Response of soil mite abundance and diversity to a monospecific timber Tectona grandis plantation in Ivory Coast

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Abstract This study aims to assess the impact of monospecific Tectona grandis forest plantation on the soil mite abundance and diversity. To achieve these objectives, two sites situated in Ivory Coast were investigated. The first, a primary forest was characterized by a very weak human activities whereas the second, a teak plantation was characterized by a high disturbance performed during the planting. After extracting, sorted and description, 116 mite species were described in the two sites. Mite densities were lower in teak plantation and also higher in the litter and decreased to the depth in both sites. Species richness recorded in teak plantation (52 species) was significantly lower compared to primary forest (98 species). The same trend was observed for Orbatida but not for Gamasida. The lower Orbatida (5 vs. 17) and higher Orbatida (24 vs. 41) were recorded respectively in teak plantation and primary forest. Mite Shannon index and evenness were significantly different between sites. High Jaccard index values and the appearance of exclusive species in both habitats showed that the sites are very distinct. Total number of species recorded corresponded to 58%–63% of the total number of species estimated by ACE and Chao 1&2 estimators, indicating that the sampling effort was not sufficient. Mite abundance and diversity varied depending on the characteristics of habitats. Chemical element (Corg, Ctot, Ntot, and SOM) values were lower in teak plantation (disturbed habitat) and significantly different to primary forest in the topsoil. Apart from litter height, soil depth, pH and C/N ratio, others variables were strongly correlated to mite abundance and diversity [Current Zoology 59 (5): 633–643, 2013].

Keywords Soil mite, Teak plantation, Diversity and community structure, Disturbance.

Deforestation and soil disturbance are major threats to species diversity in the tropics. According to FAO (2001), the annual deforestation rate in Africa is about twice as high as the global rate (0.7 versus 0.3%). One of the recommendations of the Convention on Biological Diversity is that measures have to be taken in order to conserve natural forests, mainly tropical forests, which are among the diversity species hotspots considered as a global priority for conservation (Sayer and Wegge, 1992; Myers et al., 2000). To cope with this situation, strategies and concepts such as “enrichment planting, forest plantation and rehabilitation of degraded ecosystems” have been developed. In Ivory Coast government officials reacted by creating protected areas such as national parks and the state-controlled “Forêts Classées” (Tondoh et al., 2011) for which teak plantations represent the most common landscape due to its economic value. Around 13 million hectares of forest were converted to other uses, largely agriculture or lost through natural causes each year in the last decade (FAO, 2010) with obvious consequences on soil processes including soil properties and biological diversity.

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modification. Not surprisingly, many problems such as loss of soil nutrients, soil erosion, and land degradation related to the establishment of teak plantations have been reported (Chacko, 1995\(^3\)). Many studies have recorded change in soil physico-chemical properties (Assie et al., 2008; Yao et al., 2010) and soil macroinvertebrates communities (Tondoh et al., 2007; Kra et al., 2010) consecutive to the conversion of degraded area into teak plantations. However, informations about the response of microarthropods, known to be very sensitive to changes in soil (André et al., 1997; Giller et al., 1997), are still lacking. Species richness, abundance, and community composition of arthropods respond to human habitat modification, and these effects were in part reported to be mediated by environmental habitat variables (Noti et al., 2003; Ducarme et al., 2004; Dexter, 2004; Lipiec et al., 2006; Sinclair and Stevens, 2006; Morris et al., 2007; Bokhorst, 2008; Greenwood et al., 2011). Therefore the role of monospecific timber plantations of teak as an alternative solution to the disappearance of natural forests is raising questions. This study aims to assess the monospecific forest plantation system impact on the soil mite abundance and diversity compared to natural forest. We tested the hypothesis that soil mites are sensitive to a change in ecosystem because of (i) their tremendous diversity and (ii) the fact that their niche is mostly located within the organic layer of soils which is therefore subjected to significant variations of soil properties.

1 Materials and Methods

1.1 Study area and sites selection

The study site was located in the Oumé Region, mid-west Ivory Coast, near the village Goulikao (6°31’ N, 5°30’ W) situated within semi-deciduous forest areas. The average annual rainfall over 10 years (1998–2007) was 1448 mm. The annual rainfall in 2008 was 1,592 mm. The average monthly temperature was 26°C. Historical (1965–1975), the mid-West region houses one of the most important primary forest reserves of the country, which is well-suited for coffee and cocoa farming. With time, part of this natural forest was completely degraded, due to overexploitation and so requires rehabilitation. Two sites were investigated. The first, Oumé primary forest is a semi deciduous forest where the influence of human activities is very weak and limited to some tracks. The second, Oumé Tectona grandis plantation was 14-year-old at the year of the study (2008) and characterized by a higher human disturbance activities such as clearing, cutting and associated sampling. Soils were ferrallitic (Yao et al., 2010).

1.2 Sampling method

The sampling design consisted of a monospecific teak plantation and the adjacent primary forest considered as reference system. In each site, a 14-m transect along which 15 sampling points were allocated every 1-m interval was set up. Each point was sampled as follow: litter and mineral soil at regular increment of 5 cm (0–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35 and 35–40 cm). Hence, a total of 540 soil cores were collected with a steel corer (Ø 3.5 cm) over two sampling periods from January to March 2008 and August to October 2008 in order to obtain specimens following the main seasons.

