals/dm^3) in different layers (N = 15) and the entire profile (N = 9) of the four sites (P-values of Mann-Whitney tests).*

	LAS		OPF		OTK		TPF
Litter	0.310		0.000	***	0.010	**	0.141
0-5 cm	0.044	*	0.003	**	0.245		0.351
5-10 cm	0.237		0.431		0.078		0.507
Profile	0.427		0.566		0.122		0.200

Significant at levels 0.05 (*), 0.01 (**) and 0.001 (***).

In the dry season, the mean mite density observed in litter was not significantly different between the four sites (Table 3). In mineral soils and in the entire profile however, there was a significant difference in densities surveyed in OPF compared to the other sites.

In the rainy season, the opposite trend was observed in litter: OPF was significantly different from other sites. The same trend was found in mineral soils, but less deeper than in the dry season. In addition, densities recorded in the 0-5 cm layer in LAS were significantly greater (8389 ind/m^2) than those in OTK (2426 ind/m^2) and TPF (2149 ind/m^2). Profile densities differed significantly only in OPF and TPF.

Major taxa

Oribatida dominated in most sites (LAS: 59%, OPF: 58%, TPF: 82%) in the dry season and in TPF (61%) only in the rainy season. In other cases, Gamasida represented the dominant group (LAS: 65%, OPF: 48%, OTK: 44% in the dry season and OTK: 57% in the rainy season). Whatever the season Oribatida and Gamasida were the morjors dominant group , respectively in TPF and OTK. Actinedida were a minor group, with a maximum of 11% in OTK in the rainy season. Acaridida constituted a second minor group, with a maximum of 13% in OTK in the dry season. The major group, Oribatida, Gamasida and Acaridida were significantly ($N = 36$; $p < 0.05$) different between the four sites in the dry season. However in the rainy season, major group are not different in the four site ($N = 36$; $p > 0.05$).

SD_{50} and SD_{90}

All SD_{50} values, except OPF in the dry season, were less than the litter height (Table 5). SD_{90} was around 30 cm.

TABLE 3. *Effects of sites on mite density (individuals/dm^3) in different layers (N = 15) and the entire profile (N = 9) in different seasons (P-values of Mann-Whitney tests).*

	DRY SEASON			RAINY SEASON		
	LAS	OPF	OTK	LAS	OPF	OTK
Litter						
OPF	0.632			0.004 **		
OTK	0.272	0.110		0.709	0.001 ***	
TPF	0.917	0.494	0.468	0.983	0.000 ***	0.576
0-5 cm						
OPF	0.272			0.089		
OTK	0.373	0.082		0.044 *	0.000 ***	
TPF	0.093	0.012 *	0.619	0.026 *	0.000 ***	0.272
5-10 cm						
OPF	0.019 *			0.548		
OTK	0.229	0.001 ***		0.407	0.034 *	
TPF	0.351	0.002 **	0.772	0.178	0.018 *	0.468
10-15 cm						
OPF	0.017 *			0.300		
OTK	0.221	0.001 ***		0.340	0.020 *	
TPF	0.120	0.000 ***	0.756	0.967	0.245	0.245
15-20 cm						
OPF	0.065			0.034 *		
OTK	0.507	0.002 **		0.756	0.054	
TPF	0.507	0.002 **	1.000	0.756	0.054	1.000
20-25 cm						
OPF	0.002 **			0.135		
OTK	1.000	0.002 **		0.590	0.075	
TPF	0.787	0.002 **	0.787	0.885	0.147	0.772
25-30 cm						
OPF	0.013 *					
OTK	0.983	0.017 *				
TPF	0.756	0.028 *	0.787			
30-35 cm						
OPF	0.384					
OTK	0.330	0.054				
TPF	0.330	0.054	1.000			
Profile						
OPF	0.013 *			0.251		
OTK	0.158	0.007 **		0.596	0.085	
TPF	0.133	0.007 **	0.596	0.402	0.027 *	0.566

Significant at levels 0.05 (*), 0.01 (**) and 0.001 (***).

