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Soil mesofauna: biological indicator of soil quality

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ABSTRACT

The search, use and application of soil quality indicators have been intensified in the last decades, due to the need to preserve this non renewable resource which is essential for human life, in the face of the increasing deterioration. The selection of the indicators has been aimed, mainly, at learning the effect of the applied uses and the course of the rehabilitation of degraded or contaminated soils. The groups which integrate the soil mesofauna are sensitive to natural and anthropic disturbances of the edaphic environment, which cause changes in their specific composition and abundance, and produce loss of species and their diversity, with the subsequent decrease of soil stability and fertility. For such reason, the soil mesofauna is considered a good biological indicator of the soil conservation status. The number, density and balance of its groups allow to predict and evaluate the transformations brought about by the application of different agricultural production methods under specific soil and climate conditions, as well as to consider integrally the functioning of the ecosystem.

Key words: indicator organisms, soil conservation

INTRODUCTION

The soil mesofauna participates in the processes of organic matter decomposition, aeration and nutrient recycling and, particularly, of phosphorus and nitrogen mineralization (García-Álvarez and Bello, 2004). The groups that integrate it are regulators of the trophic process in the soil environment, helping in the formation of its microstructure with their contributions of dejections, excretions, secretions and their own dead bodies. They also facilitate the dissemination of spores, fungi and other microorganisms, for which they are known as catalysts of the microbial activity. In addition, they are acknowledged as micro-engineers of the soil environment, because they construct galleries in the soil and improve its physical properties, by favoring aeration and water infiltration. For such reason, they constitute decisive factors for productivity maintenance.

Many of the groups which integrate the mesofauna are sensitive to natural and anthropic disturbances of the environment, which cause changes in their specific composition and abundance, and bring about the loss of species and their diversity, with the subsequent decrease of stability and fertility (Scheu, 2002). That is why the mesofauna is considered a good biological indicator of the soil conservation status.

The number, density and balance of these groups allow to predict and evaluate the transformations caused by the application of different agricultural production methods under specific soil and climate conditions; as well as to consider, integrally, the functioning of the ecosystem, so that the soil-plant relation is the basic link for the maintenance of the other system components and, in turn, allows to evaluate their influence on fertility maintenance and soil conservation.

The objective of this review was to collect the highest possible amount of information about the use of the groups of the soil mesofauna as biological indicators in the diagnosis and evaluation of the disturbances produced in a certain ecosystem, subject to a management or use type.

Main groups of the soil mesofauna

The mesofauna is a zoological category whose components live all their lives in the soil, which includes: mites (Acari), springtails (Collembola), symphylans (Symphyla), proturans (Protura), diplurans (Diplura), pauropods (Pauropoda), Thysanoptera, barklice (Psocoptera), enchytraeids (Enchytraeidae) and polyxenidans (Polyxenida), measuring 0,2-2,0 mm of diameter. Many of these groups are bioindicators of soil stability and fertility (García-Álvarez and Bello, 2004); among them mites and springtails stand out, for being the main representatives of this type of fauna and having better conditions to be used for this purpose.

These groups show extremely diverse feeding habits; thus, according to their main feeding categories, they may be: herbivores, detritivores, predators (carnivores) and fungivores.

Mites, according to Behan-Pelletier (1999), are potentially powerful indicators, of the ecosystem nature as well as its disturbance. This statement is based on their abundance, because they reach several hundreds of thousands of individuals per square meter. In addition, they show a large taxonomic and trophic diversity and are easy to collect and preserve.

Among Acari are oribatid mites (Cryptostigmata), which are important facilitators of organic matter decomposition in interaction with the microflora, because they act on the remains of animals and plants, fragmenting them and making them more accessible to the action of microorganisms. These individuals are sensitive to the organic matter content, humidity percentage, pH, agricultural practices carried out by man and insecticide use. Within this group there are different types of response to environmental alterations, because their morphological characteristics can make them more resistant. Certain oribatid mite species show the existence of adverse circumstances, natural as well as anthropic; and also of favorable conditions, such as the existence of well preserved forests. Nevertheless, studies are yet to be conducted on their ecology, biology and physiology, to consider them a group with great uses as bioindicators (González, 2001).

