# LAND USE AT ST. MARTA RANGE, LOS TUXTLAS, VERACRUZ, MEXICO – HOW DOES IT AFFECT THE COLLEMBOLA COMMUNITY?

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**Abstract.** The abundance of Collembola families were studied in three localities with four different land-use types: forest, agroforestry, grassland and corn crop, all located in the Santa Marta Range, Los Tuxtlas Biosphere Reserve, Veracruz, Mexico. Samples of litter and soil were collected in each land use during the dry season, February and March 2005, and processed by Berlese-Tullgren funnels. In addition, physical and chemical parameters of soil were measured. A nested MANOVA was applied to evaluate land-use and site effect on edaphic parameters, and a nested ANOVA was used to evaluate their effect on the Collembola abundance. In addition to this, a Cluster Analysis (CA) and Canonical Correspondence Analysis (CCA) were used. Besides, Shannon diversity index was calculated. A total of 1,088 collembolans from seven families were gathered, with the most abundant being Isotomidae, Entomobryidae and Hypogastruridae. The nested MANOVA and ANOVA revealed significant effect of the site and land-use on the soil parameters and Collembola abundance, respectively. CA formed two main groups based mainly on sites and biotopes. The CCA, showed that abundance of Onychiuridae and Odontellidae are related with altitude, Na and Cation Exchange Capacity (CEC). Diversity was higher in forest than in corn crop and grassland. The corn crop showed a higher incidence of Isotomidae and Entomobryidae than the other sites. Thus, the changes in the Collembola community at family level can be useful to recognize the quality of soil in different land uses.
**Keywords:** *bioindicators, canonical correspondence analysis, Entomobryidae, Hypogastruridae, Isotomidae*

## Introduction

Land-use change is the main factor determining patterns of biodiversity of soil organisms (Bengtsson, 2002; Martins da Silva et al., 2015). Thus, the need to highlight the fact that disturbances caused by human land-use practices can affect biodiversity positively or negatively, usually having a loss of species (Bengtsson et al., 2000; Cuchta et al., 2012) is important to land management. Understanding the impact that changes in land-use practices has on the environment biodiversity is essential for the implementation of effective measures to preserve biodiversity in human-disturbed landscapes (Niemelä, 2000; Gisladottir and Stocking, 2005; Wu and Cho, 2007). Therefore, since Collembola is highly sensitive to changes in soil conditions, they have been used as bioindicators to follow the evolution of several types of edaphic systems


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(Fiera, 2009; Muturi, 2009; Paul et al., 2011; Ponge et al., 2003; Sousa et al., 2004, 2006). Some species, as *Mesaphorura krausbaueri*, have also been proposed as possible indicators of soil fertility; they have been considered pioneer in secondary succession on cultivated soil (Dunger, 1986). Other species, such as *Protaphorura armata*, have been considered in the study of the effects that pollution from human activities have on biological and ecological processes such as reproduction, mortality and population growth (Bengtsson et al., 1983, 1985a, b). Furthermore, the important role that Collembola play in the edaphic process makes them a useful tool in identifying the modification and quality of the soil ecosystems (Rusek, 1998; Culliney, 2013). They can be used at a species and even at a family levels, as has been shown in studies of the subtropical forest floor in Manipur, India (Waikhom et al., 2006) and those carried out in areas with *Araucaria* forest in Brazil (Baretta et al., 2008) have demonstrated. It has been shown that data sets built at the family systematic rank can also detect the effects of disturbance with little loss of information and can be a preliminary tool for describing patterns and successions in human-disturbed soil ecosystems (Caruso and Migliorini, 2006).

Veracruz State is recognized for its high biodiversity, and high rate of endemism as well as its contribution to global diversity, and the ongoing conservation of the tropical forest. The State takes the first place in the species richness of many groups, including Collembola (Palacios-Vargas et al., 2000, 2004). Nevertheless, as most of the State is in the tropics, its territory is experiencing severe and rapid change in land-use, increasing the alarm at the deforestation rate and original vegetation loss (Phillips, 1997; Dalrymple, 2006).

The deforestation of tropical rain forest at Los Tuxtlas region has been particularly high in the last five decades, mainly due to the conversion of forest land in pastures and corn fields, that is the dominant land use at this region (Flint et al., 2000). Adding, the region was transformed severely to gain cattle pastures and only about 21% of the original forest vegetation remains unspoiled (Gutiérrez-García and Ricker, 2011).

The change in use modifies the biogeochemical cycles of the soil at local, regional and global scales, and also produces important effects in the diversity and role of soil organisms. Many studies on this subject have been developed in the tropics (Lemessa et al., 2015; Smith et al., 2015; Peña-Peña and Irmler, 2016). Although Collembola is one of the major components of the soil biota, the evaluation of human activities' effect on Collembola assemblages has not been reviewed recently in Mexico (Lavèlle et al., 1981; Palacios-Vargas, 1985; Villalobos, 1989, 1990; Miranda and Palacios-Vargas, 1992; Mendoza, 1995; Mendoza et al., 1999). Palacios-Vargas and Castaño-Meneses (2014) compiled recently the information about importance of Collembola as bioindicators in different environments. There are evidences that Collembola richness and abundance show modifications in agroecosystems according to the quality of irrigation, moreover some edaphic parameters, such as pH, organic matter and exchangeable cations are altered as well (Cutz-Pool et al., 2007).

The main purpose of this study is to evaluate the effects of four land-use types: corn crop, grassland, agroforestry and forest on the Collembola family abundance patterns in three sites. Besides, this article will explore the relationships of these organisms to some soil variables. We hypothesize that agricultural and livestock practices produce negative effects on the Collembola diversity and abundance, and changes in the composition and dominance of Collembola families, suggest that some families can be as indicators of


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land use and agricultural practices, and can be a useful tool in management and conservation programs.