1.3 Mite extraction and identification

Mites were extracted using the Berlese-Tullgren funnels during one week after testing the extraction timing in a preliminary study. All developmental stages were described and considered as adult specimen as the abundance of immature was very low (1.65% of mite) and was supposed not to affect significantly the mite diversity. Individuals were identified at the species level with the help of keys of oribatid genera (Balogh and Balogh, 1992) and details about family (Krantz, 1978; Dindal, 1990; Krantz and Walter, 2009). In the absence of African keys, the hierarchy was maintained at a morphospecies level in most cases.

1.4 Soil variables

In order to relate soil properties with mite communities, soil pH-H\(_2\)O, water content (WC) and bulk density (N’Dri and André, 2011) were measured on soils from the different layer (0–5 cm; 5–10 cm; 10–15 cm; 15–20 cm; 20–25 cm; 25–30 cm; 30–35 cm; 35–40 cm). Other chemical analyses such as organic carbon (C\(_{\text{org}}\)), total carbon (C\(_{\text{tot}}\)), total nitrogen (N\(_{\text{tot}}\)), carbon/nitrogen ratio (C/N) and soil organic matter (SOM) were realized on the upper and bottom layer (0–5 cm and 35–40 cm) in order to assess correlation between these and mite abundance and diversity. The analyses were conducted by the “Centre Provincial de l’Agriculture et de la Ruralité” in La Hulpe (Belgium). The ISO norm 10 694 and 13 878 methods were used to measure Organic and

\(^3\) Chacko KC, 1995. Silvicultural problems in management of teak plantations. Proceedings of the 2nd Regional Seminar on Teak ‘Teak for the Future’ Yangon, Myanmar May 1995 FAO (Bangkok), 91–98.
total Carbon. Soil organic matter (SOM) was estimated using the formula $C_{\text{org}} \times 1.7$ as recommended by Noti et al. (2003). More detail is given by N’Dri and André (2011).

### 1.5 Data analysis

In this study, data from each campaign (sampling period) were pooled and mite abundances, i.e. the number of individuals per sample, were transformed into density (mean individuals per m$^2$). As the distribution did not follow the normality, non parametric (Mann-Whitney) tests were used to compare mite densities in the different soil layers.

Species richness, $s$, Shannon and Wiener (1962) and evenness, Pielou (1969) was measured as the alpha diversity (Whittaker, 1972). These indexes were computed by using the SpeDiv program (André, 1997$^4$).

Furthermore the similarity of mite communities between both sites was estimated through the Jaccard index (Jaccard, 1901) as follows:

$$S_{ij} = \frac{a}{a+b+c}$$

where, $a$ is the number of species common to the two sites, $b$ the number of species found in the first site and $c$, the number of species collected in the second site. The similarity index was calculated from a presence/absence matrix with 116 morphospecies. The same matrix was used to determine common and exclusive species. The dissimilarity (Jaccard distance) between sites was obtained by subtracting the Jaccard index (%) from 100. The comparison of environmental variables was done using a $t$-test and One-Way ANOVA ($P < 0.05$). However the comparison of species richness and diversity indexes from the biological profile (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) was performed by using a $t$-test ($P < 0.05$). All tests were conducted using the software Statistica 7.0 (StatSoft Inc., 1984–2004).

We also used the species rarefaction curves to estimate species richness and abundance across both sites. The rarified species richness observed in the different sites was considered significantly different if the 95% confidence intervals of sample-based rarefaction curves did not overlap (Gotelli and Colwell, 2001). The completeness of the sampling method was assessed by comparing the rarified species richness and the abundance-based coverage estimator (ACE) and Chao 1&2 using EstimateS (Colwell, 2005).

### 2 Results

#### 2.1 Soil variables

Whatever the site, bulk density increased significantly ($P < 0.05$) from the 0-5 to 35–40 cm layers (Table 1). Apart from the different layers 5–10, 10–15 and 20–25 cm, the bulk density differed significantly ($P < 0.05$) between sites. Contrary to bulk density, water contents decreased significantly with layer depth in both sites ($P < 0.05$). Apart from the topsoil (0–5 cm), water contents measured in teak plantation were significantly

| Layers$^1$ | Bulk density$^2$ (g.cm$^{-3}$) | Water content$^3$ (%) | pH–H$_2$O |
|------------|-------------------------------|----------------------|-----------|
| 0–5        | 0.81±0.03 0.52±0.04 0.00001*** | 21.16±1.19 20.32±1.73 0.52000*** | 7.55±0.05 7.50±0.04 0.26230*** |
| 5–10       | 0.92±0.03 0.92±0.04 0.99260*** | 18.26±0.84 14.02±0.70 0.00001*** | 7.51±0.06 7.54±0.04 0.45153*** |
| 10–15      | 0.97±0.04 1.05±0.04 0.07850*** | 16.49±0.84 11.01±0.70 0.00001*** | 7.41±0.06 7.50±0.05 0.10175*** |
| 15–20      | 1.02±0.04 1.13±0.05 0.03500*** | 14.58±1.03 9.42±0.60 0.00001*** | 7.32±0.05 7.39±0.05 0.22113*** |
| 20–25      | 1.13±0.06 1.22±0.07 0.22480*** | 13.07±0.89 8.63±0.43 0.00001*** | 7.31±0.05 7.32±0.05 0.84279*** |
| 25–30      | 1.18±0.08 1.35±0.05 0.04740*** | 13.21±0.78 8.18±0.46 0.00001*** | 7.21±0.05 7.23±0.06 0.72893*** |
| 30–35      | 1.16±0.05 1.41±0.05 0.00001*** | 13.07±0.80 8.47±0.42 0.00001*** | 7.19±0.04 7.18±0.06 0.84728*** |
| 35–40      | 1.20±0.06 1.47±0.05 0.00030*** | 13.06±0.76 9.27±0.37 0.00001*** | 7.19±0.04 7.14±0.05 0.38473*** |
| $P$-values | 0.00001*** 0.00001*** 0.00001*** | 0.00001*** 0.00001*** 0.00001*** | 7.33±0.05 7.35±0.05 0.00001*** |