Likewise, Uropodidae form a group of saprophagous Acari, but have little abundance in the soil, because they show morphological and bioecological characteristics which makes them highly demanding regarding habitat quality. They are abundant in the ecosystems with high organic matter value, in compost areas and decomposing trunks (García-Álvarez and Bello, 2004). They are also humus-producers and respond positively to good soil aeration conditions. Together with Oribatida, they are reported as indicators of high-productivity soils. The study of their variations constitutes an accurate criterion of the health status of the soil environment.

The Acari also include Astigmata, which belong to the trophic group of fungivores and are considered good indicators of disturbed soils because they survive under unfavorable environmental conditions (Andrés, 1990).

Gamasidae are predator mites which exert control over the populations of nematodes and other soil microarthropods. Chocobar (2010) stated that this taxon is sensitive to disturbed soils and to the unfavorable changes in rainfall and soil humidity, which could be due to the fragility of their body. These characteristics turn it into a good indicator of soil quality, showing higher abundance in the least disturbed ones.

However, Prostigmata are dominant in nutrient-poor soils, with low calcium carbonate values, low organic matter and little humidity. They are mostly predators, with fragile structure and small size, for which they presumably have remarkable sensitivity to the fluctuations of the water conditions of the substratum (Andrés, 1990). They are more abundant in disturbed areas because they have high reproductive potential; this allows them to adapt to the effect of the disturbing factor, for which in the relative absence of predators and competitors for food, they may rapidly increase their number. This group, because of its ecological characteristics, also constitutes a good indicator.

In the case of springtails (Collembola), they are known to depend on the conjugation of the factors organic matter and humidity, and are sensitive to environment disturbances (Chocobar, 2010). According to Bellinger, Christiansen and Janssens (2003), they play a decisive role in the recycling of organic remains and are capable of fractioning and grinding plant remains, which increases the implantation of the microflora. The food ingested, once degraded, intervene in humus formation; many soils incorporate millions of little balls of Collembola feces which benefit the roots, due to the continuous release of nutrients, as they are disintegrated by soil microorganisms (Chocobar, 2010). On the other hand, they participate in the maintenance of fungi and nematode concentrations favorable for plant growth; but they can also eat pathogen fungi and with it they decrease fungal concentrations in crops, for which they are used as bioindicators of soil contamination (González, Díaz and Prieto, 2003). These hexapods constitute indicators of the soil pH and humidity; some species are sensitive to chemical products, while others increase their densities. They also serve to reveal the differences among forests, as well as in the evolution of ecosystems with different degrees of disturbance (Palacios-Vargas, 2000).

Barklice (Psocoptera), on the contrary, include pioneer insects in the re-colonization of altered or disturbed areas, for which their presence is an indicator of the progressive recovery process of the soil. It is considered a more abundant group under drought conditions. Hansen y Coleman (2000) reported that these insects are more numerous in uncovered areas without plant cover. On the other hand, Ducarme, André, Wauthy and Lebrun (2004) report them as good decomposers of plant, hypha and spore fragments, in addition to organic detritus.

Protura, Diplura and Pauropoda are groups of the mesofauna with very little frequency and little-known ecology. Due to their morphological characteristics (soft, small and chitinless body) and their trophic functions (detritivores, fungivores, phytophages or herbivores and predators) are considered indicators of soil stability.

Diplura is a group of micro-arthropods which are generally found in the soil, under trunks or stones and in the litter; they move very rapidly when disturbed. Some species are also known which inhabit caves, are highly specialized and prefer deep strata with lower exposure to soil disturbances. Diplurans are detritivores and depend especially on a moderate and constant humidity degree (Palacios-Vargas, 2000). In Spain, Andrés (1990) reported the presence of this group in forestry plantations with low abundance and its preference for depths under more constant water conditions.

Regarding Protura, their styliform bucal pieces suggest they feed on nutrients in aqueous dissolution (Andrés, 1990), which may come from mycorrhizae. The ecology of this group is very similar to that of springtails and it inhabits the deep strata, thus, it is not affected by the alterations which occur in higher strata.