## Materials and methods

### *Study site*

The St. Marta Range (SMR), is located at the East of Veracruz (extreme coordinates: 18° 15´ 18´´ N; 94° 40´ 95´´ W) in Los Tuxtlas Biosphere Reserve (*Fig. 1*), Mexico. SMR comprises 20,000 hs in the Soteapan and Mecayapan municipalities. The highest peaks are the volcanoes Santa Marta (1720 m), San Martín Tuxtla (1680 m), and San Martín Pajapan (1180 m) (Ramírez, 1999). The climate of Los Tuxtlas region is tropical, hot and humid in the lowlands (below 300 m) and medium altitudes (300-700 m). It turns semi-warm at higher elevation (700-1700 m). The rainfall is abundant in the area, close to 5,000 mm in the lowlands though this could increase in elevated places. Overall annual average temperature can reach 26 °C falling to 18 °C (Soto and Gama, 1997). Among the most important types of vegetation are high evergreen tropical forest, medium evergreen tropical forest, cloud forest, pine forest, oak forest and savanna (Castillo-Campos and Laborde, 2004). Unfortunately, the region of Los Tuxtlas has been deforested severely, mainly to gain cattle pastures, and only about 21% of the original forest vegetation remains unspoiled (Gutiérrez-García and Ricker, 2011).

### *Sample collection*

Sampling of fauna was carried out in February and March 2005 during the dry season (which runs from January to April in the area). Three sites with different altitude and vegetal cover percentages were sampled: San Fernando (SF; range 740-1145 m asl; 50% vegetal cover), López Mateos (LM; 191-357 m asl; 75% vegetal cover) and Venustiano Carranza (VC; 160-380 m asl; 25% vegetal cover) on the slopes of the Santa Marta Volcano in the biosphere reserve of Los Tuxtlas. In each site, we sampled four land-use types: forest (Fr), agroforestry (Ag), grassland (Gr) and corn crop (Cc). Sampling methodology and extraction of soil fauna followed that recommended by Franklin and Morais (2008). We chose 5 points in each land-use at random. Beside, we sampled litter (Li) and soil at 0-5 cm (So1) and 5-10 cm (So2) being 15 samples a total: 5 of Li, 5 of So1 and 5 of So2 for each site/land-use. Samples were taken in the same core: first, we removed the litter then we took the first 5 cm, and finally the following 5 cm. In this way, the total of samples per site was 60, being 180 the sample total in all three sites. For sampling, a metal cylinder was used: 5 cm diameter and 5 cm height. Samples of Li, So1 and So2 were taken in a vertical profile fashion in each point.

Fauna extraction was by Berlese funnels with electric light bulb 40 W/funnel for five days. All fauna was first fixed in formalin 5% and then was preserved in 70% alcohol.

In addition to faunal sampling, soil samples were analyzed to obtain some soil parameters; pH was measured in a solution of $CaCl_2$ extract (1:2.5); moisture percentage; particle-size distribution (clay, sand and silt) was determined by hydrometer method (Bouyoucos, 1962); $Mg^+$ and $Ca^+$ were extracted by 1 M ammonium acetate pH7 and quantified by EDTA, whereas $Na^+$ and $K^+$ were evaluated using a flame photometer (Page et al., 1982); also Cationic Exchange Capacity (CEC) and porosity were recorded.


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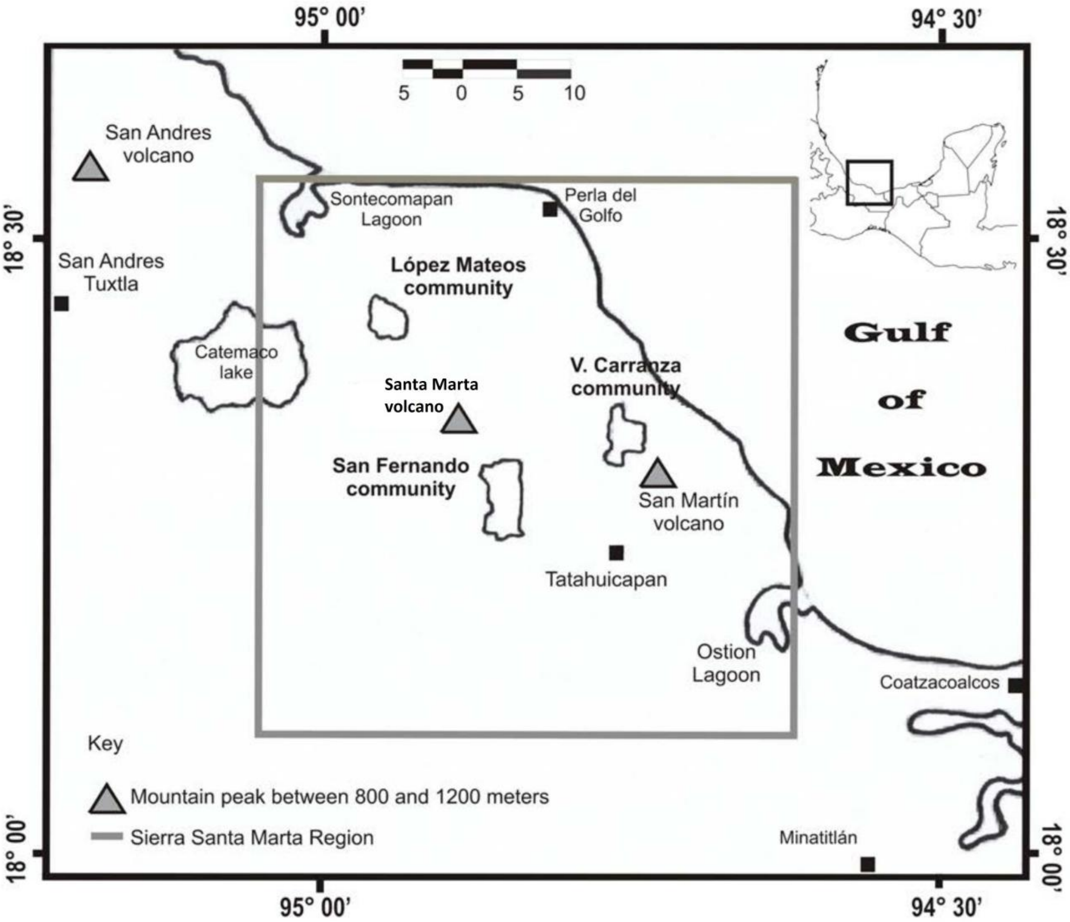


***Figure 1.*** *Location of the three study sites, López Mateos, San Fernando and Venustiano Carranza in St. Marta Range (grey frame), in Los Tuxtlas Biosphere Reserve*

### *Statistical analysis*

A nested multiple analysis of variance (MANOVA) was applied with two hierarchized level, land-use nested within sites, and sites, to evaluate the effect of these factors on all the physical and chemical soil variables. A nested analysis of variance (ANOVA) with three hierarchized levels, depth strata nested within land-uses; land-use nested within sites, and sites, to evaluate their effect on the Collembola abundance transformed as $\log_{10}(x + 1)$ to meet homoscedasticity and normality (Zar, 1999). A post hoc multiple comparisons with Bonferroni paired test (Zar, 1999) was performed when significant effects were found. Statistical analyses were performed using Statistica 6.0 (StatSoft, 2006). A Cluster analysis (CA) on a Bray-Curtis similarity matrix and using the unweighted pair-group average (UPGMA) amalgamation rule was performed on all data including site, land-use type and biotope: litter and soil at two depth levels in order to explore the faunal relationships. The analysis were made using PC-ORD v. 5.0. A Canonical Correspondence Analysis (CCA) was used to explore the influence of soil variables on faunal composition by using CANOCO 4.5 (Ter Braak and Smilauer, 1998). A Montecarlo test with 500 permutations was used to evaluate the significance of axes. Also Shannon diversity index (*H*) was calculated using the abundance of family level of taxa.