$^1$: cm, $^2$: g.cm$^{-3}$, $^3$: %, Significant at levels 0.05 (*), 0.002 (**), 0.001 (***) One-Way ANOVA and $t$-test.

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$^4$ André HM, 1997. SpeDiv 3.08, An Interactive Program for the Estimation Of Biological Diversity: Three Input Formats, Eight Indices. Language: VIP-Basic 1.5. Platform: Macintosh exportable to PC (unpublished). Bibliotheque of Computer Programs. UCL, Laboratory of Animal Ecology.
higher ($P < 0.05$) compared to primary forest. Whatever the site, soil pH-H$_2$O values decreased significantly ($P < 0.05$) from the upper layer to the bottom. However soil pH-H$_2$O comparison performed between the same layers from both sites revealed that there was not a significant difference.

Whatever the sites, chemical variables (Organic carbon, total carbon, total nitrogen and soil organic matter) results showed that values were higher in the upper (0–5 cm) layer than in deep soils. However, exceptionally total carbon and total nitrogen values were significantly higher ($P < 0.05$) from the topsoil to the bottom. Chemical values were also lower in teak plantation compared with primary forest (Table 2). Organic carbon ($C_{org}$), total carbon ($C_{tot}$), total nitrogen ($N_{tot}$) and soil organic matter (SOM) from the upper layer (0–5 cm) were significantly higher ($P < 0.05$) in the primary forest relative to teak plantation.

### 2.2 Mite density

The mite density was greater in the litter and decreased with depth (Table 3) irrespective of the site. The global mite density observed in primary forest was significantly higher ($P < 0.05$) compared to teak plantation. The average thickness of the litter was higher in the primary forest ($7.6 \pm 0.55$ cm) relative to the teak plantation ($5.6 \pm 0.38$ cm). The comparison between sites, if we considered the same layers revealed that: (1) for Acari and Oribatida, there was a significant difference ($P < 0.05$) between layers apart from the 30–35 cm (2) there was not a significant difference between layers as to concern Acaridida and Actinedida (3) for Gamasida, there was a significant difference between layers apart from 5–10, 20–25, 30–35 and 35–40. The major taxa density represented respectively (Oribatida 36%, Gamasida 50%, Acaridida 7%, Actinedida 7%) in the teak plantation relative to primary forest (Oribatida 52%, Gamasida 44%, Acaridida 3%, Actinedida 1%). In view of point, the Oribatida and Gamasida were regarded as the two main groups of the community.

### 2.3 Species richness, diversity and community structure

#### 2.3.1 Species richness

A total of 116 mite species were reported in the two sites (see appendix), but not named as indicated by the Code of Zoological Nomenclature because the lack of taxonomic information for African soil mites. 52 species were recorded in teak plantation whereas 98 species were observed in primary forest. Species richness and diversity indexes from the biological profile (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) were hugely different. Species richness recorded in teak plantation was significantly ($P = 0.008$) lower compared to primary forest. Mite species richness in Oribatida were also significantly lower ($P = 0.004$) in teak plantation relative to primary forest but not in Gamasida ($P = 0.06$), where species richness was greater in primary forest compared to teak plantation.

The observed species richness from teak plantation was lower compared to primary forest. Total number of species observed corresponds to approximately 58%–63% of the value predicted by ACE, and Chao 1&2 estimators (Table 4). The rarefaction data was significantly ($P = 0.001$) lower in teak plantation relative to primary forest (Fig. 1). However these rarefaction curves did not reach an asymptote in any case, indicating that the sampling effort was not sufficient to complete the mite species inventories.

#### 2.3.2 Diversity indexes

The Shannon indexes were similar in the two sites as was the evenness if we considered the biological profile (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). Nevertheless, Shannon index ($P = 0.001$) and mite evenness ($P = 0.001$) were significantly lower in teak plantation relative to primary forest (Fig. 1).

### Table 2 Mean and SE values (n=10) of chemical characteristics measured in the two extreme layers (0–5 cm and 35–40 cm) of mineral soils in the sites

|                      | Teak plantation | Primary forest | Inter sites |
|----------------------|-----------------|----------------|------------|
|                      | 0–5 cm | 35–40 cm | 0–5 cm | 35–40 cm | 0–5 cm | 35–40 cm |
| Organic C1           | 16.70±1.13 | 5.44±0.14 | 0.0794*   | 31.70±4.50 | 5.74±0.36 | 0.6145**  |
| Total C2             | 1.70±0.14  | 0.54±0.01 | 0.0017**  | 3.17±0.45  | 0.58±0.04 | 0.0024**  |
| Total N2             | 0.18±0.02  | 0.05±0.01 | 0.0012**  | 0.32±0.05  | 0.05±0.01 | 0.0012**  |
| C/N ratio            | 9.43±0.17  | 12.63±1.15 | 0.0660**  | 9.81±0.28  | 12.27±1.07 | 0.0660**  |
| SOM1                 | 28.39±1.93 | 9.25±0.24 | 0.5896**  | 53.89±7.64 | 9.76±0.61 | 0.3462**  |