TABLE 4. *Density (mean individuals/m^2) in litter and mineral soils (0-40 cm) of the major groups of mites in the four sites and two seasons. Totals and percentages are also given.*

	Litter	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	0-40	%
DRY SEASON											
LAS											
Gamasida	1 109	555	69	555	139	69	0	416	69	2 981	35
Actinedida	208	139	0	139	69	0	0	0	0	555	6
Oribatida	2 080	1 733	485	139	139	69	208	139	0	4 992	59
Acaridida	0	0	0	0	0	0	0	0	0	0	0
Total	3 397	2 426	555	832	347	139	208	555	69	8 527	100
%	40	28	7	10	4	2	2	6	1	100	
OPF											
Gamasida	1 941	1 941	832	971	277	485	693	485	416	8 042	39
Actinedida	139	69	0	208	0	0	0	0	69	485	2
Oribatida	3 120	2 288	971	1941	832	1456	485	347	485	11 924	58
Acaridida	0	0	0	0	0	0	0	0	0	0	0
Total	5 200	4 298	1803	3120	1109	1941	1179	832	971	20 451	100
%	25	21	10	15	5	9	6	4	5	100	
OTK											
Gamasida	1 387	1 387	139	69	0	69	69	0	139	3 258	57
Actinedida	139	0	0	0	0	0	0	0	0	139	2
Oribatida	832	555	0	69	69	0	0	69	0	1 595	28
Acaridida	139	277	0	0	0	69	277	0	0	763	13
Total	2 496	2 218	139	139	69	139	347	69	139	5 754	100
%	44	39	2	2	1	2	7	1	2	100	
TPF											
Gamasida	277	208	69	0	0	0	277	69	0	901	17
Actinedida	69	0	0	0	0	0	0	0	0	69	1
Oribatida	2 842	1 040	139	0	69	139	69	0	0	4 298	82
Acaridida	0	0	0	0	0	0	0	0	0	0	0
Total	3 189	1 248	208	0	69	139	347	69	0	5 269	100
%	61	24	4	0	1	2	7	1	0	100	
RAINY SEASON											
LAS											
Gamasida	5 338	5 962	1 941	416	69	208	208	139	69	14 351	65
Actinedida	139	139	69	0	0	0	0	0	69	416	2
Oribatida	1 317	2 218	555	139	69	69	0	69	69	4 506	20
Acaridida	69	69	0	0	0	0	0	2 634	0	2 773	13
Total	6 863	8 389	2 565	555	139	277	208	2 842	208	22 046	100
%	31	38	12	3	1	1	1	12	1	100	
OPF											
Gamasida	6 794	6 239	1 525	485	832	277	69	69	277	16 569	48
Actinedida	0	0	69	0	0	0	69	0	0	139	0
Oribatida	6 378	4 576	1 040	277	1 525	485	901	485	69	15 737	46
Acaridida	624	832	277	0	69	69	69	0	0	1 941	6
Total	13 796	11 647	2 912	763	2 426	832	1 109	555	347	34 386	100
%	40	34	8	2	7	2	4	2	1	100	
OTK											
Gamasida	1 525	1 040	347	139	69	69	277	485	69	4 021	44
Actinedida	69	0	0	0	0	208	208	555	0	1 040	11
Oribatida	1 941	1 387	277	69	139	0	139	69	0	4 021	44
Acaridida	0	0	0	0	0	0	0	0	0	0	0
Total	3 536	2 426	624	208	208	277	624	1 109	69	9 082	100
%	39	27	7	2	2	3	7	12	1	100	
TPF											
Gamasida	693	485	347	69	69	277	69	139	0	2 149	30
Actinedida	277	69	0	0	0	0	69	0	0	416	6
Oribatida	1 941	1 525	208	277	139	69	208	0	0	4 368	61
Acaridida	0	69	0	139	0	0	0	0	0	208	3
Total	2 912	2 149	555	485	208	347	347	139	0	7 141	100
%	41	30	8	7	3	5	5	1	0	100	

TABLE 5. *Soil Depth$_{50}$ and Soil Depth$_{90}$ (in centimeters) estimated for the four sites and in the two seasons.*

	LAS	OPF	OTK	TPF
Dry season				
SD_{50}	5.1	13.4	4.7	2.2
SD_{90}	26.6	35.6	29.7	25.0
Rainy season				
SD_{50}	5.6	4.4	3.5	3.0
SD_{90}	34.5	22.2	32.4	22.6

Physico-chemical Parameters

Whatever the site and whatever the season, apparent density increased significantly ($N = 120$, $P < 0.05$) from the 0-5 to 35-40 cm layers (Fig. 3A, B). Apart from the 10-15 cm layer in the dry season, the apparent density also differed significantly ($N = 60$, $P < 0.05$) between sites. Mean values observed in each site were close to each other whatever the season (LAS: 1.04 in the dry season vs. 0.90 in the rainy season; OPF: 1.22 vs. 1.04; OTK: 1.03 vs. 1.05; TPF: 1.06 vs. 1.12).