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## Results

Nested MANOVA showed significant effect of site ($\lambda$ = 0.04, $F_{18, 164}$ = 37.13, $p < 0.01$) and land use nested in site ($\lambda$ = 0.11, $F_{81,538.9}$ = 2.66, $p < 0.01$) on physical and chemical soil parameters. Means and 95% confidence intervals (CI) for all variables are shown in *Table 1*.

***Table 1.*** *Means and 95% confidence intervals for all the physical and chemical soil variables. Moisture to porosity in %, pH to CEC in cmol/Kg$^{-1}$*

| | Moisture | Clay | Sand | Silt | Porosity | pH | Na | K | Mg | Ca | CEC | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LM | 44.09 | 20.06 | 57.59 | 22.34 | 74.92 | 5.21 | 0.47 | 0.99 | 3.61 | 8.62 | 13.68 | 32 |
| ±95 | ±2.02 | ±3.21 | ±3.90 | ±2.19 | ±1.85 | ±0.08 | ±0.08 | ±0.20 | ±0.72 | ±1.49 | ±2.26 | |
| SF | 67.35 | 47.82 | 30.16 | 22.01 | 69.35 | 5.05 | 0.15 | 0.54 | 3.04 | 9.18 | 12.91 | 37 |
| ±95 | ±5.77 | ±5.73 | ±3.31 | ±4.16 | ±3.26 | ±0.16 | ±0.02 | ±0.11 | ±0.50 | ±1.73 | ±2.08 | |
| VC | 38.27 | 55.21 | 25.09 | 19.70 | 68.32 | 4.63 | 0.12 | 0.31 | 1.78 | 4.35 | 6.55 | 33 |
| ±95 | ±4.43 | ±3.47 | ±1.93 | ±3.04 | ±3.63 | ±0.13 | ±0.03 | ±0.07 | ±0.43 | ±1.07 | ±1.48 | |
| LM-Ag | 44.12 | 15.00 | 64.50 | 20.50 | 76.08 | 5.13 | 0.55 | 0.82 | 3.04 | 8.49 | 12.89 | 8 |
| ±95 | ±5.18 | ±5.91 | ±8.32 | ±3.66 | ±5.50 | ±0.11 | ±0.16 | ±0.26 | ±1.21 | ±2.14 | ±3.57 | |
| LM-Cc | 39.88 | 15.88 | 55.38 | 28.75 | 71.80 | 5.26 | 0.29 | 0.75 | 2.54 | 6.19 | 9.77 | 8 |
| ±95 | ±3.24 | ±6.68 | ±10.35 | ±4.87 | ±3.2 | ±0.16 | ±0.15 | ±0.59 | ±1.33 | ±2.53 | ±4.23 | |
| LM-Gr | 46.91 | 28.13 | 51.63 | 20.25 | 74.31 | 5.17 | 0.44 | 1.45 | 3.88 | 7.86 | 13.63 | 8 |
| ±95 | ±2.74 | ±8.64 | ±9.33 | ±2.96 | ±2.82 | ±0.14 | ±0.11 | ±0.38 | ±1.65 | ±2.31 | ±3.92 | |
| LM-Fr | 45.44 | 21.25 | 58.88 | 19.88 | 77.47 | 5.28 | 0.59 | 0.95 | 4.96 | 11.95 | 18.45 | 8 |
| ±95 | ±5.54 | ±1.99 | ±5.20 | ±4.90 | ±4.37 | ±0.26 | ±0.20 | ±0.37 | ±1.94 | ±4.72 | ±6.69 | |
| SF-Ag | 64.09 | 43.79 | 32.43 | 23.79 | 71.08 | 5.24 | 0.13 | 0.25 | 3.27 | 11.30 | 14.95 | 7 |
| ±95 | ±3.85 | ±18.77 | ±13.43 | ±8.62 | ±4.33 | ±0.43 | ±0.07 | ±0.10 | ±1.52 | ±6.53 | ±7.82 | |
| SF-Cc | 70.05 | 44.47 | 26.88 | 28.65 | 66.81 | 5.34 | 0.09 | 0.45 | 4.13 | 9.78 | 14.45 | 8 |
| ±95 | ±4.64 | ±16.67 | ±4.36 | ±15.08 | ±1.6 | ±0.26 | ±0.05 | ±0.29 | ±1.32 | ±2.59 | ±3.69 | |
| SFGr | 72.87 | 54.81 | 30.00 | 15.19 | 62.93 | 4.95 | 0.16 | 0.78 | 2.79 | 7.40 | 11.13 | 12 |
| ±95 | ±13.75 | ±6.93 | ±4.80 | ±3.65 | ±8.03 | ±0.23 | ±0.03 | ±0.21 | ±0.89 | ±1.98 | ±2.83 | |
| SF-Fr | 60.85 | 44.95 | 31.40 | 23.65 | 77.87 | 4.81 | 0.19 | 0.52 | 2.33 | 9.36 | 12.39 | 10 |
| ±95 | ±15.81 | ±13.47 | ±8.68 | ±9.22 | ±3.70 | ±0.41 | ±0.05 | ±0.21 | ±0.73 | ±4.91 | ±5.51 | |
| VC-Ag | 34.91 | 51.63 | 25.31 | 23.06 | 66.64 | 4.53 | 0.13 | 0.21 | 2.33 | 4.51 | 7.18 | 8 |
| ±95 | ±2.64 | ±7.84 | ±3.18 | ±8.94 | ±3.47 | ±0.27 | ±0.10 | ±0.05 | ±1.38 | ±2.29 | ±3.49 | |
| VC-Cc | 32.49 | 53.38 | 25.44 | 21.19 | 68.69 | 4.94 | 0.12 | 0.45 | 2.26 | 7.33 | 10.17 | 8 |
| ±95 | ±3.13 | ±7.64 | ±5.08 | ±5.77 | ±11.94 | ±0.23 | ±0.08 | ±0.19 | ±1.14 | ±2.82 | ±4.06 | |
| VC-Gr | 43.49 | 60.44 | 25.22 | 14.33 | 66.34 | 4.53 | 0.11 | 0.36 | 1.19 | 2.38 | 4.05 | 9 |
| ±95 | ±17.09 | ±5.60 | ±5.31 | ±5.61 | ±10.94 | ±0.20 | ±0.05 | ±0.14 | ±0.32 | ±1.15 | ±1.48 | |
| VC-Fr | 41.53 | 54.75 | 24.38 | 20.88 | 71.88 | 4.54 | 0.11 | 0.20 | 1.41 | 3.39 | 5.11 | 8 |
| ±95 | ±4.34 | ±10.34 | ±4.47 | ±6.40 | ±1.78 | ±0.38 | ±0.07 | ±0.12 | ±0.75 | ±1.66 | ±2.41 | |