1: g.kg$^{-1}$, 2: %, Significant at levels 0.05 (*), 0.002 (**), 0.001 (***), t-test.
Table 3  Major groups of mite density (Mean ±SE, n=15, individuals.m⁻²) measured in litter and mineral soils (0–40 cm)

| Majors taxa | Layers | Teak plantation | Primary forest | U     | P-values |
|-------------|--------|-----------------|----------------|-------|----------|
|             | Litter | 1456±310        | 4368±338       | 26.5  | 0.00040 |
|             | 0–5    | 1213±316        | 4090±640       | 29.0  | 0.00050 |
|             | 5–10   | 243±368         | 1179±353       | 37.0  | 0.05900 |
|             | 10–15  | 104±75          | 728±232        | 38.5  | 0.00210 |
|             | 15–20  | 35±35           | 55±255         | 58.0  | 0.02300 |
| Gamasida    | 20–25  | 69±35           | 381±148        | 66.5  | 0.06500 |
|             | 25–30  | 173±141         | 381±94         | 63.5  | 0.04200 |
|             | 30–35  | 243±56          | 277±112        | 88.5  | 0.31900 |
|             | 35–40  | 104±56          | 347±121        | 79.5  | 0.17100 |
|             | Total  | 3640±536        | 12306±1531     | 17.0  | 0.00007 |
|             | Litter | 104±35          | 69±47          | 105.0 | 0.75500 |
|             | 0–5    | 0±0             | 35±47          | 97.5  | 0.53300 |
|             | 5–10   | 0±0             | 35±35          | 105.0 | 0.75500 |
|             | 10–15  | 0±0             | 104±69         | 105.0 | 0.75500 |
|             | 15–20  | 0±0             | 112±99         | 112.5 | 0.99900 |
| Actinedida  | 20–25  | 104±108         | 0±0            | 97.5  | 0.53300 |
|             | 25–30  | 104±104         | 35±35          | 112.0 | 0.98300 |
|             | 30–35  | 277±316         | 0±0            | 97.5  | 0.53300 |
|             | 35–40  | 0±0             | 35±35          | 105.0 | 0.75500 |
|             | Total  | 589±379         | 312±99         | 103.0 | 0.69300 |
| Oribatida   | 20–25  | 1387±234        | 4749±531       | 14.5  | 0.00005 |
|             | 0–5    | 971±253         | 3432±602       | 28.5  | 0.00040 |
|             | 5–10   | 139±61          | 1005±200       | 34.5  | 0.00120 |
|             | 10–15  | 69±47           | 1109±351       | 31.5  | 0.00070 |
|             | 15–20  | 104±56          | 1179±529       | 42.0  | 0.00340 |
| Acaridida   | 20–25  | 208±178         | 1387±460       | 38.5  | 0.00210 |
|             | 25–30  | 485±431         | 1144±536       | 56.0  | 0.01900 |
|             | 30–35  | 589±419         | 693±195        | 106.0 | 0.78700 |
|             | 35–40  | 104±56          | 659±242        | 57.0  | 0.02100 |
|             | Total  | 7418±1002       | 27419±2988     | 11.0  | 0.00002 |

Significant at levels 0.05 (*), 0.002 (**), 0.001 (**), Mann-Whitney test.

Table 4  Observed and estimated number of species based on ACE and Chao 1&2 estimators (Colwell, 2005) in relation to land-use type, with percentage saturation observed

|              | Observed | Estimated |              |
|--------------|----------|-----------|--------------|
|              | ACE (%)  | Chao1 (%) | Chao2 (%)    |
| Teak plantation | 52a      | 89.85     | 58           |
| Primary forest | 98b      | 155.58    | 63           |

T-test was applied to species richness accumulation. Significant at levels 0.05, when letters are different.

Fig. 1  Sample-based rarefaction curves of species richness from teak plantation and primary forest. 95% confidence intervals not shown

0.016 were significantly different when the sites were compared (Table 5). The Shannon index of the Oribatida group was significantly (P = 0.0006) higher in primary forest. As for the Gamasida group, Shannon index (P = 0.130) and evenness (P = 0.806) were not significantly different when we compare the two sites.

2.3.3  Community structure

The number of species recorded was lower in teak plantation compared to primary forest if we consider total mites, Oribatida and Gamasida. The same trend was observed with the body size. Indeed the lower Oribatida (5 vs. 17) and higher Oribatida (24 vs. 41) were recorded respectively in teak plantation and primary forest. The similarity or Jaccard index calculated within mite communities from the two sites was very weak, respectively 29% for mites and 32% for both Oribatida and Gamasida.

The Jaccard distance or dissimilarity between teak plantation and forest was 71% if we considered the total soil mites. The distance remains similar 68% if we retained the Oribatida and Gamasida. From this analysis, it turned out that the number of exclusive mite species was lower in teak plantation (18) than in primary forest, respectively 18 vs. 64 species. The common species in
both sites were 34 mites, 21 Oribatida and 12 Gamasida. The higher Jaccard distance and exclusive mite species show that the sites are very distinct.