Contrary to apparent density, water content (Fig. 3C, D) significantly decreased with layer depth in the two seasons ($N = 120$, $P < 0.05$), except in LAS in the dry season ($P = 0.928$). Water contents were also significantly different when sites were compared ($N = 60$, $P < 0.05$). Mean values were: LAS: 8.08% in the dry season vs. 14.63% in the rainy season; OPF: 7.03 vs. 15.29%; OTK: 12.51 vs. 18.21%; TPF: 19.48 vs. 14.81%). Note that the values obtained in TPF were in the reverse order than in other sites.

TPF soils were acid and the pH values differed significantly from those observed in other sites ($N = 120$, $P < 0.05$; Fig. 3E, F). Beside, the pH gradient in TPF was reverse from that noticed elsewhere: the deeper the layer, the greater the pH. The pH values obtained in the layers of the three remaining sites differed significantly, except in OTK in the rainy season (P = 0.054). Mean values were similar in the two seasons: LAS: 6.52 in the dry season vs. 6.48 in the rainy season; OPF: 7.20 vs. 7.49; OTK: 7.32 vs. 7.34; TPF: 6.01 vs. 5.88).

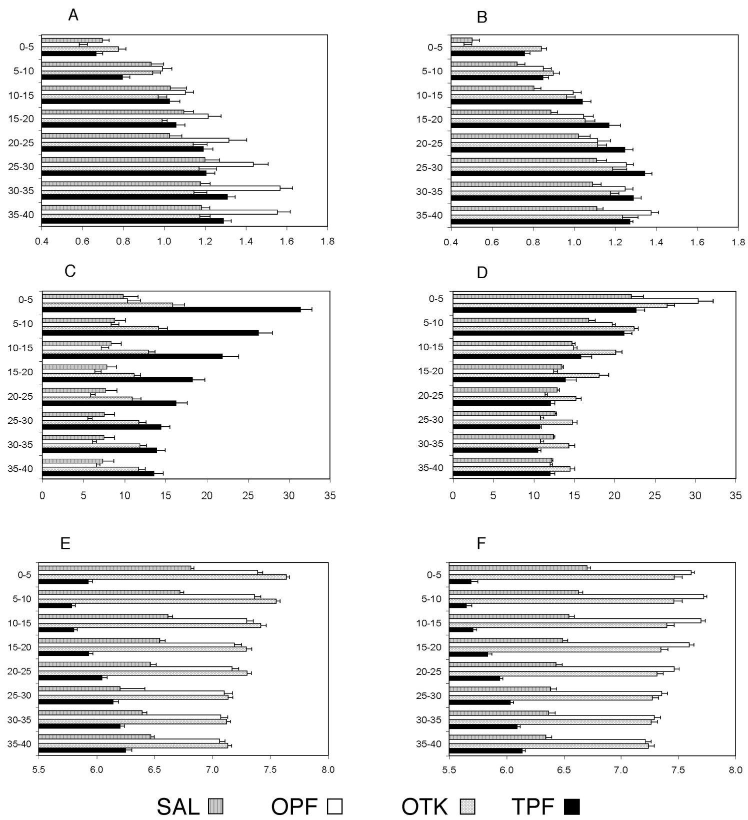

Figure 3. Physico-chemical parameters (mean values and SE) in the four sites and during the two seasons. Apparent density: (A, B); water content: (C, D); pH: (E, F); dry season: (A, C, E); rainy season: (B, D, F).

Whatever the season, C_{org} contents were identical with C_{tot} contents, except in the 0-5 cm layer in OTK during the rainy season. Carbon and nitrogen values were greater in 0-5 cm layer than in deeper soils (Table 6). These values were significantly different ($p < 0.05$) between sites except for the 35-40 cm layer in the dry season.

