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Does Gamasid mites (Acari, Mesostigmata) observed in oil palm and rubber plantations can be used as indicators of tropical secondary forest soil transformation?

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Abstract

The aim of the study was to assess modifications in the community of soil mesostigmatid mites', as indicator of environment stability with land-use change across 2–4 texturally distinct soils in La Mé and Grand Lahou, Côte d'Ivoire. The fieldwork was carried out in humid period on two study sites: 1– rubber landscape (secondary forest, 7-, 12- and 25-year-old rubber plantations) and 2– oil palm landscape (secondary forest, 13-, 20- and 39-year-old oil palm plantations). Three sampling stands were established in each land-use type and age class, for a total of 24 sampling stands. On each sampling stands, soil cores for Gamasid mite's extraction were taken at 10 cm soil depth through a 40–50 m transect. Our findings highlighted a drop of mesostigmatid mites' density (–49% and –52%), species richness (–41% and –40%), and diversity (–35% and –49%), respectively after conversion of the secondary forests into rubber and oil palm plantations. The soil with clayey sandy and clayey textures favored the development of the mesostigmatid mites, particularly in the abundance and species richness of Uropodina. However, the soil with sandy clayey textures improved the abundance and species richness of Gamasina. The mesostigmatid mites' community was degraded in sandy-textured soils. In light of the Maturity Index values, a better quality of soil and environment was detected in the secondary forests compared to plantations. The results also suggest that the mesostigmatid mites' community influence the soil nutrients and probably plant productivity indirectly by influencing the populations of their prey.

Keywords: Soil textures, mesostigmatid mites' community, secondary forests conversion, rubber and oil palm plantations, soil and environment quality

1. Introduction

Forests are complex ecosystems that harbor a high number of plant and animal species (Fall, 2001). Containing 80% of terrestrial biodiversity (Fall, 2001). Forests provide habitat for 80% of amphibian species, 75% of bird species, 68% of mammal species and about 60% of vascular plants (FAO, 2020). With an estimated area of 4.06 billion hectares, the forest is the second carbon sink after the oceans (FAO, 2020). The diversity of natural ecosystems is essential to ensure ecosystem functions. Unfortunately, the forests are threatened by human activities such as the conversion of forests into agricultural systems (Krashevska *et al.*, 2016).

The deforestation and subsequently habitats degradation are the main causes for biodiversity loss (FAO, 2020). The agricultural practices in a forest stand is a global issue. Indeed, a perennial plantation is a cultivated area where species and structure have been simplified dramatically to produce only a few goods (Swarnalatha, 2010). Since 1990, 420 million hectares of forests have disappeared by conversion into other uses (FAO, 2020). In the tropics, the conversion of forests into agrosystems leads to a strong reduction in biodiversity (N'Dri *et al.*, 2017) and also affects the state of soil nutrients in the short and long term (Allen *et al.*, 2015). These changes will also affect the viability, persistence and resilience of terrestrial ecosystems. Changes in ecosystems will in turn affect the delivery of ecosystem services, thereby affecting human wellbeing (Swarnalatha, 2010). Plant life including trees is essential for maintaining the integrity of the soil. If plants are removed (deforestation), then the soil is more at risk of erosion (Swarnalatha, 2010).

In recent decades, the rubber and oil palm plantations have boomed in the humid tropics zone due to growing demand from the population. To meet the demand, focus on rubber and oil plantations led to a rapid expansion in tropical forests (Krashevska *et al.*, 2015; Hemati *et al.*, 2020; Singh *et al.*, 2021). The financial returns provided by these crops are considerable and decisive for the economies of producing countries (Despréaux and Nicolas, 2001). In Ivorian land, the rubber production system occupied 165 000 farmers and an area of 600 000 hectares (Commodafrica, 2018) with an annual production estimated at 990 000 tones in 2019 (Ndiaye and Fainke, 2020), which makes Côte d'Ivoire the leading African producing country and the sixth world producer of natural rubber (Adiko, 2021). Planted on an area of 250 000 hectares in Côte d'Ivoire, the average annual production of crude palm oil is estimated at 550 000 tones (Fages, 2019).

Despite this, the large scale transformation of rainforests into monoculture plantation systems, such as oil palm and rubber, is one of the main drivers for biodiversity loss (Krause, 2020) and various environmental changes which influence the soil microarthropod biodiversity (Krashevska *et al*., 2015). The mesostigmatid mites are the most species rich order within parasitiformes with nearly 11,000 described species (Walter and Proctor, 2013). Most of the mesostigmatid mites are predator species, having as trophically preferences some other soil invertebrates such as springtails, nematodes, enchytreides, dipterans larva and oribatids (Călugăr and Ivan, 2013; Manu *et al*., 2013; Manu and Ion, 2014; Sakhidad *et al*., 2016). As predators, they influence the soil structure and plant productivity indirectly by influencing the populations of other organisms (Gulvik, 2007; Díaz-Aguilar *et al*., 2013; Sakhidad *et al*., 2016). The Uropodina mites (slow-moving fungus feeders) and Gamasina mites (actively moving predaceous) are commonly found in soil (Dhooria, 2016). Being predators in the great majority, the abundance and community structure of Gamasina reflect mostly the availability of their prey (Călugăr and Ivan, 2013). Likewise, the particular conditions of each stand (vegetation cover, forest types, soil and plantation types, age, tillage, pesticides and fertilizers application, soil compaction during harvest, and removal of plant biomass) as well as climatic conditions influence both the quantitative and qualitative aspects of the structure of the mesostigmatid mites' communities (Arroyo *et al*., 2013; Călugăr and Ivan, 2013; Díaz-Aguilar *et al*., 2013; Elmoghazy and Shawer, 2013; Manu and Onete, 2013; Sakhidad *et al*., 2016; Călugăr, 2018; Dervash *et al*., 2018; Meehan *et al*., 2018; Heydari *et al*., 2020; Zagatto *et al*., 2020; Pator and Ray, 2021).

The mesostigmatid mites' assemblages are distinguished according to stand floor thickness and microhabitats, probably reflecting species-specific habitat preferences within accumulated litter (Díaz-Aguilar *et al*., 2013; Kamczyc *et al*., 2020). The vegetation covers and the resulting litter as well as intensive agriculture affect mite population densities and diversity in the soil (Elmoghazy and Shawer, 2013). Many ecological studies revealed that the litter-fermentation layer is the most favorable habitat for Mesostigmatid species (Manu and Onete, 2013; Kamczyc *et al*., 2018). A rich substrate in organic matter determine the presence of abundant soil fauna invertebrates, which represent the food source for predator mites (Manu and Ion, 2014). Natural forests are complex and very stable ecosystems with regard to the specific ecological niches of all species (Sakhidad *et al*., 2016) that create refuges for the soil mites due to their high spatial heterogeneity (Kamczyc *et al*., 2020). Unfortunately, their abundance and species richness decreased after the forests transformation into plantations (Călugăr, 2018; Kamczyc *et al*., 2018; Urbanowski *et al*., 2018). The mesostigmatid mites with *r*- and *K*-selected species may be impacted differently by the forest conversion disturbance. These characteristics make them good bioindicators of habitat and soil condition, since their presence or absence as well as their quantity may reflect soil health or environmental quality (Călugăr, 2018; Manu *et al*., 2021).

Soil fauna communities rely on energy derived from aboveground primary producers, i.e. carbon and nutrients, most importantly nitrogen which limits the growth of plants, soil microorganisms and soil animals (Eißfeller, 2013). Plants and soil organisms are strictly linked to each other and aboveground and belowground communities can be powerful mutual drivers (Heydari *et al*., 2020). For this reason, the conversion of rainforest into monoculture plantations is likely to have a strong impact on belowground biodiversity. Otherwise, consequences of the tropical rainforests transformation into oil palm and rubber plantations on Gamasid mite diversity and community composition are rather unexplored. Most of the works on the soil biological components, carried out simultaneously in rubber and oil palm landscapes only concerns bacteria, fungi, and enzymes (Krashevska *et al*., 2015; Kerfahi *et al*., 2016; Nurulita *et al*., 2016), nematodes (Kerfahi *et al*., 2016), and protists (Krashevska *et al*., 2016). This work helps to understand the reaction of soil mesofauna to changes in forest soil environments after long-term plantation establishment. Plant life including trees is essential for maintaining the integrity of the soil. If plants are removed (deforestation), then the soil is more at risk of erosion (Swarnalatha, 2010). The reconciliation between economic interests and ecological sustainability in tropical agricultural landscapes remains an international issue, poorly understood by most farmers (Drescher *et al*., 2016). Nonetheless, it could be possible to find a sustainable balance between the needs of humans and nature (Allen, 2015). Increasing productivity of tree plantations to reduce the need for new lands for production is a valid alternative to gaining land to be reforested, and it seems to represent the only option in tropical areas where tree plantations are in most cases used for the needs of local populations (Chiti *et al*., 2014). In order to improve the soil quality and sustainable biodiversity, management such as agroforestry is adopted in rubber and oil palm plantations (Conti, 2015; Vrignon-Brenas *et al.*, 2019; Hemati *et al.*, 2020).