2.4 Correlation between mite communities and environmental variables

Pearson correlations between mite densities and some environmental variables including litter thickness, bulk density, water content, soil pH-H$_2$O, and depth revealed that water content was positively correlated to mite densities, whereas depth was negatively correlated to this one. Bulk density was negatively related to mite density only in the primary forest (Table 6). Furthermore the correlations performed between species richness and all environmental variables showed that C$_{org}$ (g/kg), C$_{tot}$ (%), N$_{tot}$ (%), SOM (g/kg) and water content were positively correlated to species richness (Table 7), whereas bulk density and depth were negatively related to this one. Soil pH-H$_2$O was positively correlated to species richness only in the primary forest.

3 Discussion

3.1 Soil disturbance and variation of mite communities

The scale and intensity of disturbances can, in turn, significantly affect the response of organisms and resulting successional patterns (Egerton-Warburton and Allen, 2000; Greenwood et al., 2011). Certainly creating a monospecific forest plantation on a site originally

| Table 5 | Species richness (S), diversity (H') and evenness (J) for Acari, Oribatida and Gamasida in teak plantation and primary forest |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Species richness | Shannon index | Evenness |
| Teak plantation | Primary forest | Teak plantation | Primary forest | Teak plantation | Primary forest |
| Oribatida | 27 ± 1.90$^a$ | 58 ± 3.91$^b$ | 4.02 ± 0.45$^a$ | 5.05 ± 0.30$^b$ | 0.86 ± 0.16$^a$ | 0.85 ± 0.03$^a$ |
| Gamasida | 20 ± 1.06$^a$ | 29 ± 1.46$^a$ | 2.79 ± 0.31$^a$ | 2.36 ± 0.15$^a$ | 0.64 ± 0.13$^a$ | 0.48 ± 0.04$^a$ |
| Acari | 52 ± 2.91$^a$ | 98 ± 5.52$^b$ | 4.63 ± 0.29$^a$ | 4.91 ± 0.21$^b$ | 0.81 ± 0.02$^a$ | 0.74 ± 0.02$^b$ |

T-test was applied to data from the biological profile. Significant at levels 0.05, when letters are different.

| Table 6 | Pearson correlation between mite density (mean individuals.m$^{-2}$) and environmental variables, respectively in teak plantation and primary forest. |
|-----------------|-----------------|-----------------|-----------------|
| | Teak plantation | | Primary forest |
| N | r | r$^2$ | P | N | r | r$^2$ | P |
| Bulk density | 8 | -0.629 | 0.395 | 0.095** | 8 | -0.922 | 0.851 | 0.0010*** |
| Water content | 8 | 0.738 | 0.545 | 0.036* | 8 | 0.951 | 0.905 | 0.0002*** |
| pH-H$_2$O | 8 | 0.562 | 0.316 | 0.146ns | 8 | 0.602 | 0.363 | 0.1130ns |
| Depth | 9 | -0.71 | 0.504 | 0.032* | 9 | -0.842 | 0.709 | 0.0040** |
| Litter heigth | 15 | 0.152 | 0.023 | 0.586** | 15 | 0.110 | 0.012 | 0.6950** |

Significant at levels 0.05 (*), 0.002 (**), 0.001 (***)

| Table 7 | Pearson correlation between species richness (mean individuals per sample) and environmental variables, respectively in teak plantation and primary forest. |
|-----------------|-----------------|-----------------|-----------------|
| | Teak plantation | | Primary forest |
| n | r | r$^2$ | P | n | r | r$^2$ | P |
| Bulk density | 20 | -0.672 | 0.4520 | 0.0011** | 20 | -0.7130 | 0.508 | 0.00010*** |
| Water content | 20 | 0.611 | 0.3740 | 0.0041** | 20 | 0.7690 | 0.592 | 0.00007*** |
| pH-H$_2$O | 20 | 0.344 | 0.1180 | 0.1360** | 20 | 0.5600 | 0.314 | 0.01000* |
| Depth | 20 | -0.633 | 0.4010 | 0.0026** | 20 | -0.6520 | 0.425 | 0.00180** |
| Organic carbon | 20 | 0.572 | 0.3270 | 0.0083** | 20 | 0.7150 | 0.512 | 0.00030*** |
| Total nitrogen | 20 | 0.574 | 0.3300 | 0.0080** | 20 | 0.6970 | 0.487 | 0.000060*** |
| Total carbon | 20 | 0.593 | 0.3520 | 0.0050** | 20 | 0.7150 | 0.512 | 0.00030*** |
| C/N ratio | 20 | -0.403 | 0.1620 | 0.0770** | 20 | -0.3520 | 0.124 | 0.12700** |
| Soil organic mater | 20 | 0.572 | 0.3270 | 0.0080** | 20 | 0.7150 | 0.512 | 0.00030*** |

Significant at levels 0.05 (*), 0.002 (**), 0.001 (***).
degraded and frequently used for crop production constitutes a microclimate change in the habitat. It necessarily leads to quantitative and qualitative changes in soil organisms.