Table 6. *Mean and SE values of chemical parameters measured in the two extreme layers of mineral soils in the four sites and two seasons.*

	LAS			OPF			OTK			TPF		
DRY SEASON												
0-5 cm												
C_{org} (g/kg)	9.60	±	0.68	26.60	±	2.69	16.80	±	1.39	23.60	±	2.77
C_{tot} (%)	0.96	±	0.07	2.66	±	0.27	1.68	±	0.14	2.36	±	0.28
N_{tot} (%)	0.09	±	0.01	0.27	±	0.03	0.18	±	0.02	0.19	±	0.02
C/N	10.64	±	0.26	9.69	±	0.23	9.35	±	0.05	12.49	±	0.51
SOM (g/kg)	16.32	±	1.15	45.22	±	4.58	28.56	±	2.37	40.12	±	4.71
35-40 cm												
C_{org} (g/kg)	5.30	±	0.00	6.18	±	0.72	5.44	±	0.14	7.20	±	0.97
C_{tot} (%)	0.53	±	0.00	0.62	±	0.07	0.54	±	0.01	0.72	±	0.10
N_{tot} (%)	0.03	±	0.00	0.06	±	0.01	0.05	±	0.01	0.07	±	0.01
C/N	15.90	±	1.08	10.93	±	1.00	12.31	±	0.94	10.85	±	0.68
SOM (g/kg)	9.01	±	0.00	10.51	±	1.22	9.25	±	0.24	12.24	±	1.65
RAINY SEASON												
0-5 cm												
C_{org} (g/kg)	11.80	±	1.59	36.80	±	6.30	16.60	±	0.87	17.80	±	1.39
C_{tot} (%)	1.18	±	0.16	3.68	±	0.63	1.72	±	0.14	1.78	±	0.14
N_{tot} (%)	0.11	±	0.02	0.37	±	0.06	0.18	±	0.01	0.14	±	0.01
C/N	10.99	±	0.11	9.92	±	0.33	9.50	±	0.28	12.49	±	0.40
SOM (g/kg)	20.06	±	2.71	62.56	±	10.70	28.22	±	1.48	30.26	±	2.37
35-40 cm												
C_{org} (g/kg)	5.30	±	0.00	5.30	±	0.00	5.44	±	0.14	6.00	±	0.00
C_{tot} (%)	0.53	±	0.00	0.53	±	0.00	0.54	±	0.01	0.60	±	0.00
N_{tot} (%)	0.03	±	0.00	0.04	±	0.00	0.04	±	0.01	0.05	±	0.00
C/N	17.67	±	0.00	13.60	±	1.14	12.95	±	1.35	12.00	±	0.00
SOM (g/kg)	9.01	±	0.00	9.01	±	0.00	9.25	±	0.24	10.20	±	0.00

Mite density and physico-chemical parameters

In OPF during the dry season only, litter height and pH were significantly correlated to the mite density (Table 7). Except in OTK in the rainy season, there was a significant and negative correlation between depth and mite density. Apart TPF in the dry season and OTK in the rainy season, apparent density and water content were also significantly correlated to the mite density. Last, there was a significant correlation between mite density and

C_{tot}, N_{tot}, C/N and SOM in the 0-5 cm layer observed in LAS in the rainy season.

TABLE 7. *Correlation between mite density (mean individuals/dm^3) and mesological variables in the four sites and two seasons. App. density = apparent density*.