The aim of the study was to assess modifications in the community of soil mesostigmatid mites', as indicator of environment stability with land-use change across 2–4 texturally distinct soils in La Mé and Grand Lahou, Côte d'Ivoire. We hypothesized that (i) the Gamasid mites' abundance, species richness, diversity and environmental stability will be higher in the secondary forests compared to rubber and oil palm plantations, and (ii) the structure composition of Gamasid mites' will be greater in the clayey and clayey sandy textures compared to sandy clayey and sandy soil textures.

2. Materials and Methods

2.1. Study sites description

This research was conducted in 2013 and 2017 in Côte d'Ivoire throughout two study sites. The first site hosting the rubber landscapes is based in the department of Grand Lahou (5°13'N; 5°03'W) situated in southern Côte d'Ivoire about 140 km of Abidjan. The second site, characterized by the oil palm landscape is located in the La Mé Station (5°26'N, 3°50'W) in the south-eastern of Côte d'Ivoire, ~30 km from Abidjan (Fig. 1). The climate of the two study sites is an equatorial type with four seasons: a long dry season from December to March, a long wet season from April to July, a short dry season from August to September, and a short wet season from October to November (Péné and Assa, 2003; Ettian *et al.*, 2009; Konan *et al.*, 2013). Monthly rainfall during the study year on the site of Grand Lahou (site 1) varied between 0 mm in January and 282 mm in June, with an annual total of 1,085 mm. Monthly mean temperature ranged from 25°C in August to 29°C in February and March, with an annual average of 27°C. Different land uses, particularly, secondary forests, agrosystems dominated by the rubber plantations and fallow systems characterize this site. Monthly rainfall during the field work on the site of La Mé (site 2) ranged from 18 mm in January to 486 mm in June, with an annual total of 1,915 mm. Monthly mean temperatures are the same to whose observed in the first site. In the La Mé Station, secondary forests are adjacent to oil palm plantations. The upper soils of both sites is ferrallitic type (Perraud, 1971; Yeboua and Ballo, 2000) with different textures. The soils of the site of Grand Lahou are characterized by clayey, clayey sandy, sandy clayey and sandy textures while the soils of the site of La Mé present clayey sandy and sandy textures.

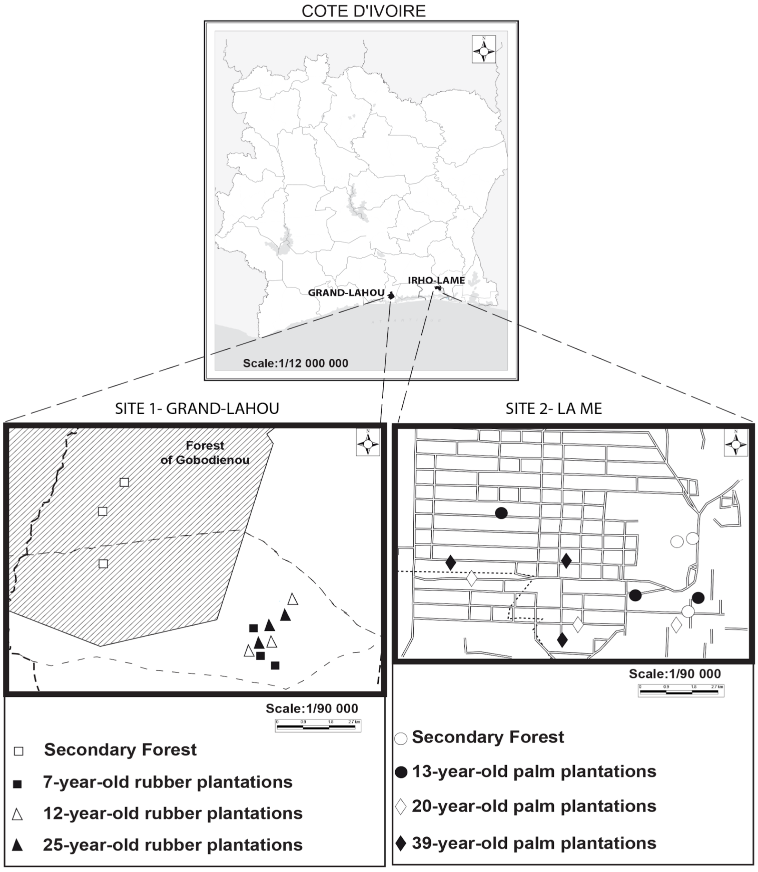

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Figure 1. Location of the study sites in Côte d'Ivoire, and design of the selected plots

2.2. Sampling design and soil characteristics

For better understanding in the variation of mesostigmatid mites structure and a good appreciation of the impact of environmental severity following the conversion of secondary forests into an agrosystem, three secondary forests (baseline) and nine rubber plantations (7-, 12- and 25-year-old) were selected on the site of Grand Lahou, for a total of 12 sampling stands (Table 1). We applied the same method on the site of La Mé, where the oil palm plantations were 13-, 20-, and 39-year-old. A total of 24 stands was selected throughout the two study sites. On each stand from the site of Grand Lahou, data were collected along a 40 m transect, whilst on the La Mé site, sampling was performed along a 50 m transect. This difference in transect length favored the soil cores collection in the inter-rows (fertile zone) of plantations. According to Koffi (2019), the soils under the secondary forests of Grand Lahou (29.12 ± 3.95%) contained higher moisture than those of the other land use types. The soil bulk density was low in the secondary forests of Grand Lahou (0.95 ± 0.05 g cm^{-3}) and La Mé (0.91 ± 0.04 g cm^{-3}). Soil pH ranged from 4.43 ± 0.08 (secondary forests of Grand Lahou) to 5.37 ± 0.13 (oil palm plantations). Whatever the study site, the soil organic carbon, total nitrogen and organic matter were higher in the secondary forests of Grand Lahou (SOC: 22.90 ± 3.31 g kg^{-1} soil, TN: 2.00 ± 0.29 g kg^{-1} soil, SOM: 38.93 ± 5.63 g kg^{-1} soil) and La Mé (SOC: 19.55 ± 1.33 g kg^{-1} soil, TN: 1.60 ± 0.09 g kg^{-1} soil, SOM: 33.23 ± 2.27 g kg^{-1} soil).

2.3. Soil cores collection, mesostigmatid mite's extraction and identification

On each sampling stand, five soil cores including litter thickness were taken with a steel corer (Ø 5 cm) at 0–10 cm soil depth (Manu and Onete, 2013; Kamczyc *et al*., 2018). The sampling points were defined with 10–12.5 m interval between two consecutive points along the transect. Thus, a total of 120 soil cores was taken through the 24 sampling stands and brought to the laboratory. Mites were extracted from soil samples using Berlese Tullgren funnels with a mesh size of approx. 2mm (Kamczyc *et al*., **Table 1.** Previous cropping and soil characteristics of the selected plots. Soil physico-chemical values (mean ± standard error) were presented

2021). The temperature and moisture gradient in the Berlese Tullgren funnels forced active soil fauna to move down into container with 75% ethyl alcohol over 14 days (Manu and Ion, 2014). After extraction, mesostigmatid mites were selected from samples under a stereomicroscope, then mounted on temporary slides for clearing in 85% lactic acid for a minimum of 3 days (Kamczyc *et al*., 2021). Mesostigmatid mites were identified using a digital camera VC.5000 mounted on a NOVEX light microscope and identified to family, genus and morphospecies level using acarological keys (Krantz, 1978; Krantz and Walter, 2009).