Certainly the average values of bulk density were similar between sites; however values from the topsoil (0–5 cm) were higher in teak plantation than primary forest. Since bulk density is considered to be the reverse of the porosity, the high bulk density observed in teak plantation (topsoil) indicates indirectly a low porosity and a high compaction (Dexter, 2004). In that context Acari group in which the mean size is so small that individuals can find refuge in soil interstices, and which may not subjected to predation (Franklin et al., 2004) or collect. This approach could explain the weak number of lower and higher Oribatida recorded in teak plantation, even if the lower mobility of mite had been demonstrated by Berthet (1964). Furthermore this observation was supported by the high value of moisture (water content) measured in teak plantation at the same time, relative to primary forest. These results meet observations made by Assié et al. (2008) who reported low (36 KPa) soil resistance of horizontal penetration in the forest compared to higher value (325.1 KPa) in teak plantation from the same study site. In fact the microhabitats and mite community structure modification due to clearing, cutting, damage or agriculture practice could eliminates some species, specifically those with a life cycle longer than one year (Behan-Pelletier 1999). These remarks could explain the low mite density and species recorded in teak plantation, expressing the negative impact of soil disturbance on mite community as has been confirmed by Aritajat et al. (1977). Soils were ferrallitic and classified as sandy-clay under the primary forest and sandy loam beneath teak plantations (Yao et al., 2010). The soil type may be a factor to discriminate the distribution of the mite. In fact, whatever the type of the substratum (natural or artificial) and the type of forest (disturbed or non-disturbed primary forest), the Oribatida species richness varied depending whether the soils were clay or sandy clay (Franklin et al., 2006, 2007). Also, in most case the number of lower Oribatida was inferior compared to higher Oribatida. This observation was so close to our data. Beyond of the disturbance, other biota may affect diversity patterns in the land use type through direct and indirect mechanisms (Eisenhauer, 2010). Among these negative mechanisms, we can cite i.e. loss of organic layers, competition for organic resources, decreased microbial biomass and activity, ingestion/digestion of micro-and mesofauna. Indeed in the same study site, Tondoh et al. (2007, 2011) found out that earthworm abundance and diversity were higher in teak plantations than in primary forest. The presence of earthworms in degraded areas (teak plantation) could be attributed to the persistence of native species (Millsonia omodeoi, Dichogaster terrae-mugrae, Dichogaster baeri) and the availability of soil organic matter fractions (Tondoh et al., 2007). The strong presence of biogenic structures (casts) contributes hugely to compact the topsoil as like observed in teak plantation.

3.2 Soil nutrients availability, sampling effort and variation of mite communities.

All terrestrial ecosystems consist of aboveground and belowground biodiversity that interact to influence the community and the process at different levels (Wardle et al., 2004). The high abundance and diversity of mites in the primary forest could be explained by the heterogeneity of sources of organic residues due to vegetation composed of several timbers. Attignon et al. (2004) emphasize a more rapid breakdown of the litter in natural forest than in teak plantation. The thinner litter layer observed in the teak plantation as compared to the natural forest could be explained by lower input of litter, higher decomposition rate of litter, mixing of litter into the soil profile by earthworms (Eisenhauer, 2010) and human disturbance. According to Dinakaran and Krishnayya (2010), the dry weight loss of teak litter takes a long time and varies with soil depth. Nevertheless, the decomposition was faster in bags kept at the topsoil than in deep soils. These remarks were in accordance with our result. Indeed the C$_{org}$, C$_{abs}$, N$_{lua}$, C/N and SOM were greater in Oumé forest than in teak plantations (see Table 2), and whatever the land-use, the nutrients were higher in the topsoil than in the bottom, which were similar to data from Yao et al. (2010) and Assié et al. (2008) in the same area. In Contrast to primary forest, the lower mite abundance and species richness observed in teak plantation accords with the results of Badejo and Ola-Adams (2000), if we consider the Oribatida densities and species richness from the topsoil. Furthermore, an analysis of samples rarefaction curves indicated that if the number of samples exceeded 270, more species would probably be discovered there. This would, however, also require a much higher effort for sorting and identification. In general, sample-based rarefaction, by design, preserves the spatial structure of the data, which may reflect processes such as spatial aggregation or segregation both within and between species (Gotelli and Colwell, 2010). On the other hand, the probability
of drawing a new species will depend both on the complete number of species in the assemblage and their relative abundances (Gotelli and Colwell, 2010). The more species in the assemblage and the more even the species abundance distribution, the more rapidly this curve will rise, as like curve from primary forest. In contrast, sample-based rarefaction curve from teak plantation arise more slowly, because the species abundance distribution is highly uneven. Hence, as said by Gotelli and Colwell (2010) most of the individuals sampled will represent more common species that have already been added to the sample rather than rarer ones that have yet to be detected.

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Appendix: List of the mite with abundance (total from all samples) recorded in the sites, respectively in the litter \((n=15)\) and mineral soils \((n=120)\)

| Species               | Teak plantation | Primary forest |
|-----------------------|-----------------|----------------|
|                       | Litter 0–40 cm  | Total          | Litter 0–40 cm | Total |
| **Actinedida**        |                 |                |               |       |
| Actinedide sp1        | 0               | 0              | 0             | 1     |
| Actinedide sp8        | 0               | 14             | 0             | 1     |
| Actinedides sp12      | 0               | 0              | 0             | 1     |
| Eupodidae sp1         | 0               | 0              | 1             | 2     |
| Erythraeidae sp1      | 0               | 0              | 0             | 1     |
| Trombicalidae (Larvae)|                 |                |               |       |
| Bdellidiae sp.1       | 0               | 5              | 0             | 0     |
| Camerobia sp1         | 0               | 0              | 0             | 1     |
| Canaxidae sp1         | 0               | 1              | 0             | 0     |
| Anystidae sp1         | 0               | 0              | 1             | 0     |
| **Gamasida**          |                 |                |               |       |
| Evimirus uropodinus   | 0               | 3              | 0             | 0     |
| Fuscuropoda sp1       | 0               | 0              | 2             | 1     |
| Holocelaeno sp1       | 0               | 0              | 1             | 3     |
| Hypoaspis sp1         | 0               | 1              | 0             | 1     |
| Hypoaspis sp2         | 0               | 1              | 0             | 1     |
| Ololaelaps sp1        | 0               | 0              | 0             | 1     |
### Continuation of Appendix