	LAS				OPF				OTK				TPF			
	N	*r*	*P*		*N*	*r*	*P*		*N*	*r*	*P*		*N*	*r*	*P*	
DRY SEASON																
Entire profile																
Litter height	15	-0.09	0.751		15	0.53	0.038	*	15	0.18	0.518		15	-0.33	0.227	
App. density	8	-0.86	0.005	**	8	-0.88	0.003	**	8	-0.70	0.048	*	8	-0.70	0.051	
Water content	8	0.86	0.005	**	8	0.78	0.020	*	8	0.77	0.023	*	8	0.70	0.052	
pH	8	0.70	0.051		8	0.81	0.014	*	8	0.62	0.099		8	-0.18	0.667	
Depth	9	-0.81	0.007	**	9	-0.77	0.015	*	9	-0.68	0.041	*	9	-0.71	0.029	*
0-5 cm																
C_{tot}	5	0.62	0.262		5	-0.25	0.679		5	-0.39	0.510		5	0.74	0.149	
N_{tot}	5	0.63	0.254		5	-0.12	0.842		5	-0.39	0.510		5	0.67	0.208	
C / N	5	0.24	0.694		5	-0.67	0.215		5	0.31	0.603		5	0.12	0.846	
SOM	5	0.62	0.262		5	-0.25	0.670		5	-0.39	0.510		5	0.74	0.149	
35-40 cm																
C_{tot}	5	-	-		5	-0.06	0.920		5	-	-		5	-	-	
N_{tot}	5	-	-		5	0.21	0.723		5	-	-		5	-	-	
C / N	5	-	-		5	-0.58	0.296		5	-	-		5	-	-	
SOM	5	-	-		5	-0.06	0.920		5	-	-		5	-	-	
RAINY SEASON																
Entire profile																
Litter height	15	-0.21	0.435		15	-0.29	0.283		15	-0.13	0.629		15	0.33	0.283	
App. density	8	-0.74	0.032	*	8	-0.89	0.002	**	8	-0.52	0.186		8	-0.78	0.020	*
Water content	8	0.89	0.002	**	8	0.94	0.001	***	8	0.63	0.091		8	0.78	0.021	*
pH	8	0.69	0.054		8	0.4	0.316		8	0.46	0.248		8	-0.59	0.115	
Depth	9	-0.68	0.043	*	9	-0.8	0.008	**	9	-0.66	0.050		9	-0.76	0.015	*
0-5 cm																
C_{tot}	5	0.93	0.020	*	5	0.39	0.512		5	0.49	0.397		5	0.24	0.687	
N_{tot}	5	0.93	0.020	*	5	0.25	0.681		5	0.37	0.533		5	0.30	0.614	
C / N	5	-0.88	0.045	*	5	0.79	0.107		5	0.67	0.213		5	-0.41	0.491	
SOM	5	0.93	0.020	*	5	0.39	0.512		5	0.38	0.522		5	0.24	0.687	
35-40 cm																
C_{tot}	5	-	-		5	-	-		5	-	-		5	-	-	
N_{tot}	5	-	-		5	0.00	1.000		5	-	-		5	-	-	
C / N	5	-	-		5	-0.07	0.901		5	-	-		5	-	-	
SOM	5	-	-		5	-	-		5	-	-		5	-	-	

Significant at levels 0.05 (*), 0.01 (**) and 0.001 (***). -: spurious correlation

DISCUSSION

Efficiency of the Berlese-Tullgren funnels

The efficiency rate of traditional extraction methods is especially weak and the most frequently used extraction methods have a mean efficiency of 40%, a rough overestimation advanced by André *et al.* (2002). The absolute efficiency of the Berlese-Tullgren funnels would vary, depending on the authors, from 26% (Forsslund 1948) to 7% (André *et al.* 2002). Nevertheless, the Berlese-Tullgren funnels were retained for their low cost and feasibility in Ivory Coast. All densities published in this paper rely on abundances in berlesates and are thus rough estimations.

Comparison with Lamto results

Mite densities observed in LAS soils, 9 000 to 22 000 mites/m^2 compared to a yearly 28 000 mites/m^2 (Athias 1975) are similar as well as the extraction method, the Berlese-Tullgren funnels, and the sample size. Water contents, C_{tot}, N_{tot} and SOM also remain the same even if the herbaceous vegetation has changed over time. Contrary to Athias' (1976) conclusions, water content seems to govern the mite density observed in Lamto. Another discrepancy with previous results concerns the importance of major taxa: Gamasida from 35 to 65% of mites vs. 16% in Athias (1975) and Actinedida from 2 to 6% vs. 39% in Athias (1975). This difference within major taxa could be attributed to changement observed in the vegetation structure. Indeed, the plot sampled by Athias was dominated by herbaceous stratum (poacae) . in contraste our plot was characterized by the marked presence of *Chromolaena odorata*. The litter of this adventist was decomposed very quickly in organic matter. This idea was confirmed by the positive correlation between mite density and the chemical parameters (C_{tot}, N_{tot}, SOM).