2.4. Data analysis

Four land use types: *SFG* secondary forests of Grand Lahou, *RBP* rubber plantations of 7-25 years, *SFL* secondary forests of La Mé, and *OPP* oil palm plantations of 13-39 years were considered in the data analysis. The mesostigmatid mites' abundance was expressed as the mean number of individuals per square meter (ind m^{-2}) whereas the species richness, Shannon index, Margalef diversity index and evenness were used to analyze Gamasid mites' diversity. Margalef diversity index measures the species richness and it is very sensitive to sample size although it tries to compensate the sampling efforts (Magurran, 2004). Unlike to other diversity indices that take into account the relative abundance, Margalef diversity index (Margalef, 1958) use the absolute abundance (Gamito, 2010). The non-parametric estimators such as the observed species (Sobs) and expected species (the first-order jackknife) were determined in order to assess the discovery rate of the Gamasid species (Colwell *et al.*, 2004). The Gamasid mites' community was subdivided into three infraorders or cohorts (Gamasina, Uropodina, and Antennophorina). Their abundance and species richness were used to analyze the community structure in the different land use types. The dominance and frequency indices of Gamasid species were classified following the Napierała and Błoszyk (2013) method. Thus, five dominance and frequency classes have been defined according to the partition below:

- Dominance: eudominants (>30% of the total number of individuals), dominants (15.1–30.0%), subdominants (7.1–15.0%), residents (3.0–7.0%), and subresidents (<3%).
- Frequency: euconstants (>50% of presence), constants (30.1–50%), subconstants (15.1–30.0%), accessory species (5.0–15.0%), and accidents (<5%).

Table 1. Previous cropping and soil characteristics of the selected plots. Soil physico-chemical values (mean ± standard error) were presented

Land use types	Age (years)	Soil type	Soil texture	BD (g cm^{-3})	WC (%)	SOC (g kg^{-1} soil)	TN (g kg^{-1} soil)	C/N	SOM (g kg^{-1} soil)	pH-H_2O	Previous cropping
Site of Grand Lahou											
rubber	7	ferrallitic	sandy clay	1.23 ± 0.05	10.88 ± 1.95	6.40 ± 0.92	0.60 ± 0.05	10.56 ± 0.53	10.88 ± 1.57	5.36 ± 0.09	secondary forest–older palm tree
rubber	7	ferrallitic	clay sandy	1.25 ± 0.04	7.80 ± 0.53	8.60 ± 0.80	0.85 ± 0.08	10.13 ± 0.08	14.62 ± 1.37	6.08 ± 0.06	secondary forest–coffee
rubber	7	ferrallitic	sandy	1.33 ± 0.01	14.36 ± 0.68	7.50 ± 0.05	0.72 ± 0.01	10.35 ± 0.28	12.75 ± 0.09	6.17 ± 0.13	secondary forest–older palm tree
rubber	12	ferrallitic	clay	1.20 ± 0.01	12.16 ± 0.40	7.50 ± 0.05	0.72 ± 0.01	10.35 ± 0.28	12.75 ± 0.09	4.72 ± 0.01	secondary forest–older palm tree
rubber	12	ferrallitic	sandy clay	1.11 ± 0.02	19.47 ± 0.72	16.40 ± 1.55	1.45 ± 0.14	11.32 ± 0.05	27.88 ± 2.65	4.84 ± 0.06	secondary forest
rubber	12	ferrallitic	sandy clay	1.23 ± 0.04	24.93 ± 3.63	10.00 ± 0.69	1.00 ± 0.05	9.98 ± 0.11	17.00 ± 1.17	4.45 ± 0.02	secondary forest–cocoa
rubber	25	ferrallitic	clay	1.29 ± 0.01	13.41 ± 0.01	13.65 ± 2.56	1.10 ± 0.17	12.27 ± 0.41	23.20 ± 4.36	4.51 ± 0.10	secondary forest–older palm tree
rubber	25	ferrallitic	sandy clay	1.32 ± 0.02	12.55 ± 0.34	11.82 ± 1.63	1.05 ± 0.11	11.19 ± 0.32	20.10 ± 2.77	5.24 ± 0.01	secondary forest
rubber	25	ferrallitic	sandy clay	1.06 ± 0.01	34.74 ± 0.95	8.20 ± 0.57	0.75 ± 0.02	10.90 ± 0.35	13.94 ± 0.98	4.66 ± 0.01	secondary forest
secondary forest	100	ferrallitic	sandy clay	1.16 ± 0.06	23.41 ± 2.17	13.75 ± 1.81	1.20 ± 0.05	11.36 ± 0.97	23.37 ± 3.09	4.64 ± 0.17	primary forest
secondary forest	100	ferrallitic	sandy clay	0.82 ± 0.01	36.78 ± 11.10	32.05 ± 6.32	2.80 ± 0.57	11.49 ± 0.11	54.48 ± 10.74	4.30 ± 0.17	primary forest
secondary forest	100	ferrallitic	sandy clay	0.86 ± 0.02	27.17 ± 3.41	22.90 ± 2.25	2.00 ± 0.25	11.54 ± 0.38	38.93 ± 3.82	4.50 ± 0.05	primary forest
Site of La Mé											
oil palm	13	ferrallitic	sandy	1.42 ± 0.02	12.50 ± 0.73	10.05 ± 0.02	1.05 ± 0.02	9.58 ± 0.23	17.08 ± 0.04	5.28 ± 0.15	primary forest–older palm tree
oil palm	13	ferrallitic	sandy	1.00 ± 0.02	9.94 ± 2.21	12.80 ± 1.09	1.70 ± 0.46	8.50 ± 1.86	21.76 ± 1.86	6.60 ± 0.66	primary forest–older palm tree
oil palm	13	ferrallitic	sandy clay	1.16 ± 0.08	10.43 ± 0.96	11.42 ± 0.53	1.37 ± 0.21	8.62 ± 1.00	19.42 ± 0.90	5.94 ± 0.40	primary forest–older palm tree
oil palm	20	ferrallitic	sandy	1.05 ± 0.09	15.73 ± 4.74	17.50 ± 0.02	1.80 ± 0.05	9.74 ± 0.32	29.75 ± 0.04	4.80 ± 0.16	primary forest–older palm tree
oil palm	20	ferrallitic	sandy	1.23 ± 0.09	10.97 ± 0.81	23.90 ± 0.57	0.90 ± 0.05	26.86 ± 2.37	40.63 ± 0.98	5.02 ± 0.12	primary forest–older palm tree
oil palm	20	ferrallitic	sandy clay	0.92 ± 0.07	22.32 ± 1.67	11.10 ± 0.63	1.35 ± 1.57	8.22 ± 0.47	18.87 ± 1.07	4.91 ± 0.02	primary forest–older palm tree
oil palm	39	ferrallitic	sandy clay	1.37 ± 0.05	10.50 ± 0.15	19.55 ± 2.16	0.90 ± 0.05	21.59 ± 1.02	33.23 ± 3.68	4.98 ± 0.05	primary forest–maize–fallow
oil palm	39	ferrallitic	sandy clay	1.15 ± 0.05	7.45 ± 1.16	27.90 ± 3.52	2.10 ± 0.28	13.32 ± 0.15	47.43 ± 5.98	5.57 ± 0.02	primary forest–cassava–fallow
oil palm	39	ferrallitic	sandy clay	0.59 ± 0.09	24.06 ± 7.84	11.20 ± 0.80	1.50 ± 0.17	7.54 ± 0.33	19.04 ± 1.37	5.27 ± 0.01	primary forest
secondary forest	150	ferrallitic	sandy clay	1.00 ± 0.07	13.30 ± 3.17	15.85 ± 1.64	1.45 ± 0.20	11.04 ± 0.41	26.94 ± 2.79	5.43 ± 0.26	primary forest
secondary forest	150	ferrallitic	sandy clay	0.96 ± 0.07	9.87 ± 1.68	23.25 ± 1.58	1.75 ± 0.14	13.31 ± 0.19	39.52 ± 2.69	4.57 ± 0.01	primary forest
secondary forest	150	ferrallitic	sandy clay	0.76 ± 0.02	12.88 ± 1.12	19.55 ± 1.61	1.60 ± 0.17	12.28 ± 0.32	33.23 ± 2.74	5.00 ± 0.13	primary forest