Moisture content was higher in the four SF land uses than in other localities, with no differences among them. We observed significant differences between SF corn and grass with the four LM land uses, in addition to this, there were differences between SF agroforestry and LM corn. The four SF land uses differ from VC agroforestry and corn


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land use. The SF corn and grass vary form VC grass and forest. The sand and Na contents showed similar patterns, observing the highest averages in the four LM land uses. Both parameters, sand and sodium, were lower in SF and VC than in LM with no significant differences among them. We observed significant differences in sand content among the four LM land uses with the four SF and VC land uses. Sodium showed differences among LM agroforestry, grass and forest compared to the four SF and VC land uses. There were also differences between corn with agroforestry and forest in LM. Porosity was very homogeneous among the four land uses of the three sites. We observed differences only among SF grass compared with LM agroforestry and forest, and between SF grass and forest. The silt content did not show defined patterns between land uses and sites. The pH of VC grass, agroforestry and forest was different to LM corn, grass and forest, so were SF agroforestry and corn; we found differences between LM agroforestry and VC grass as well. Potassium content was higher in LM grass and forest. We identified important differences in the potassium levels among LM grass and the four land uses of SF and VC. Magnesium was also homogeneous among the four land uses of the three sites; we found some differences among LM and SF forests and the VC four land uses. The CEC was also very similar among the four land uses of the three sites. We recorded differences in CEC between LM forest with VC agroforestry, grass and forest, also between LM and VC grasses, SF agroforestry with VC grass and forest, and SF corn and VC grass. Calcium content also showed few important differences in such levels among land uses most of them correlated with CEC. The clay contents were significantly lower in the four LM land uses than those of SF and VC, among these, there were no differences. We observed significant differences in clay levels among LM agroforestry, corn and forest with all land uses of both SF and VC.

The nested ANOVA showed significant effect of site ($F_{2,\,154} = 13.86$, $P < 0.001$), and land-use nested within site ($F_{6,\,154} = 2.54$, $P < 0.05$) but not for depth strata nested by land-use ($F_{8,154} = 1.09$, $P > 0.05$) on Collembola abundance. The Bonferroni paired test detected significant differences among LM with SF and VC. For land-use nested by site, we identified differences among corn crop in LM with corn crop, grassland and forest in SF and VC. Other differences were found among corn crop and agroforestry in LM, grassland in SF and both grassland and forest in LM, and grassland and forest in VC. Means and 95% confidence intervals (CI) for Collembola abundance are shown in *Table 2*.

A total of 1,088 springtails of seven families were obtained from the three sites (LM, SF and VC). The most abundant families were Isotomidae (37%), Entomobryidae (27%) and Hypogastruridae (24%) (*Fig. 2a*). The number of Neanuridae and Odontellidae recorded was far less, under1% each (*Fig. 2*). LM had more than half of the total amount of Collembola (54%), while SF and VC had 25% and 21%, respectively (*Fig. 2b*). Abundance was higher in Gr and lower in Ag (*Fig. 2c*). In soil biotope the abundance was higher in So1 (40% in the first 5 cm deep) than in So2 (34%), with the lowest occurring in litter (26%) (*Fig. 2d*). All families were recorded in LM while Neanuridae was absent in SF and VC (*Fig. 3a*). We found all families in soil in both So1 and So2, however Neanuridae was absent in litter (*Fig. 3b*). In land-use types, all families were found in Gr, although Neanuridae was absent in Ag and Fr; Odontellidae also was absent in Cc (*Fig. 3c*). Shannon index showed a higher diversity in LM, mainly this fact comes from agroforestry and forest; however, we identified the highest diversity in SF forest. In biotopes, the highest diversity was observed in litter and both depth level of soil of forest (*Table 2*).


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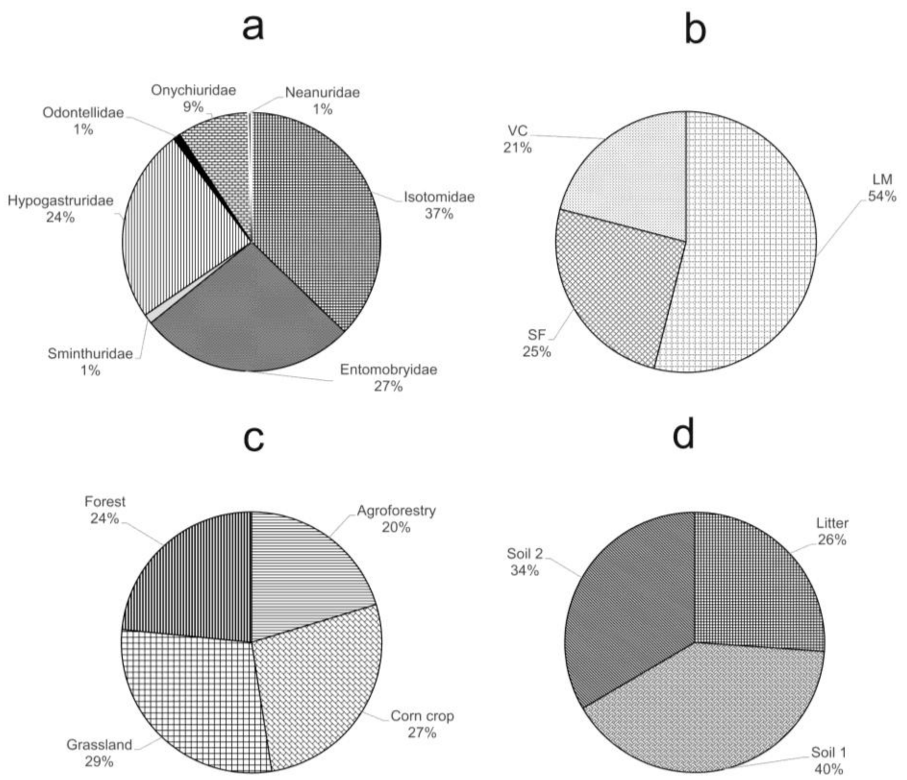