Pauropods (Pauropoda) consume microorganisms and fungal hyphae, for which they are considered to be involved in decomposition, although their contribution to this process could be relatively poor as compared to that of other mesofauna groups. Some of their representatives are predators. These individuals are very sensitive to agricultural practices, with which their population is decreased in 70 % (Palacios-Vargas, 2000).

As representatives of herbivores are thrips (Thysanoptera), which feed upon the different structures of plant roots, and have a soft and whitish body.

Relations or balances among taxa or functional groups of the mesofauna

Taking into consideration the behavior and functions of the groups that compose the soil mesofauna, in the soil environment, relations or balances have been established among them.

The utilization of these zoological groups in soil evaluation entails a qualitative analysis of the trophic and functional role of each taxon in its environment; as well as their morphological characteristics, seasonality and degree of sensitivity to the disturbances produced by men or nature. A rational study of the ecology of each group should be conducted in order to achieve a correct interpretation of what occurs in the environment, and for the predictions and recommendations to be accurate and aid the improvement and conservation of the soil.

Karg (1963) proposed the Oribatida/Astigmata balance, due to the close relation between the densities of moss mites and Astigmada, because as ones increase the others decrease; hence the importance of this balance to measure the degree of unbalance among the soil biocoenoses.

Another balance, suggested by Andrés (1990), was Oribatida/Prostigmata. When Prostigamata –group indicator of aridity and oligotrophy– reaches numerical dominance with regards to Oribatida, the unbalance degree of the soil communities is irreversible.

Mateos (1992) presented the Acari/Collembola ratio, which is useful to determine the disturbance degree in the affected zones. When it is favorable for springtails, indicators of soil fertility and stability, the ecosystem is considered to be preserved and stable; while if Acari are the most abundant, an analysis should be made of which Acari group is prevailing and of their function in the soil.

Bedano, Cantú and Doucet (2001) established as effective the Astigmata/Mesostigmata relation to predict the instability of the soil environment. If there is a strong presence of the numerator –indicator of instability–, the environment is altered and instable.

Another ratio proposed by Socarrás and Hernández (2010) was detritivores/re-colonizers, which allows to learn the degree of advancement of the soil recovery process.

Utilization of the soil mesofauna groups as indicators of the edaphic environment quality

The first reports about the use of the groups that integrate the soil mesofauna as biological indicators worldwide were published by Hermosilla, Reca, Pujalte and Rubio (1977), when studying pasturelands with different degrees of disturbance in Argentina. These authors found that moss mites, springtails, Gamasidae and Prostigmata showed densities which were affected by the increase of compaction. In another study about this topic, Aoki (1979) tested the characteristics of the families of moss mites as bioindicators, through their sensitivity to environmental changes caused by biotic, abiotic and anthropic factors; they were classified as insensitive, very sensitive and intermediate sensitivity groups. On the other hand, Ponge (1980) used springtail species as indicators of ecological variations; and recently, because of the great problem of environmental contamination, the presence of this group in contaminated soils and the possible utilization of its abundance as measurement to evaluate the effects of soil contaminants, have been studied. Prasse (1985) stated that the communities of Acari and springtails show changes in their composition, due to the influence of agricultural practices, for which the presence of a taxon or combination of taxa are effective as bioindicators of the treatments with herbicides.

In the 1990's an advance was observed in ecosystem evaluation from the performance of the members of the soil mesofauna. Andrés (1990), Van Straalen (1998) and Behan-Pelletier (1999) emphasized the role of Oribatida as biological indicators of humidity and organic matter content in forest ecosystems, as well as in forestry plantations and agroecosystems.

In more recent years, when studying the response of springtails to seasonality and to the presence of heavy metals, Cole, Bradford, Shaw and Bardgett (2006) found a maximum presence in the rainy season; while they decreased in the dry season and with the addition of inorganic compounds containing cadmium and zinc. On the other hand, Bedano *et al.* (2001) applied the Oribatida/Astigmata, Oribatida/ Prostigmata and Astigmata/Mesostigmata relations in four soil uses with different productive systems, to evaluate soil conservation; while Bellinger, Christiansen and Janssens (2003) stressed the possible role of springtails as bioindicators in reforestation, the agricultural potential of soils and their use intensity.