BD bulk density, *WC* water content, *TN* total nitrogen, *SOC* soil organic carbon, *SOM* soil organic matter, *pH-H_2O* potential of hydrogen-water, *C/N* carbon nitrogen ratio

A canonical correspondence analysis (CCA) was made between the soil physico-chemical and biological parameters and the land use types. The Maturity Index *MI* is a sensitive bioindication tool and an integrative measure of environmental impact in forest ecosystems (Ruf, 1998). The *MI* for the Gamasid mites is calculated as the weighted proportion of *K*-selected genera in the whole community (Ruf, 1998). This system is based on ranking Gamasid mite taxa according to their life-history traits on an *r/K* scale, with values ranged from 1 to 4 for *r*-strategy and from 1 to 3 for *K*-strategy. The assignation of *K* or *r* values to families of Gamasida was applied according to the egg-laying rate per day and development rate (Ruf, 1998). The minimum index value of the *MI* is zero (no *K* strategists in the land use type), and the maximum value is 1 (all species are *K* strategists). The less the soil and environment are disturbed, the greater the value of the Maturity Index.

$$MI = \frac{\sum_{i=1}^{s} Ki}{\sum_{i=1}^{s} Ki + \sum_{i=1}^{s} ri}$$

where *S* is the species number, *K* the *K*-value for the family of species *i*, and *r* is the *r*-value for the family of species *i*.

2.5. Statistical analysis

Biological data were normalized if necessary following the formula ln(x+1), after verification of the homogeneity (Batlett test). The effects of land-use types on soil mesostigmatid mites' community were assessed by using a one-way ANOVA associated to post-hoc Tukey's test. This analysis was made both within and between land use types. The same test above was used to evaluate the impact of soil textures on Gamasid mites' abundance and species richness in the site of Grand Lahou, whereas on the site of La Mé, a t-test of Student was applied. All tests were performed by using R software (R Development Core Team, 2008). With the software Statistica 7.1 (StatSoft Inc., Tulsa, USA), the factorial analysis associated to general linear mixed model (GLMM) was used to explore the effects of land use types and study sites on Gamasid mites' community. In order to establish possible relationship between the abundance of Gamasid morphospecies in land use types and their environmental variables, we performed a multivariate direct gradient analysis, specifically a canonical correspondence analysis. The CCA was conducted by using PAST software (Hammer, 2001). Rare morphospecies, occurring in fewer than three samples were omitted because they do not improve the CCA analysis (Skubala and Maslak, 2009). A Monte Carlo permutation test was used to determine statistically whether the Gamasid morphospecies composition was related to soil physico-chemical parameters. Pearson's correlation was applied in the analysis of the relationships between soil physico-chemical descriptors and the abundance of each Gamasid morphospecies included in the CCA analysis. The cumulative species richness was estimated after 500 randomizations by using the software EstimateS 7.5. The first-order jackknife non-parametric estimator was used to determine the expected species richness.

3. Results

3.1. Species composition and community structure

In total, 32 morphospecies were detected through the two study sites. Successively, 11, 15, 8 and 16 species were recorded in the secondary forests of Grand Lahou, rubber plantations, secondary forests of La Mé, and oil palm plantations. The expected species richness (the first-order jackknife) showed that the total species richness could reach 17, 24, 10 and 21 species, respectively, in the secondary forests of Grand Lahou, rubber plantations, secondary forests of La Mé and the oil palm plantations. Thereby, the observed species would represent 63–80% of the expected species.

Three infraorders or cohorts (Gamasina, Uropodina and Antennophorina) were observed in the mesostigmatid mites' community. However, the Antennophorina (Megacelaenopsidae sp.1) characterized by a single individual were not taken into account in the structure analysis.

Unlike the Gamasina, the abundance of Uropodina differed significantly ($F = 9.78$; $p = 0.0003$) within the rubber plantations. Whatever the infraorders, the Gamasid mites' abundance did not vary significantly within the other land use types. Contrary to Gamasina ($F = 2.27$; $p = 0.0899$), the abundance of Uropodina varied significantly ($F = 4.48$; $p = 0.0068$) between the land use types. The higher abundance of Uropodina (3.1 ± 0.70 individuals) was recorded in the secondary forests of Grand Lahou whilst the lower one (0.6 ± 0.14 individuals) was detected in the oil palm plantations (Fig. 2). The data analysis indicated a decrease in the abundance of Uropodina after the conversion of secondary forests into rubber and oil palm plantations. The abundance of Gamasina was poorly represented across the land use types.

Except the Gamasina, the species richness of Uropodina differed significantly (F = 10.41; p = 0.0002) within the rubber plantations. Whatever the infraorders, the Gamasid species richness did not vary significantly within the other land use types. Unlike to Uropodina (F = 0.97; p = 0.4120), the species richness of Gamasina varied significantly (F = 7.93; p = 0.0001) between the land use types. The species richness of Uropodina (2.26 ± 0.40 species) and Gamasina (0.80 ± 0.35 species) were higher, respectively, in the rubber and oil palm plantations. The mean species richness of Uropodina and Gamasina increased after the conversion of secondary forests into rubber and oil palm plantations. Apart from Gamasina, the abundance (GLMM, F = 9.31; p = 0.0001) and species richness (GLMM, F = 10.46; p = 0.0001) of Uropodina were significantly impacted by the land use types (Table 2). The study site modified significantly (GLMM, F = 4.01; p = 0.0474) the abundance of Uropodina. The interaction Site × Lut did not impact significantly the abundance and species richness of both Uropodina and Gamasina.

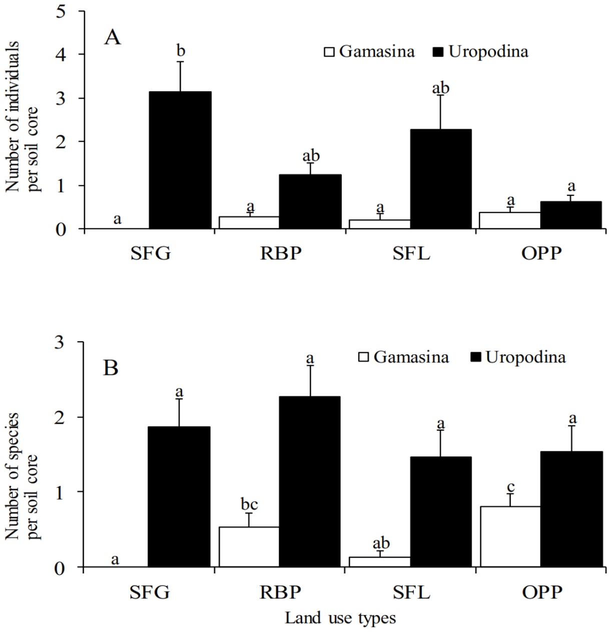

Figure 2. Abundance (A) and species richness (B) of Gamasid mite major groups recorded through the land use types. *SFG* secondary forests of Grand Lahou, *RBP* rubber plantations of 7-25 years, *SFL* secondary forests of La Mé, *OPP* oil palm plantations of 13-39 years. *N* = 120, One-way ANOVA test, *P* < 0.05. Means followed by the same lowercase letter are not significantly different at the 0.05 level (Tukey's HSD test)

Table 2. Anova table of general linear mixed model (GLMM) effects on soil Gamasid major groups abundance and species richness across the site and land use type. F-values and the corresponding *p*-values are displayed

		Abundance		Species richness	
		Gamasina	Uropodina	Gamasina	Uropodina
	df	F	F	F	F
Site	1	0.99	4.01^{*}	1.68	3.89
Lut	3	1.03	9.31^{***}	1.30	10.46^{***}
Site × Lut	3	1.94	1.33	1.80	2.28

* *P* < 0.05, *** *P* < 0.001

After the analysis of the species dominance, four groups were recorded in the 24 stands: 1 dominant specie (*Afrotrachytes* sp.1), 3 subdominant species (*Afrotrachytes* sp.3, Trachyuropodidae sp.1, and Dinychidae sp.2), 4 resident species (Eviphididae sp.1, Eviphididae sp.3, Trachyuropodidae sp.2, and Uropodidae sp.2), and 24 subresident species (Appendix 1). The distribution frequency of Gamasid species indicated three groups: 1 subconstant specie (*Afrotrachytes* sp.1), 7 accessory species (Eviphididae sp.1, Eviphididae sp.3, *Afrotrachytes* sp.3, Trachyuropodidae sp.1, Trachyuropodidae sp.2, Uropodidae sp.2, and Dinychidae sp.2) and 24 accidental species. In other words, the observed species were (i) dominant and subconstant: 1 specie (*Afrotrachytes* sp.1), (ii) subdominant and accessory: 3 species (*Afrotrachytes* sp.3, Trachyuropodidae sp.1, and Dinychidae sp.2), (iii) resident and accessory: 4 species (Eviphididae sp.1, Eviphididae sp.3, Trachyuropodidae sp.2, and Uropodidae sp.2), and (iv) subresident and accidental: 24 species.