***Figure 2.*** *Distribution of Collembola abundance by families a), sites b), land-use types c) and biotopes d) from the St. Marta Range, Veracruz*

***Table 2.*** *Averages and 95% confidence intervals ((individuals/m$^2$) for Collembola abundance in sites, land-use in sites and litter, soil at 0-5 cm and soil at 5-10 cm depth*

| | | Average | ±95 | N | Shannon index *H´* |
|---|---|---|---|---|---|
| López Mateos | | 4979.63 | ±1160.90 | 60 | 1.37 |
| San Fernando | | 2398.17 | ±1130.35 | 58 | 1.22 |
| V. Carranza | | 2072.30 | ±580.45 | 56 | 1.17 |
| López Mateos | Agroforestry | 2846.23 | ±1527.49 | 17 | 1.48 |
| López Mateos | Corn crop | 8375.76 | ±3406.31 | 11 | 1.28 |
| López Mateos | Grassland | 5962.32 | ±3324.85 | 14 | 1.21 |
| López Mateos | Forest | 4159.88 | ±1369.65 | 18 | 1.36 |
| San Fernando | Agroforestry | 2800.41 | ±2270.88 | 10 | 1.12 |
| San Fernando | Corn crop | 2362.53 | ±1125.25 | 14 | 0.82 |
| San Fernando | Grassland | 2876.78 | ±3151.73 | 20 | 0.74 |
| San Fernando | Forest | 1456.21 | ±860.49 | 14 | 1.51 |
| V. Carranza | Agroforestry | 2408.35 | ±1583.50 | 15 | 0.80 |
| V. Carranza | Corn crop | 1960.29 | ±1079.43 | 13 | 1.17 |
| V. Carranza | Grassland | 1242.36 | ±560.08 | 16 | 0.78 |
| V. Carranza | Forest | 2886.97 | ±1563.14 | 12 | 1.27 |
| Agroforestry | Litter | 1201.63 | ±509.16 | 14 | 1.32 |
| Agroforestry | Soil 1 | 3630.35 | ±2092.67 | 15 | 1.32 |
| Agroforestry | Soil 2 | 3172.10 | ±1664.97 | 13 | 1.21 |
| Corn crop | Litter | 3238.29 | ±2275.97 | 11 | 1.33 |
| Corn crop | Soil 1 | 4073.32 | ±2683.30 | 14 | 1.24 |
| Corn crop | Soil 2 | 4465.38 | ±2713.85 | 13 | 1.23 |
| Grassland | Litter | 3477.60 | ±3477.6 | 18 | 0.98 |
| Grassland | Soil 1 | 3722.00 | ±3548.88 | 13 | 1.11 |
| Grassland | Soil 2 | 2627.29 | ±1690.43 | 19 | 1.38 |
| Forest | Litter | 2107.94 | ±921.59 | 14 | 1.43 |
| Forest | Soil 1 | 4276.99 | ±1848.27 | 15 | 1.40 |
| Forest | Soil 2 | 2408.35 | ±1069.25 | 15 | 1.36 |


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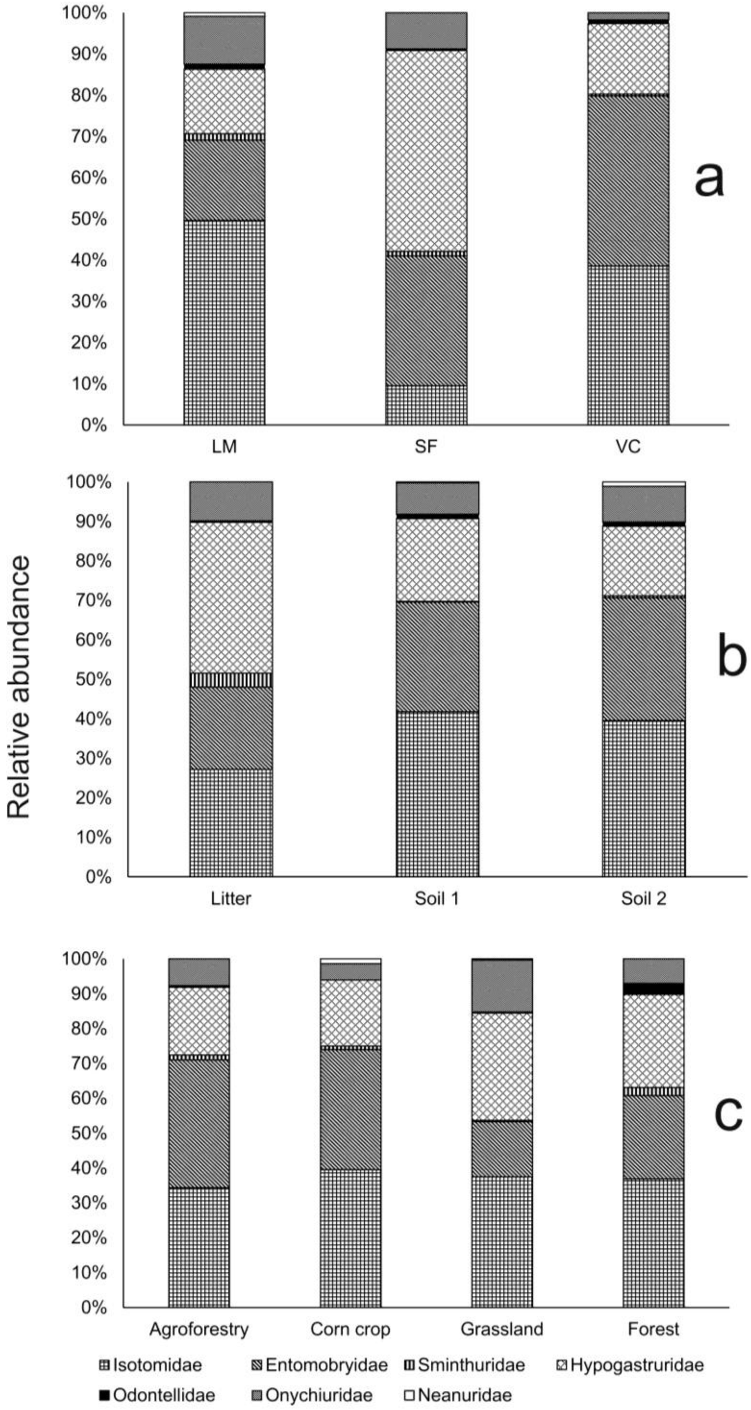