Also in this decade, Arroyo, Iturrondobeitía, Caballero and González-Carcedo (2003) studied nine cultivation plots with different treatments regarding fertilization type or agricultural management, and found a decrease of the Oribatida density values; contrary to the results obtained in a non-anthropized soil, where the families Oppiidae (Oribatida) and Ascidae (Mesostigmata) were reported as bioindicators of low heavy metal values. Baretta *et al.* (2006) applied a multivariate analysis on cultivated soils with important results in the evaluation of the edaphic environment of different ecosystems, by using Acari and springtails as biological indicators of soil stability and fertility. On the other hand, Gulvik (2007) made a bibliographical review on the use of Acari as biological indicators in pasturelands.

In Cuba, these studies were started at the end of the 1980's by different institutions of the country, the School of Biology of the University of Havana (Ministry of Higher Education) and the Institute o Ecology and Systematics of the Environment Agency (Ministry of Science, Technology and Environment). In the 1990's, two institutions of the Ministry of Higher Education were incorporated to the research to evaluate pasturelands with livestock production management from the soil mesofauna, in the Mayabeque and Matanzas provinces: the Institute of Animal Science and the EEPF "Indio Hatuey", respectively. The studies were conducted in different ecosystems, such as: forests, reclaimed mining areas, areas rehabilitated with bioenergetic species, crops and urban soils.

Forests

An approached line was forest evaluation. The highest percentage of individuals corresponded to Acari, due to the remarkable contribution of Oribatida, with numerical predominance (13 653 ind/m^2); the second position was occupied by springtails, whose average density was 3 975 ind/m^2 (Berazaín and Prieto, 2001). Prieto, González and Tcherva (2005) reported higher values of taxonomic richness for Oribatida in another secondary forest of Cuba (21 families).

The evaluations of forests in Brazil and Cuba (Prieto, Bonfante-Almeida, Ramadán and Fernández, 2002; Prieto *et al.*, 2005) showed very interesting results with regards to the sensitivity degree of the different Acari and Collembola families to the soil environment disturbances.

Pasturelands

Socarrás (1999) evaluated the relations among the groups of the soil mesofauna in pasturelands with different managements and disturbances (traditional grazing, intensive grazing and burning) in the Mayabeque and Matanzas provinces. The most affected groups were Collembola and Gamasidae, indicators of soil stability and fertility because they are highly susceptible to soil disturbances as they have whitish and soft bodies; this allowed to make an evaluation of the methods and the need to recommend the change of livestock production practice. This author developed other studies in areas of the EEPF "Indio Hatuey", in order to relate the presence of certain groups of the mesofauna in pasture species which have different morphological structures. The highest quantity of mesofauna families was found in *Andropogon gayanus* and *Cenchrus ciliaris*; these grasses show structures which guarantee the optimum conditions for the establishment of the soil fauna in extreme situations of lack and soil disturbance (Socarrás, Rodríguez, Sánchez and Ávila, 2005).

On the other hand, Rodríguez *et al*. (2008a) evaluated integrally the soil-plant complex with a silvopastoral system in a dairy unit of Havana, in which they reported lower values of Collembola and Acari with regards to the rest of the mesofauna. Rodríguez *et al*. (2008b) also made a compilation of the studies about the soil biota and its role in the sustainability of systems, as well as in nutrient recycling and the role of fauna in the pasturelands subject to rational Voisin grazing (RVG).

Reclaimed mine areas

Socarrás and Rodríguez (2004) and Socarrás and Rodríguez (2007) evaluated the variation of the relation or balance of the groups that integrate the soil mesofauna in reforested areas of the mine zone of Moa (Holguín), with regards to a remnant natural forest. The analysis of such variation, 16 years after the beginning of the rehabilitation of the area with *Pinus cubensis*, showed a qualitative and quantitative advance of soil stability and fertility (Oribatida and Collembola); as well as a strong re-colonization of the area by a higher number of native plant species. Similar density values as those of the remnant natural forest were found, which indicates the resilience of the soil system under the studied conditions (table 1).