3.2. Gamasid mite abundance

The mean density of Gamasid mites varied significantly within the rubber plantations (F = 3.53; p = 0.0380), except the secondary forests of Grand Lahou (F = 0.69; p = 0.5200), secondary forests of La Mé (F = 1.18; p = 0.3400), and the oil palm plantations (F = 1.64; p = 0.2060). The density changed significantly (F = 4.77; p = 0.0049) between the land use types (Fig. 3). The higher density was recorded in the secondary forests of Grand Lahou (2547.2 ± 571.89 ind m^{-2}), whilst the lower one was detected in the oil palm plantations (601 ± 102 ind m^{-2}). The Gamasid mites' density decreased by –49% and –52%, respectively, after the conversion of the secondary forests into rubber and oil palm plantations.

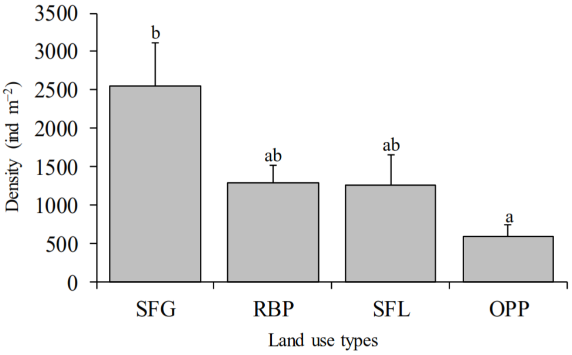

Figure 3. Density (mean and standard error) of Gamasid mites observed among the land use types. *SFG* secondary forests of Grand Lahou, *RBP* rubber plantations of 7-25 years, *SFL* secondary forests of La Mé, *OPP* oil palm plantations of 13-39 years. *N* = 120, One-way ANOVA test, *P* < 0.05. Means followed by the same lowercase letter are not significantly different at the 0.05 level (Tukey's HSD test)

3.3. Diversity indices

The mean species richness of Gamasid mites varied significantly within the rubber plantations (F = 4.52; p = 0.0166), except the secondary forests of Grand Lahou (F = 1.48; p = 0.2650), secondary forests of La Mé (F = 1.27; p = 0.3140) and the oil palm plantations (F = 2.11; p = 0.1340). However, it did not vary significantly (F = 1.37; p > 0.0500) between the land use types (Table 3). The higher species richness was determined in the secondary forests of Grand Lahou (1.93 ± 0.40 species) and La Mé (1.60 ± 0.38 species). It decreased by –41% and –40%, respectively, after the conversion of the secondary forests into rubber and oil palm plantations.

Table 3. Soil Gamasid mites' diversity indices (mean ± standard error) determined across the land use types

Parameters	Land use types				
	SFG	RBP	SFL	OPP	*P* value
Species richness	1.93 ± 0.40^a	1.07 ± 0.19^a	1.60 ± 0.38^a	0.96 ± 0.21^a	0.2600
Shannon Index	0.48 ± 0.15^a	0.29 ± 0.07^a	0.40 ± 0.14^a	0.21 ± 0.07^a	0.5900
Margalef Index	1.77 ± 0.59^a	0.94 ± 0.23^a	1.21 ± 0.55^a	0.54 ± 0.17^a	0.7540
Evenness	0.42 ± 0.12^a	0.29 ± 0.07^a	0.39 ± 0.13^a	0.21 ± 0.06^a	0.4380

SFG secondary forests of Grand Lahou, *RBP* rubber plantations of 7-25 years, *SFL* secondary forests of La Mé, *OPP* oil palm plantations of 13-39 years. *N* = 120, One-way ANOVA test
P > 0.05; Means followed by the same lowercase letter are not significantly different at the 0.05 level (Tukey's HSD test)

In contrast to the secondary forests of Grand Lahou (F = 1.40; p = 0.2840), secondary forests of La Mé (F = 0.84; p = 0.4530) and the oil palm plantations (F = 1.62; p = 0.2100), the Shannon index of Gamasid mites differed significantly (F = 5.23; p = 0.0093) within the rubber plantations, but it did not vary significantly (F =

0.64; p > 0.0500) through the land use types. The secondary forests of Grand Lahou (0.48 ± 0.15) and La Mé (0.40 ± 0.14) were the more diversified stands. However, the Shannon index dropped by –35% and –49%, respectively, after the transformation of the secondary forests into rubber and oil palm plantations. Apart from the secondary forests of Grand Lahou (F = 0.85; p = 0.4510), secondary forests of La Mé (F = 0.80; p = 0.4720), and the oil palm plantations (F = 2.00; p = 0.1480), the Margalef diversity index varied significantly (F = 4.79; p = 0.0134) within the rubber plantations. However, it did not vary significantly (F = 0.40; p > 0.0500) between the land use types. The diversification of the Gamasid mites' community was higher in the secondary forests of Grand Lahou (1.77 ± 0.59) and La Mé (1.21 ± 0.55). The values of the evenness differed significantly (F = 4.70; p = 0.0144) within the rubber plantations, except the other land use types, but it did not change significantly (F = 0.91; p > 0.0500) between the land use types. On the 24 stands, the total number of individuals was distributed less evenly among the species.

3.4. Effect of the site and land use types on the biological parameters

All the biological parameters of Gamasid mites: total density (GLMM, F = 5.80; p = 0.0010), species richness (GLMM, F = 6.19; p = 0.0006), Shannon index (GLMM, F = 4.93; p = 0.0029), Margalef diversity index (GLMM, F = 4.23; p = 0.0070) and evenness (GLMM, F = 5.22; p = 0.0020) were significantly impacted by the land use types (Table 4). The study site changed significantly (GLMM, F = 10.26; p = 0.0017) the total density of Gamasid mites, except the other biological parameters. The interaction Site × Lut did not impact the biological parameters.

Table 4. Anova table of general linear mixed model (GLMM) effects on soil Gamasid mites density and diversity indices across the site and land use type. F-values and the corresponding *p*-values are displayed

		Total density	Species richness	Shannon index	Margalef index	Evenness
	df	F	F	F	F	F
Site	1	10.26**	0.46	0.90	2.35	0.79
Lut	3	5.80***	6.19***	4.93***	4.23**	5.22**
Site × Lut	3	0.81	0.56	0.72	0.26	0.80

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

Table 5. Change in soil biological (mean ± standard error) characteristics along the soil textures of the site of Grand Lahou

Soil biological parameters	Soil textures				
	CS	CL	SC	SA	*P* value
Total density (10^3 ind m^{-2})	1.61 ± 0.39^{ab}	2.62 ± 0.29^{b}	0.79 ± 0.61^{a}	0.31 ± 0.31^{a}	0.0079**
Abundance of Gamasina^1	0.02 ± 0.02^{a}	0.40 ± 0.24^{a}	1.00 ± 0.77^{a}	0.40 ± 0.40^{a}	0.5160
Abundance of Uropodina^1	1.87 ± 0.48^{b}	2.80 ± 0.46^{b}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.0001***
Species richness^2	1.25 ± 0.25^{ab}	2.30 ± 0.43^{b}	0.60 ± 0.40^{a}	0.20 ± 0.20^{a}	0.0025**
Species richness of Gamasina^2	0.02 ± 0.02^{a}	0.30 ± 0.20^{a}	0.60 ± 0.40^{a}	0.20 ± 0.20^{a}	0.4330
Species richness of Uropodina^2	1.17 ± 0.21^{b}	2.00 ± 0.31^{c}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.0001***