| Species                        | Teak plantation | Primary forest |
|-------------------------------|-----------------|----------------|
|                               | Litter 0-40 cm  | Total          | Litter 0-40 cm  | Total          |
| **Microgynium sp2**           | 0 0            | 0 1            | 0               | 1              |
| **Pachylaelaps sp1**          | 0 0            | 0 1            | 0               | 1              |
| **Pachylaelaps sp2**          | 0 1            | 1 1            | 0               | 1              |
| **Rhodacaridae sp1**          | 1 5            | 6 0            | 0               | 0              |
| **Rhodacaridae sp3**          | 0 0            | 0 1            | 0               | 1              |
| **Rhodacaridae sp5**          | 1 1            | 2 0            | 0               | 0              |
| **Rhodacaridae sp6**          | 0 0            | 0 2            | 0               | 2              |
| **Trachyuropodide sp1**       | 0 2            | 2 1            | 1               | 3              |
| **Trachyuropodide sp2**       | 0 0            | 0 12           | 12              | 26             |
| **Trachyuropodide sp3**       | 1 2            | 3 1            | 1               | 16             |
| **Trichourpodida sp1**        | 1 0            | 1 0            | 0               | 0              |
| **Urodiaspis sp1**            | 1 2            | 3 1            | 1               | 3              |
| **Uropodide sp2**             | 6 4            | 10 8           | 8               | 11             |
| **Uropodide sp3**             | 0 1            | 1 9            | 9               | 13             |
| **Uropodide sp4**             | 0 0            | 0 2            | 0               | 2              |
| **Afrotachytes sp1**          | 23 28          | 51 82          | 82              | 142            |
| **Afrotachytes (larvae)**     | 0 0            | 0 4            | 4               | 5              |
| **Ameroseiidae sp1**          | 0 1            | 1 0            | 0               | 0              |
| **Halarachnidae sp1**         | 1 0            | 1 0            | 0               | 3              |
| **Gamaside sp1**              | 0 1            | 1 0            | 0               | 0              |
| **Gamaside sp2**              | 0 1            | 1 1            | 1               | 0              |
| **Gamaside sp3**              | 7 2            | 9 0            | 1               | 0              |
| **Gamaside sp4**              | 0 1            | 1 0            | 0               | 0              |
| **Gamaside sp5**              | 0 0            | 0 0            | 0               | 1              |
| **Gamaside sp6**              | 0 0            | 0 0            | 0               | 1              |
| **Gamaside sp8**              | 0 1            | 1 0            | 0               | 0              |
| **Gamaside sp11**             | 0 0            | 0 0            | 0               | 2              |
| **Gamaside sp14**             | 0 0            | 0 0            | 0               | 1              |
| **Gamaside sp16**             | 0 0            | 0 0            | 0               | 1              |
| **Gamaside sp18**             | 0 0            | 0 3            | 3               | 0              |
| **Gamaside sp19**             | 0 0            | 0 1            | 0               | 1              |
| **Oribatida**                 |                |                |                 |                |
| **Belbidae sp1**              | 0 1            | 1 1            | 1               | 3              |
| **Belbidae sp2**              | 1 0            | 1 2            | 2               | 4              |
| **Lamellibates sp1**          | 0 1            | 1 4            | 4               | 14             |
| **Lamellibates sp2**          | 0 3            | 3 0            | 0               | 1              |
| **Malaconomithrus sp1**       | 1 1            | 2 0            | 0               | 0              |
| **Malaconomithrus sp2**       | 1 0            | 1 1            | 1               | 0              |
| **Paralopheremaeus sp1**      | 0 0            | 0 1            | 1               | 2              |
| **Paralopheremaeus sp2**      | 4 3            | 7 0            | 0               | 0              |
| **Oribatulidae sp1**          | 1 7            | 8 17           | 17              | 18             |
| **Oribatulidae sp2**          | 2 0            | 2 2            | 2               | 5              |
| **Oribatulidae (Larvae)**     | 0 0            | 0 0            | 0               | 1              |
| **Oribatulidae (Protonymph)** | 0 1            | 1 0            | 0               | 0              |
| **Sphaerochtonius sp1**       | 0 0            | 0 1            | 1               | 0              |
| **Malacoangelia sp1**         | 0 0            | 0 1            | 1               | 5              |
| **Sabahtritia sp1**           | 0 0            | 0 2            | 2               | 6              |
| **Mesoplophora sp1**          | 0 1            | 1 3            | 3               | 15             |
| **Dolichermesia sp1**         | 0 0            | 0 4            | 4               | 7              |
| **Lohmannitidae sp2**         | 0 0            | 0 1            | 1               | 2              |
### Continued Appendix