Comparison with other data from Africa

Whatever the site, mite density is greater in the rainy than in the dry season. A similar trend is reported by Badejo & Tian (1999) in southwest Nigeria. Such a trend could be attributed to a low soil moisture regime associated to a high soil temperature (Badejo 1990, Badejo *et al*. 1998, Badejo & Tian

1999). During the rainy season, the litter accumulated throughout the dry season starts disappearing gradually due to decomposition.

Maldague (1961) and Noti *et al.* (1996) showed that mites were particularly abundant in African forests. The highest densities of soil mites observed in OPF might be explained by the heterogeneity of vegetation and ensuing microhabitats. Such a hypothesis is supported by the positive correlation with the litter height estimated in the dry season. However, the oribatid density observed in OPF is higher in the rainy than in the dry season, which contradicts the results published by Noti *et al.* (1996)

At the same sampling depth (7.5 cm) and whatever the season, mite density in OPF is greater than that reported in Nigeria by Badejo & Tian (1999) and Adeduntan (2009). Mite densities in OPF remain however very weak compared to results by Noti *et al.* (1996) and limited to adult oribatids in Congo Democratic Republic, they are even less than values recorded in the Namib desert by André *et al*. (1997), although these authors were used carbon tetrachloride flotation method.

Contrary to expectation and despite the absence of disturbance lowest densities are reported from TPF where the climate is humid all the year round. Highly desaturated ferrallitic soils and hydromorphic soils cover almost all areas (Avenard *et al.* 1971, Moreau 1983). Soil type and quality could be an obstacle to the mites development in this zone.

These results agree with recent observations on spiders (R. Jocqué, pers. obs.) and Myriapoda (D. Van den Spiegel, pers. obs.) on the same site (soil acid), but require further investigations.

Low densities are also reported in OTK, where there is no understory and the litter is monospecific. Oribatid densities in OTK however are clearly higher than reported by Badejo & Ola-Adams (2000) in a similar habitat. The same major group dominant, mesostigmatid mite was also observed by Badejo & Ola-Adams (2000), in spite of the soil sampled was acid (pH: 5.18) and low in organic matter (3.43 %). The low density of mites in the teak plantation could be explained by the disturbance and soil compaction during the establishment of plants. The soil bulk density was higher in the upper layer and in this case , limit the water infiltration.

A seasonal effect is visible only in litter (OTK and OPF) and in the upper layer of mineral soil (LAS and OPF). These results suggest the presence of surface species sensitive to a seasonal effect, which agrees with Badejo's (1990) findings.

Influences of physico-chemical parameters

Whatever the season and whatever the site, the litter height and the pH little affect the mite vertical distribution. However, parameters as soil apparent density (or porosity alike), and water content play a key role in determining the mite density (Noti 1991, Ducarme *et al.* 2004). In contrast, C_{tot}, N_{tot}, C/N and SOM are correlated with mite density only in LAS and seem to have a minor role.

Soil Depth$_{50}$

Most values of SD_{50} are below 5.6 cm and clearly indicate that a study of topsoil may suffice to describe the soil mite densities from Ivory Coast. The only exception is OPF in the dry season (SD_{50} = 13.4 cm). Our conclusions are conflicting to those reported by Athias (1975) who claimed that, contrary to what is observed in temperate areas, microarthropods from tropics have a deep distribution. Altough our results confirm the findings by Adis *et al.* (1987) and Illig et al. (2010) that most arthropods live in the top 3.5 cm in Manaus (Brazil) and are opposite to André's *et al*. (2002) estimation of 11 cm for the SD_{50} in temperate forests. However this vertical distribution could be affected by an altitude variation between the study sites (Illig et al. 2010).

The different results reveal that the density of mites is higher when the site is undisturbed, as is the case with Oumé primary forest. However this alone factor could not explain the weak density observed in others sites. other parameters such as soil quality, the speed of litter decomposition, and ecosystem productivity could greatly infuenced the mite abundance. The relatively high density of mites in Lamto savannah will be the reponse of site protection and its transition to a woodland.

Our results also suggest a bimodal distribution of soil mite density. This has to be supported by biological diversity studies as proposed by André *et al.* (1992).

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