CS clayey sandy, *CL* clayey, *SC* sandy clayey, *SA* sandy, *N* = 120, One-way ANOVA test. ^{1} individuals per soil core; ^{2} species per soil core. ** $P < 0.01$, *** $P < 0.001$; different superscript lowercase letters indicate significant variations between the soil textures (Tukey's HSD test)

3.5. Influence of soil texture on biological parameters

The biological parameters, such as the total density (F = 5.61; p < 0.0100), abundance of Uropodina (F = 17.42; p < 0.0010), species richness of Gamasid mites (F = 7.38; p < 0.0100) and Uropodina (F = 25.21; p < 0.0010) varied significantly across the four soil textures detected in the site of Grand Lahou (site 1). The clayey soils (density: 2620 ± 290 ind m^{-2}; species richness: 2.30 ± 0.43 species) and clayey sandy (density:

1610 ± 390 ind m^{-2}; species richness: 1.25 ± 0.25 species) favored the emergence of Gamasid mites (Table 5) as well as the cohort of Uropodina (abundance: 2.80 ± 0.46 individuals; species richness: 2.00 ± 0.31 species). The sandy clayey soils more stimulated the development of Gamasina (abundance: 1.00 ± 0.77 individuals; species richness: 0.60 ± 0.40 species). However, the sandy-textured soils contributed to the degradation of the biological parameters. On the site of La Mé (site 2), only the species richness varied significantly (test t, $p < 0.0500$) through the observed textures (Table 6). Mean values of the biological parameters studied were higher in the soils with clayey sandy texture than the soils with sandy one.

Table 6. Variation in soil biological (mean ± standard error) characteristics across the soil textures of the site of La Mé

Soil biological parameters	Soil textures						
	CS			SA			*P* value
Total density (10^3 ind m^{-2})	0.95	±	0.22^a	0.38	±	0.12^a	0.0575
Abundance of Gamasina[1]	0.37	±	0.15^a	0.25	±	0.07^a	0.4995
Abundance of Uropodina[1]	1.32	±	0.36^a	0.45	±	0.14^a	0.0559
Species richness[2]	1.35	±	0.24^a	0.65	±	0.21^a	0.0668
Species richness of Gamasina[2]	0.25	±	0.08^a	0.20	±	0.05^a	0.6356
Species richness of Uropodina[2]	0.90	±	0.15^b	0.40	±	0.15^a	0.0461^*

CS clayey sandy, *SA* sandy, *N* = 120, t-test of Student. [1] individuals per soil core; [2] species per soil core

[*] $P < 0.05$; different superscript lowercase letters indicate significant variations between the soil textures

3.6. Environmental impact severity assessing

The families used for the assignation of *r* or *K*-values are presented in Table 7. About 11% of the Gamasid species could not be assigned *r* or *K*-values because their families were not classified.

Table 7. *r*- and *K*-values assigned to Gamasid mites

Family	*K −value*	*r −value*
Trachytidae	3	
Ascidae		1
Dinychidae	3	
Eviphididae		4
Pachylaelapidae	1	
Polyaspididae		1
Rhodacaridae	2	
Trachyuropodidae	3	
Uropodidae	3	

The majority of the species were *K* strategists, most of them 3 *K* (Fig. 4). The life history classes 2*r* and 3*r* were not detected in the material. The Maturity Index values (Table 8) were higher in the forest stands (secondary forests of Grand Lahou: 1; secondary forests of La Mé: 0.84) and decreased after their conversion into agricultural systems (rubber plantations: 0.72; oil palm plantations: 0.65). In the other words, the environmental impact severity increased with the plantations establishment in the forest landscapes.

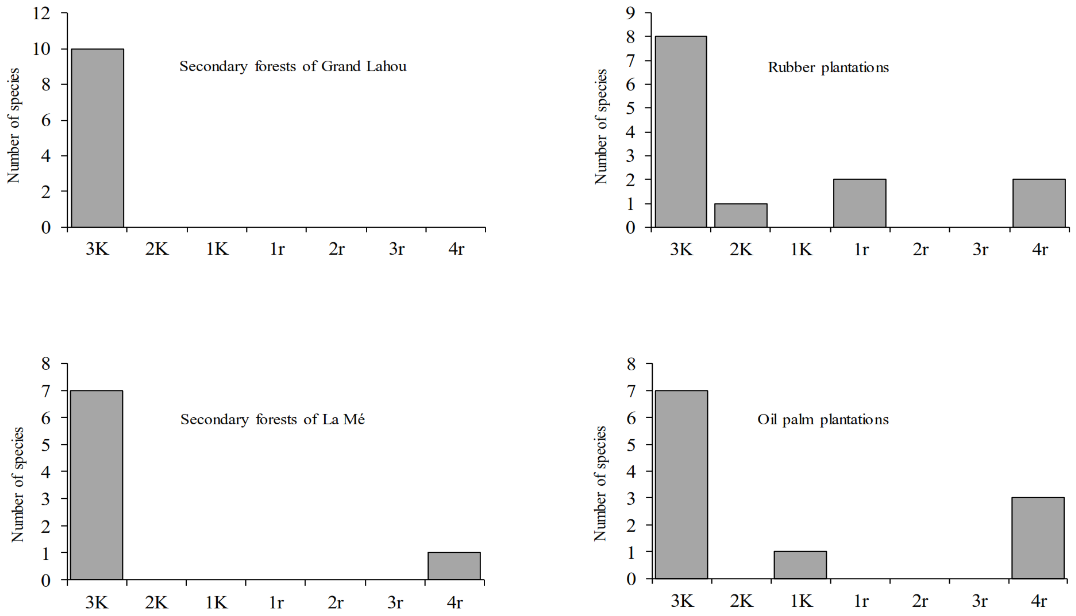

Figure 4. Frequency distribution of life history classes of Gamasid mite species in the land use types. Assignment of *K* or *r* values to families of Gamasid mites was made according to these factors: the egg-laying rate per day, development rate, dispersal ability and stability of populations.

Table 8. Value of the Maturity Index estimated along the land use types

Land use types	Maturity Index
Secondary forests of Grand Lahou	1
Rubber plantations	0.72
Secondary forests of La Mé	0.84
Oil palm plantations	0.65

3.7. Ordination

Canonical correspondence analysis yielded eigenvalues of Axes1 and 2 of $\lambda1 = 0.547$ and $\lambda2 = 0.201$, respectively (Fig. 5). Of the variance, 99% was explained by the first two axes (73% for the first and 26% for the second), so there was little need to consider further axes. The Anderson–Darling test with Monte Carlo p-value showed that the *Afrotrachytes* sp.1 ($F = 0.63$, $p = 0.0298$), *Afrotrachytes* sp.3 ($F = 0.57$, $p = 0.0468$), and Pachylaelapidae sp.1 ($F = 0.82$, $p = 0.0001$) were significantly distributed along Axis 1, whereas the Dinychidae sp.4 ($F = 0.82$, $p = 0.0001$) was significantly distributed along the Axis 2. The Axis 1 shared the rubber and oil palm plantations “monospecific agrosystem”, characterized by a high human disturbance, with the secondary forests of Grand Lahou and La Mé “plurispecific system”, representing the reference system with low disturbance. The Axis 2 shared the site of Grand Lahou (forests converted to rubber plantations) with the site of La Mé (forests converted to oil palm plantations). The emerging patterns of individual species were as follows. Quadrant I contained