| Species                  | Litter 0–40 cm | Primary forest 0–40 cm | Total 0–40 cm | Litter Total | Primary forest Total | Total Total |
|-------------------------|---------------|------------------------|---------------|--------------|----------------------|------------|
| **Lohmanniidae sp3**    | 0             | 0                      | 0             | 1            | 1                    | 2          |
| **Epilohmannia sp1**    | 3             | 7                      | 10            | 5            | 7                    | 12         |
| **Lohmannia sp1**       | 0             | 0                      | 0             | 1            | 1                    | 2          |
| **Lohmannia sp2**       | 0             | 0                      | 0             | 1            | 3                    | 4          |
| **Euphthiracarus sp1**  | 0             | 0                      | 0             | 1            | 0                    | 1          |
| **Euphthiracarus sp2**  | 1             | 0                      | 1             | 4            | 2                    | 6          |
| **Phthiracarus sp3**    | 0             | 0                      | 0             | 2            | 3                    | 5          |
| **Australcarus sp1**    | 0             | 0                      | 0             | 0            | 1                    | 1          |
| **Meristacarus sp1**    | 6             | 5                      | 11            | 12           | 14                   | 26         |
| **Mixacarus sp1**       | 0             | 0                      | 0             | 4            | 5                    | 9          |
| **Rhysotritia duplicata** | 5           | 2                      | 7             | 0            | 5                    | 5          |
| **Oppia sp1**           | 0             | 0                      | 0             | 1            | 5                    | 6          |
| **Brachychnthionius sp1** | 0         | 0                      | 0             | 1            | 0                    | 1          |
| **Galumellidae sp1**    | 0             | 0                      | 0             | 0            | 2                    | 2          |
| **Galumna sp4**         | 0             | 0                      | 0             | 7            | 7                    | 14         |
| **Galumna sp5**         | 0             | 0                      | 0             | 1            | 23                   | 24         |
| **Galumna sp6**         | 0             | 0                      | 0             | 8            | 0                    | 8          |
| **Galumna sp9**         | 2             | 0                      | 2             | 0            | 1                    | 1          |
| **Galumna sp10**        | 0             | 0                      | 0             | 7            | 15                   | 22         |
| **Galumna sp11**        | 2             | 0                      | 2             | 1            | 0                    | 1          |
| **Ceratozetidae sp1**   | 1             | 0                      | 1             | 0            | 0                    | 0          |
| **Damaeidae sp1**       | 0             | 0                      | 0             | 1            | 2                    | 3          |
| **Damaeidae sp3**       | 0             | 0                      | 0             | 1            | 0                    | 1          |
| **Mycobatidae sp1**     | 0             | 0                      | 0             | 0            | 1                    | 1          |
| **Oribate sp1**         | 4             | 4                      | 8             | 1            | 6                    | 7          |
| **Oribate sp9**         | 2             | 0                      | 2             | 16           | 5                    | 21         |
| **Oribate sp10**        | 0             | 1                      | 1             | 0            | 0                    | 0          |
| **Oribate sp15**        | 0             | 0                      | 0             | 0            | 2                    | 2          |
| **Oribate sp21**        | 0             | 1                      | 1             | 0            | 2                    | 2          |
| **Oribate sp24**        | 0             | 0                      | 0             | 1            | 0                    | 1          |
| **Oribate sp25**        | 0             | 0                      | 0             | 2            | 1                    | 3          |
| **Oribate sp26**        | 1             | 0                      | 1             | 3            | 16                   | 19         |
| **Oribate sp29**        | 0             | 0                      | 0             | 0            | 1                    | 1          |
| **Oribate sp30**        | 0             | 3                      | 3             | 0            | 3                    | 3          |
| **Oribate sp31**        | 0             | 0                      | 0             | 1            | 0                    | 1          |
| **Oribate sp32**        | 0             | 0                      | 0             | 0            | 1                    | 1          |
| **Oribate sp35**        | 0             | 0                      | 0             | 2            | 1                    | 3          |
| **Oribate sp36**        | 0             | 0                      | 0             | 1            | 0                    | 1          |
| **Oribate sp38**        | 0             | 0                      | 0             | 1            | 0                    | 1          |
| **Oribate sp41**        | 1             | 0                      | 1             | 5            | 5                    | 10         |
| **Oribate sp42**        | 0             | 0                      | 0             | 0            | 1                    | 1          |
| **Oribate sp43**        | 0             | 0                      | 0             | 0            | 1                    | 1          |
| **Oribate sp45**        | 4             | 0                      | 4             | 2            | 0                    | 2          |
| **Oribate sp53**        | 1             | 0                      | 1             | 0            | 0                    | 0          |
| **Oribate sp54**        | 0             | 0                      | 0             | 2            | 3                    | 5          |
| **Oribate sp59**        | 0             | 0                      | 0             | 0            | 1                    | 1          |
| **Endeostigmata sp1**   | 0             | 0                      | 0             | 0            | 1                    | 1          |

**Acaridida**

- **Rhysoglyphus sp1**    | 2             | 5                      | 7             | 0            | 0                    | 0          |
- **Rhysoglyphus sp2**    | 0             | 8                      | 8             | 0            | 0                    | 0          |
- **Rhysoglyphus sp3**    | 0             | 0                      | 0             | 9            | 19                   | 28         |
- **Acaridae sp4**        | 0             | 0                      | 0             | 0            | 25                   | 25         |