***Figure 3.*** *Relative composition of Collembola assemblages in sites a), biotopes b), and land-use types c). LM, López Mateos; SF, San Francisco and CV, Venustiano Carranza*

In the CA, almost all the samples of LM and VC tended to form one high group (Gr1), while those of SF formed a second high group (Gr2, *Fig. 4*). In the first group, soil samples of all the land-use types from VC tended to be close forming a sub-cluster. The litter samples of all land use of VC had low abundance of Collembola and they were dispersed in Gr2.


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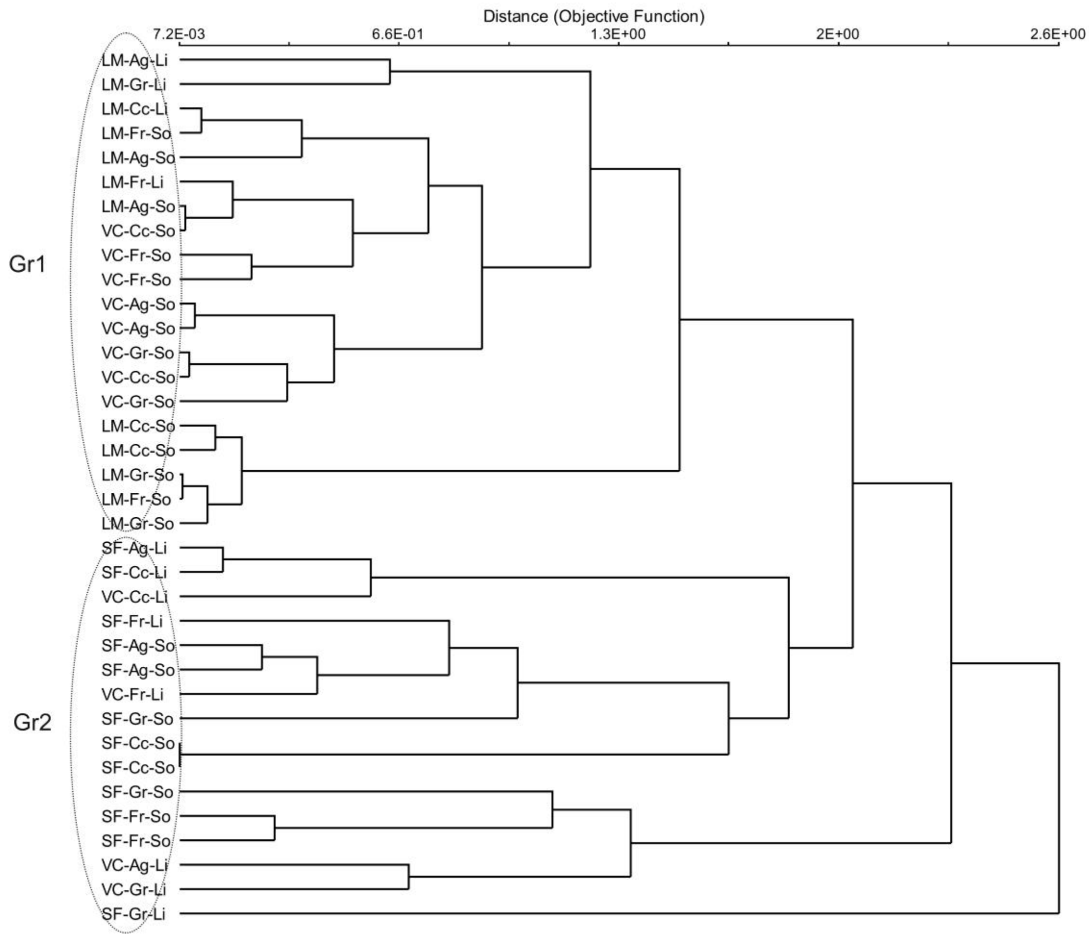


***Figure 4.*** *Classification dendrogram showing faunal relationships of Collembola assemblages based on a Bray-Curtis similarity matrix and UPGMA amalgamation rule using all the samples including sites, biotopes and land-use types*

The CCA analysis (*Fig. 5*) showed that canonical axes 1 and 2 together explain 84% of the variance in family composition of Collembola. Correlation coefficients between ordination axes and environmental variables, rather than canonical coefficients, were used to infer the importance of each parameter in predicting the family composition. More related land uses were Cc and Gr and in our analysis, they were opposite located to Fr (*Fig. 5*). Corn crop and forest axes (although opposed) exerted the strongest influence on Collembola abundance. Odontellidae were more related to forest axis and soil moisture. Sand, porosity and the presence of silt and clay are also important in determining the distribution of Collembola abundance. We represented these variables by longer arrows in *Figure 5*. The first two exerted an opposite effect on each other but sand was an important determinant of abundance of both Sminthuridae and Onychiuridae. We mainly recorded the abundance of these two families in all the land uses of LM except Sminthuridae in Ag, in which higher records of sodium and sand were obtained. Neanuridae seems to be related to the corn crop of LM because only a few specimens of this family were found in this land use. Samples of all the land uses from VC and LM were well separated in the plane generated by the first two axes; however, samples of SF crossed between LM and VC. Samples of Ag and Cc from SF were more related to VC-Cc and samples of Fr and Gr from SF to LM-Fr and LM-Ag.