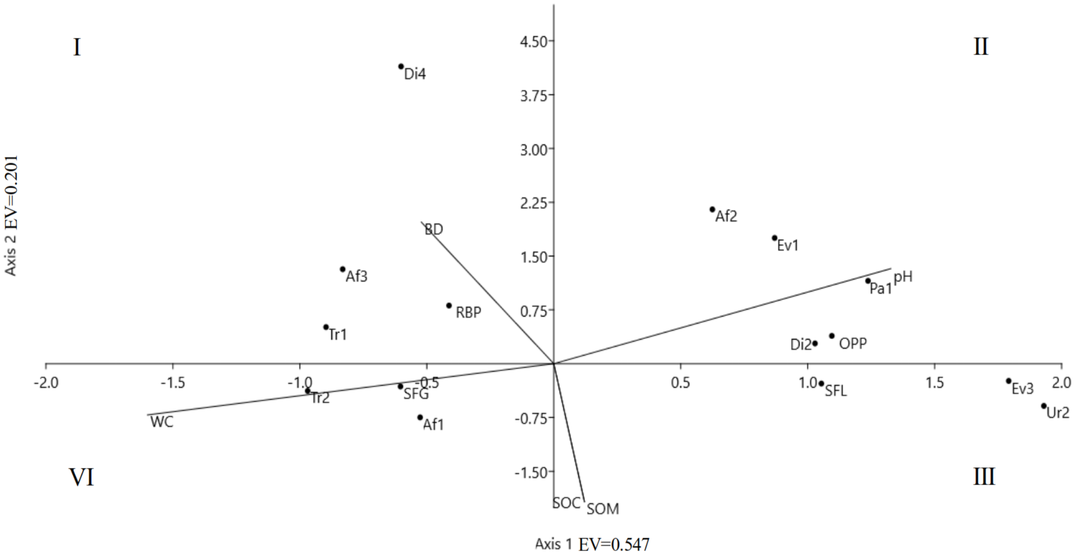

Figure 5. Biplot of CCA result showing an ordination of most Gamasid morphospecies abundances, land use types and soil physico-chemical parameters. *SFG* secondary forests of Grand Lahou, *RBP* rubber plantations of 7-25 years, *SFL* secondary forests of La Mé, *OPP* oil palm plantations of 13-39 years, *Ev1* Eviphididae sp.1, *Ev3* Eviphididae sp.3, *Af1 Afrotrachytes* sp.1, *Af2 Afrotrachytes* sp.2, *Af3 Afrotrachytes* sp.3, *Tr1* Trachyuropodidae sp1, *Tr2* Trachyuropodidae sp.2, *Ur2* Uropodidae sp.2, *Di2* Dinychidae sp.2, *Di4* Dinychidae sp.4, *Pa1* Pachylaelapidae sp.1, *BD* bulk density, *WC* water content, *SOC* soil organic carbon, *SOM* soil organic matter, *pH* potential of hydrogen, *EV* eigenvalues.

abundant individuals of Trachyuropodidae sp.1, *Afrotrachytes* sp.3 and Dinychidae sp.4 associated with the rubber plantations. The soil under the rubber plantations was influenced by the bulk density. Quadrant II contained abundant individuals of *Afrotrachytes* sp.2, Eviphididae sp.1, Pachylaelapidae sp.1 and Dinychidae sp.2 associated with the oil palm plantations. The soil in the oil palm plantations was affected by the pH. Quadrant III contained abundant individuals of Eviphididae sp.3 and Uropodidae sp.2 associated with the secondary forests of La Mé. In this forest, the soil was also affected by the pH. Quadrant IV contained abundant individuals of *Afrotrachytes* sp.1 and Trachyuropodidae sp.2 associated with the secondary forests of Grand Lahou. The soil under these forests was impacted by the water content. Overall, a positive and significant Pearson correlation was recorded between (i) the abundances of Eviphididae sp.1 and *Afrotrachytes* sp.1 ($r = 0.96$, $p = 0.0344$), and Pachylaelapidae sp.1 ($r = 0.96$, $p = 0.0315$), (ii) the abundances of *Afrotrachytes* sp.1 and Trachyuropodidae sp.2 ($r = 0.97$, $p = 0.0275$), and water content ($r = 0.96$, $p = 0.0379$), and (iii) the abundance of Trachyuropodidae sp.2 and water content ($r = 0.99$, $p = 0.0044$). However, a negative and significant correlation was observed between the abundances of *Afrotrachytes* sp.3 and Eviphididae sp.3 ($r = –0.96$, $p = 0.0377$).

4. Discussion

The structure of the mesostigmatid mites' communities are highly influenced by the particular characteristics of each stand (vegetation cover, forest types, soil and plantation types, age, tillage, pesticides and fertilizers application, soil compaction during harvest, and removal of plant biomass) and climatic conditions (Arroyo *et al*., 2013; Călugăr and Ivan, 2013; Díaz-Aguilar *et al*., 2013; Elmoghazy and Shawer, 2013; Manu and Onete, 2013; Sakhidad *et al*., 2016; Călugăr, 2018; Dervash *et al*., 2018; Meehan *et al*., 2018; Heydari *et al*., 2020; Zagatto *et al*., 2020; Pator and Ray, 2021). Several studies are pointed out a decrease of the mesostigmatid mites' abundance, species richness and diversity after forest logging and converting into agricultural land or plantations (Elmoghazy and Shawer, 2013; Dhooria, 2016; Călugăr, 2018; Kamczyc *et al*., 2018; Urbanowski *et al*., 2018). This trend is in line with our results, because a decrease of the mesostigmatid mites' abundance, species richness and diversity was detected following the conversion of secondary forests into rubber and oil palm plantations. The habitat fragmentation such as soil tillage, reduction of vegetation covers and subsequently the changes in microclimate affect negatively the Gamasid mites' community (Elmoghazy and Shawer, 2013). Living trees especially maintain populations of soil mites in forests as their abundance is higher in soil near growing trees (Kamczyc *et al*., 2020). The differences in the mesofauna abundance, diversity and composition should be related to the characteristics of the woody species (Heydari *et al*., 2020). The conversion of forests into rubber and oil palm plantations is clearly viewed as an acute threat to plant diversity, which was also lower in monocultural plantations than in forests (Drescher *et al*., 2016; Singh *et al*., 2021). In fact, the forest had almost six times as many species, especially in vascular plant as the monocultures (Drescher *et al.*, 2016). In forests, Mesostigmata forms 20 % of the total soil mite fauna observed, but it's less abundant in open habitats (Dhooria, 2016). We can find the coexistence of some Gamasid mites in forests due to the heterogeneity of trophical source. Spatial distance between the sites (Meehan *et al*., 2018) and living trees density (Heydari *et al*., 2020) had almost the same explanatory power, as environmental factors. Indeed, the mesostigmatid mites' assemblages became more dissimilar with increasing spatial distance (Meehan *et al*., 2018). The greater diversity of microhabitats and high spatial heterogeneity of the forest in the horizontal dimension (e.g., different branch and canopy abundance, variation of forest light and temperature) and vertical variations in the quantity and quality of leaves and woody texture can create different microclimates beneficial for the mesostigmatid mites (Díaz-Aguilar *et al*., 2013; Heydari *et al*., 2020).

The type of vegetation covers and the resulting litter as well as intensive agriculture affect the mite population densities and diversity in the soil (Elmoghazy and Shawer, 2013). With the decline of plant diversity in monocultural plantations (Drescher *et al.*, 2016), the litter thickness is strongly reduced particularly in oil palm by 84% (Beckendorff, 2016). Kamczyc *et al*. (2018) found a decrease in abundance, species richness and diversity with the reduction of soil organic layer depth in broadleaved forest. Indeed, the OH layer characterized by a partial decomposed organic matter, which represents the main trophic reservoir for gamasid mites is also considered as a "refuge" for species of small dimension on unfavorable environmental conditions (Manu and Ion, 2014). The soil mesofauna with climate, together actively participate in the initial fragmentation (decomposition) of organic matter and cycling of both macro- and micronutrients back into forms that plants can use (Dhooria, 2016; Zagatto *et al*., 2020). However, the activity of mesostigmatid mites is higher beneath trees, where soil pH, water content and organic carbon are higher (Heydari *et al*., 2020). The changes in abundance, diversity and the species richness of mite assemblages within the rubber and oil palm landscapes could be a direct result of changes in environmental conditions (e.g., insulation, rainfall, atmospheric and soil temperature, relative humidity, soil moisture) after the secondary forests transformation (Dervash *et al*., 2018; Meehan *et al*., 2018; Zagatto *et al*., 2020; Pator and Ray, 2021). Previous researches showed that drought decrease microarthropod abundance and species richness and the humidity is the most important factor determining distribution, abundance, and survival (Dervash *et al*., 2018; Zagatto *et al*., 2020).