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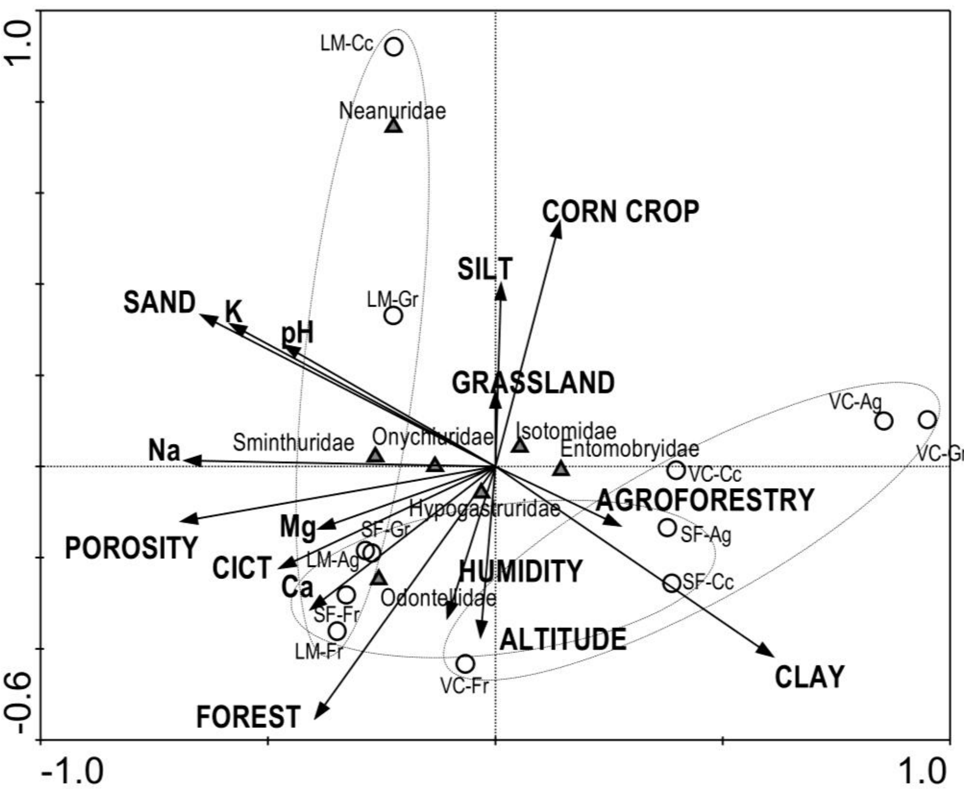


***Figure 5.*** *Triplot of CCA ordination showing environmental variables (large arrows) most strongly correlated with axes CC1 and CC2; families in black triangles and sites-land-use in clear circles. Abbreviations for sites and land use as in Table 1. In terms of predicting family composition, important environmental variables have longer arrows than less important ones*

## Discussion

Abundance patterns of the Collembola from SMR correlates with most of those reported in literature. Such correlation lies in the fact that the dominant families in soil and litter are Isotomidae, Entomobryidae and Hypogastruridae, although some types of soils can contain great populations of other families such as Onychiuridae (Lavèlle et al., 1981) or Neanuridae (Garita-Cambronero et al., 2006).

The estimation of Collembola density (individuals/$m^2$) for the grassland of SMR was 3,361 $m^2$, similar to that registered by Lavèlle et al. (1981) from the grassland of the Laguna Verde region, Veracruz (3,005 – 4,383 $m^2$). The estimated density of 2,834 $m^2$ for the forest of SMR is lower than that reported by the same author from the tropical rain forest of Laguna Verde region (6,257-7,025 $m^2$). Collembola density for the agroforestry of SMR was 2,685 $m^2$ and for that of the corn crop was 4,232 $m^2$. In agricultural zones of tropical regions, densities of 60,600 $m^2$ have been registered (Culik et al., 2002), which represent important differences within this study. Meanwhile, in the litter of SMR a density of 2,506 $m^2$ could be expected and for the first 5 cm deep of the soil of 3,925 $m^2$ and for the next 5 cm deep 3,168 $m^2$. Isotomidae, accounting for 37%, dominated the Collembolan assemblage in the study area. Particularly, Isotomidae accounted for 65% in the forest, and 40%, 37% and 34% for corn crop, grassland and agroforestry, respectively.


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Luanga-Reyrel and Deconchat (1999) reported similar results for oak coppice forests in France and Muturi et al. (2009) for Embu, Kenia. Dominant Isotomidae species represented high reproductive rate and adaptive ability. The feature has allowed some of the genera to colonize forests and open micro-habitats.

In general, Collembola density was higher in the land uses subjected to a greater impact such as corn crop and grass. It is possible that this fact is related to a higher incidence of individuals from one or a few dominant species of Isotomidae and Entomobryidae.

The land-use practices have an important effect on the soil biodiversity and they are usually associated with the loss of species and a reduction of biodiversity (Bengtsson et al., 2000). The results of this study are compatible with this assertion. The lowest diversity of Collembola was recorded in both grassland and agroforestry of Venustiano Carranza (VC) and corn crop of San Fernando and from litter of grassland use type. Opposite to this, the highest diversity was found in the forest of SF, the most unspoiled site. This fact is consistent with the hypothesis of finding greater diversity in the most conserved sites such as the forest that represents our control use type. The next most diverse land use was agroforestry of López Mateos. It is possible that the intensity and duration of practices in agroforestry of LM produce few fluctuations in the original Collembola assemblage.

On the other hand, the highest abundance of collembolans was recorded (in decreasing order) at corn crop, grassland and forest of LM, most of them pertaining to the Isotomidae family. All families were recorded in the four land uses of LM, except Odontellidae which was absent in corn crop. On the contrary, the lower densities of colembolans were recorded in grassland of VC and forest of SF. In grassland of VC diversity was 0.78 because only three families were present, Isotomidae, Entomobryidae and Hypogastruridae unlike the diversity of forest of SF (1.51) because six families out of seven were present. We discovered Neanuridae only in López Mateos, in corn crop and grassland, but in very low densities. Additionally, Odontellidae was a rare family, only recorded in the three land uses of LM and both forest of SF and VC in very low densities. The low densities of Odontellidae and Neanuridae throughout the land uses did not show a clear pattern, so their role as reliable bioindicators is here uncertain despite the fact that some authors have mentioned them as important bioindicators of edaphic conditions. Mendoza et al. (1999) reported incidence of Odontellidae (*Superodontella*) in a recovery land with corn crop from a tropical site in Balún Canán, Chiapas, Mexico. Perhaps the presence of Odontellidae in a recovery soil could be considered as an indicator of restoration.

About Collembola distribution on biotopes, it seems clear that, with rare exceptions, soil contains a greater abundance and diversity of Collembola than litter as has been reported for other tropical forests (Gómez-Anaya et al., 2010) but in this study the diversity of litter was little higher than that of both soil layers. In LM the highest diversity was recorded in the soil of forest and the lowest in the litter of forest, this could be because this biotope was scarce and variable. In litter the abundance of springtails can be extremely variable, due to the different levels of the accumulation of litter on the ground depending on many factors: slope, soil relief, vegetable cover. Especially, abundance in litter depends largely on precipitation and moisture level. In biotopes of land uses the lowest abundance of Collembola was recorded in the litter of agroforestry and the highest abundance in the deepest layer of soil (So2) of corn crop. The accumulation of litter in some grassland systems can be high because of an increase


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of the number of herbaceous plants (Sánchez et al., 2007). Litter accumulation in grassland of SMR was more variable than in the other land uses and may correlate to the lower Collembola abundance recorded. In relation to the higher Collembola abundance in corn crop, the species composition is likely to be represented only by one or few species of Isotomidae and/or Entomobryidae, the most abundant families recorded, that find by peculiar temporal microhabitat conditions, e.g. moisture, favorable to maintain high populations. Agricultural stubble is mainly represented by cornstalk debris, that can be either highly variable or a very homogeneous medium depending on the type of management used. Under humid conditions stubble can generate a fungal mycelium-rich medium during the decaying cycle which provides abundant food for sustain high populations of Isotomidae (pers. obs. J. A. Gómez). Particularly in the two layers of soil abundance was higher in the deepest layer So2 (0-5 cm deep) in the corn crop and then in the first layer of soil of the forest. This shows a contrast between the site of greatest intensity of use and the control one. Composition of families shows that most of the Collembola collected from So1 of forest soil were epiedaphic forms of the Isotomidae family. Similar dominance of Isotomidae have been reported from other tropical site used in a corn cultivation (Mendoza et al., 1999) in Balún Canal, Chiapas. In corn crop soil, the abundance of Collembola was very similar between the two soil layers, 4073 $m^2$ and 4465 $m^2$ for So1 and So2, respectively. This is because the variation in depth between the two layers of soil was minimal and the land preparation promote a more homogeneous edaphic vertical profile in characteristics e.g. moisture, sand, clay, silt, porosity and therefore the vertical distribution of Collembola was similar. However, this was only for abundance distribution since in composition there was no Sminthuridae in So1 and no Odontellidae in either soil layers.

It is a fact that some soil physicochemical properties are modified by different agricultural practices and grazing. For example, silt content has been reported to tend to increase in the grassland and farmland (Evrendilek et al., 2004). Particularly, silt content was higher in cropland and grassland in SRM in which higher Isotomidae and Entomobryidae were registered (see CCA *Fig. 5*). Contrary, porosity is another property that tends to decrease in soils with grassland and agricultural management and increases in preserved soil, like forest, as this study proved. Apparently, the clay content also tends to decrease with soil management even though our study showed to be higher in the grassland (Evrendilek et al., 2004). The highest abundances of Isotomidae and Entomobryidae seem to be correlated mainly to corn crop cultivation practices, agroforestry and grazing but not to the preserved forest. Undoubtedly, the different land-use practices tend to transform the physicochemical properties of soil and thus to modify assemblages structure of wildlife that inhabits it.

Among Poduromorpha some species of Hypogastruridae, Neanuridae, Odontellidae and Onychiuridae have been regarded as reliable indicators of perturbation (Barbercheck et al., 2009; Ponge et al., 2003; Van Straalen, 1998). Nevertheless, contrary to expectations, there was Neanuridae recorded in the corn crop and grassland of LM but absent in the tropical rain forest of the same site. Whereas, Odontellidae was absent in the most land-use types, except in forest, the most unspoiled site, in Santa Marta Range. It is feasible that, Neanuridae and Odontellidae could be more sensitive than other Collembola to human influence.

As a group, Collembola has shown to be an efficient bioindicator of the effects of land-use mainly in aspects of incorporation of Nitrogen and pesticides in soils, as well as in the evaluation of the quality of grassland environments (Hodkinson and Jackson,


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2005). Several families are more or less sensitive to the pollution of the environment. It is of great value to detect the assemblages of microarthropods at family level, those of Collembola, to provide an efficient tool to determining the quality and health of altered soils (Garita-Cambronero et al., 2006). We consider that a family level of quantification can give an effective indication to the different human impacts on soils such as the different land-use types in Santa Marta.

## Conclusions

According to our results, it can be concluded that the differential land use by practices such as corn crop, grazing and agroforestry in St. Marta Region (Los Tuxtlas) produces significant changes in abundance and diversity of the Collembola families in leaf litter and soil when compared to a barely modified forest. These changes occurred in the three sites as well as in the two biotopes, leaf litter and soil, of the four land uses. Collembola showed a reduction in diversity and abundance in those land uses subjected to a more intensive use such as corn crop, grazing and agroforestry. On the other hand, as expected, the Collembola were more diverse and abundant in the land use that experiences less intensity as the forest. The higher abundance of Isotomidae and Entomobryidae recorded in corn crop can be probably associated with the soil management in agricultural soils, with more humidity due the crop requirements, and promote mycelial growth, and that is exploited for those Collembola families increasing their abundances. A detailed study of the taxonomy of these two families would, undoubtedly, reveal that relatively a few opportunistic epiedaphic species are dominant in corn crop and that a reduction in diversity is always constant consequence that can be verified in any place where the intensity of land use is increased. Odontellidae and Neanuridae were rare families because of their abundance, however, their incidence/absence patterns are not clear here and their value as bioindicators was not possible to be highlighted. Nonetheless, some authors have proposed that some Collembola species with higher bioindicator value are in these families. Apparently, they tend to disappear with farming practices and grazing. They are probably sensitive to the use of agrochemical and pesticides used in agriculture and cattle farming. Particularly we think that the Odontellidae, which were not registered in the corn crop in St. Marta, could be used as good bioindicators. It is recommended to observe their abundance and/or presence-absence in soils subjected to intense use. Finally, the use of higher taxonomic categories other than species is recommended, as in this case the family level, in rapid assessments to detect coarse quantitative/qualitative changes introduced by human impact. Our results suggest that the changes in dynamic community of Collembola can be used as indicator of modified soil use and quality.

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