It is possible that the mesostigmatid mites are indirectly affected by precipitation through the influence of precipitation on prey (Meehan *et al*., 2018). During water stress, there is also a great feeding difficulty because the decomposition of soil organic matter and the metabolic activities become much slower. In this case, the precipitation is likely linked to food availability for mesostigmatid mites (Meehan *et al*., 2018). In the forest and plantation stands, the distribution of Gamasid mites is an aggregate type and their horizontal distribution pattern is probably linked to the distribution of the groups of edaphic fauna which constitute their preferred prey (Călugăr, 2018). Being, in their majority predator species, Mesostigmata communities are influenced initially by the availability of the trophic source (Manu and Onete, 2013). They are very mobile arthropods, capable of migrating to different habitats, favorable to their ecological requirements (Manu *et al*., 2013; Sakhidad *et al*., 2016).

The results from our investigation showed an increase in species richness of Uropodina and Gamasina following the conversion of secondary forests into rubber and oil palm plantations. These observations could be explained by the fact that any disturbance can induce quantitative (abundance) and qualitative (species composition) modifications on soil mite communities. In the early ecological succession (poorly ecosystem), the mite's abundance and diversity can be very high, as their trophical specialization is not so strict, and Gamasina are able to exploit spatially and temporarily restricted habitats (Manu *et al*., 2013). These mites can recolonize various trophic source and habitats due to their high dispersal capacity (Minor and Cianciolo, 2007). Whatever the site, our results showed that the clayey sandy and clayey textures favored the development of the mesostigmatid mites, particularly in the abundance and species richness of Uropodina. However, the sandy clayey textures improved the abundance and species richness of Gamasina. We noticed also that the sandy soils degraded the community structure of Gamasid mites. The most important factor affecting soil N availability is soil texture and clay is assumed to protect organic matter against decomposition (Demessie *et al*., 2013). The low organic matter and the dryness detected in the sandy soil could be perceived as disturbance factors for the mite's dynamics (Honciuc and Manu, 2010). The analysis of the dominance and constancy (frequency) indices revealed, respectively, the absence of eudominants species and euconstants-constants one across the rubber and oil palm landscape. Additionally, the high number of resident-subresident species and accessory-accidental one showed that the unfavorable environmental conditions influence the stability of the mesostigmatid mites (Manu *et al*., 2013). This fact demonstrates the high mobility of these edaphic mites, being capable to looking after food from different microhabitats (Manu and Onete, 2013; Manu *et al*., 2013).

Many studies have documented that the composition of mite communities reflects the gradient of stress in the ecosystems and indicates the status of both biodiversity and natural resources (Ruf, 1998; Coja and Bruckner, 2006; Gulvik, 2007; Manu *et al*., 2021). The Maturity Index estimated in the secondary forests of Grand Lahou (1) and La Mé (0.84) are higher than those from plantations (rubber plantations: 0.72; oil palm plantations: 0.65), indicating a better quality of soil and environment in the secondary forests. Gamasid species with *r* selection (dominated by colonizer species) were more common in the rubber and oil palm plantations (unstable habitats), whereas those with *K* selection were predominant in the secondary forests of Grand Lahou and La Mé (stable habitats) (Coja and Bruckner, 2006). Recent works demonstrated that the conversion of natural forests into monocultural plantations is associated with soil disturbance and changes in vegetation structure, leading to changes in soil properties (Conti, 2015; Vrignon-Brenas *et al*., 2019; Hemati *et al*., 2020; Nguyen *et al*., 2020). These observations were in line with our results as, the CCA biplot showed that the site of La Mé (secondary forests and oil palm plantations) was affected by the pH whilst, in the site of Grand Lahou, the rubber plantations and the secondary forests were respectively impacted by the bulk density and water content. Furthermore, a positive and significant Pearson correlation was detected between the water content and the abundances of *Afrotrachytes* sp.1 ($r = 0.96$, $p = 0.0379$) and Trachyuropodidae sp.2 ($r = 0.99$, $p = 0.0044$). The absence of relation between the mesostigmatid mites' community and soil carbon as well as organic matter could be explained by the fact that being predators, they influence the soil nutrients and probably plant productivity indirectly by influencing the populations of other organisms considered as prey (Gulvik, 2007; Díaz-Aguilar *et al*., 2013; Sakhidad *et al*., 2016).

5. Conclusion

Our findings highlighted a drop of mesostigmatid mites' density (–49% and –52%), species richness (–41% and –40%), and diversity (–35% and –49%), respectively after conversion of the secondary forests into rubber and oil palm plantations. The soil with clayey sandy and clayey textures favored the development of the mesostigmatid mites, particularly in the abundance and species richness of Uropodina. However, the soil with sandy clayey textures improved the abundance and species richness of Gamasina. The mesostigmatid mites' community was degraded in the sandy-textured soils. In light to the Maturity index values, a better quality of soil and environment was detected in the secondary forests compared to plantations. The results also suggest that the mesostigmatid mites' community influence the soil nutrients and probably plant productivity indirectly by influencing the populations of their prey.

6. Conflicts of Interest

The authors have no conflict of interest to declare.

7. Acknowledgments

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Appendix 1. Abundance (secondary forests: individuals per 15 soil cores / plantations: individuals per 45 soil cores) of the species observed among the land use types. Total number of soil cores N = 120. Dominance and frequency were determined at the landscape scale. *SFG* secondary forests of Grand Lahou, *RBP* rubber plantations of 7-25 years, *SFL* secondary forests of La Mé, *OPP* oil palm plantations of 13-39 years

	Land use types				Landscape			
Gamasida	SFG	RBP	SFL	OPP	% of total Gamasida	Dominance	% of occurrence	Frequency
Gamasina								
Eviphididae sp.1	0	5	0	7	5.80	resident	7.50	accessory
Eviphididae sp.2	0	0	0	2	0.97	subresident	0.83	accident
Eviphididae sp.3	0	2	3	7	5.80	resident	6.67	accessory
Laelaptonyssidae sp.1	0	0	0	1	0.48	subresident	0.83	accident
Rhodacaridae sp.1	0	2	0	0	0.97	subresident	0.83	accident
Ascidae sp.1	0	1	0	0	0.48	subresident	0.83	accident
Macrochelidae sp.1	0	2	0	0	0.97	subresident	0.83	accident
Uropodina								
Afrotrachytes sp.1	24	11	9	7	24.64	dominant	23.33	subconstant
Afrotrachytes sp.2	2	1	0	3	2.90	subresident	4.17	accident
Afrotrachytes sp.3	5	11	0	0	7.73	subdominant	8.33	accessory
Trachyuropodidae sp.1	5	11	0	4	9.66	subdominant	12.50	accessory
Trachyuropodidae sp.2	4	7	0	0	5.31	resident	6.67	accessory
Trachyuropodidae sp.4	1	0	0	0	0.48	subresident	0.83	accident
Trachyuropodidae sp.5	1	0	0	0	0.48	subresident	0.83	accident
Uropodidae sp.1	0	0	5	0	2.42	subresident	2.50	accident
Uropodidae sp.2	0	0	9	4	6.28	resident	5.83	accessory

Uropodidae sp.3	1	0	0	0	0.48	subresident	0.83	accident
Uropodidae sp.5	0	0	4	1	2.42	subresident	3.33	accident
Uropodidae sp.6	0	0	1	0	0.48	subresident	0.83	accident
Uropodidae sp.7	0	0	1	0	0.48	subresident	0.83	accident
Dinychidae sp.1	1	0	0	0	0.48	subresident	0.83	accident
Dinychidae sp.2	3	5	5	6	9.18	subdominant	14.17	accessory
Dinychidae sp.4	0	5	0	0	2.42	subresident	4.17	accident
Dinychidae sp.5	0	1	0	0	0.48	subresident	0.83	accident
Evimirus sp.1	0	0	0	1	0.48	subresident	0.83	accident
Pachylaelapidae sp.1	0	0	0	2	0.97	subresident	1.67	accident
Polyaspididae sp.1	0	4	0	0	1.93	subresident	1.67	accident
Antennophorina								
Megacelaenopsidae sp.1	0	1	0	0	0.48	subresident	1.67	accident
Gamasida sp.1	0	0	0	2	0.97	subresident	2.50	accident
Gamasida sp.2	1	0	0	2	1.45	subresident	2.50	accident
Gamasida sp.3	0	0	0	3	1.45	subresident	2.50	accident
Gamasida sp.4	0	0	0	1	0.48	subresident	0.83	accident