Table 1. Rehabilitated area/natural forest for the mesofauna and the groups that integrate it (ind/m^2).

	16 years	10 years	6 years	4 years
Mesofauna	0,969	1,008	0,920	0,945
Oribatida	0,709	0,429	0,162	0,161
Astigmata	1,500	2,818	2,764	2,277
Gamasidae	0,666	0,506	0,363	0,666
Prostigmata	0,912	0,818	1,692	1,583
Collembola	0,714	0,187	0,376	0,333
Psocoptera	1,504	2,607	1,433	0,994

Areas rehabilitated with bioenergetic species

From the results of the evaluations in areas rehabilitated by sowing bioenergetic plant species, a new index was proposed to learn the degree of advancement of the process of soil recovery, which involved two functional groups: detritivores and re-colonizers (Socarrás and Hernández, 2010). The functional category of numerator included the taxa whose trophic function is to decompose the organic material and simplify the attack by soil microorganisms, for its later incorporation to the soil. Re-colonizers are composed by barklice, which are pioneer insects in the re-colonization of altered or disturbed areas. When this balance favors the denominator or it is lower than one, it shows that there is superiority in the density of Psocoptera with regards to that of detritivore groups in the analyzed areas. In addition, it indicates that the area is still undergoing the fertility and stability recovery process, and that the necessary conditions for the establishment of the most demanding detritivore groups have not been created. As the value of the numerator becomes higher than one, this means that there is a dominance of detritivores and a reestablishment of stability conditions in the soil may be foreseen.

Crops

Prieto, González and Díaz (1989), when studying the influence of crop techniques on cassava plantations, obtained minimum values of mesofauna; Oribatida stood out and the springtail populations were depressed. The evaluations were extended to other crops, such as sugarcane in the Havana province (González, 2001; González *et al*., 2003), and density values of 2 000 ind/m^2 were found for Psocoptera, on Ferralitic Red soil.

In the citrus fruit plots of Artemisa, during the reconversion period, Socarrás and Vallín (2004) found higher diversity and density of detritivore groups in organic plots and plots associated to legumes. Likewise, the evaluation of an integral livestock production-agriculture farm in Artemisa, from the Oribatida/Astigmata ratio and the presence of other groups of the soil mesofauna allowed to learn that the agricultural practices which were being applied in the polycrop area did not favor the recovery of this fauna, or the stability and conservation of the soil environment (Socarrás, 2006). In Jovellanos –Matanzas–, in a pastureland and a sugarcane plantation with mulch, Robaina (2009) and Robaina, Socarrás and Pérez (2010) observed that one of the most important aspects to be taken into consideration to guarantee life in the soil is to maintain adequate cover, through the Oribatida/Astigmata and Oribatida/Prostigmata relations. On the other hand, in a study conducted in four land uses (forest, pastureland, varied crops and sugarcane) of the red plain of Artemisa and Mayabeque (fig. 1) the Oribatida/Astigmata ratio was applied and in sugarcane the ratio was observed to be lower than one, that is, Astigmata prevailed, for which there was a disturbance in this use (Socarrás and Robaina, 2011).

Urban soils

The urban soils of the Regla municipality, Havana City (Fresquet *et al*., 2009), were evaluated from the relations among the groups that integrate the mesofauna (fig. 2). In some areas the ratio was dangerously close to one, that is, there was the same quantity of fertility and infertility indicators. These results allowed to recommend a change of management in those scenarios.

In the evaluations conducted at international level, the most widely applied relations or balances have been Oribatida/Astigmata, Oribatida/Prostigmata and Acari/Collembola, because these edaphic groups are more abundant in the soil and have a well defined function. In Cuba, the most used ones are the first two as they express very well the ecological status of the soil. Nevertheless, the author of this review has made little use of the Acari/Collembola ratio, because according to her criterion it does not present clearly the situation of the soil, having in the numerator a category (Acari) that involves indicator groups of fertility and infertility, for which their dominance does not show the real situation of the medium and a qualitative analysis of the groups and their functions is necessary.

In general, the utilization in Cuba of these biological indicators in studies and/or monitoring of the ecosystems with different degrees of anthropic or natural disturbance has allowed to observe the

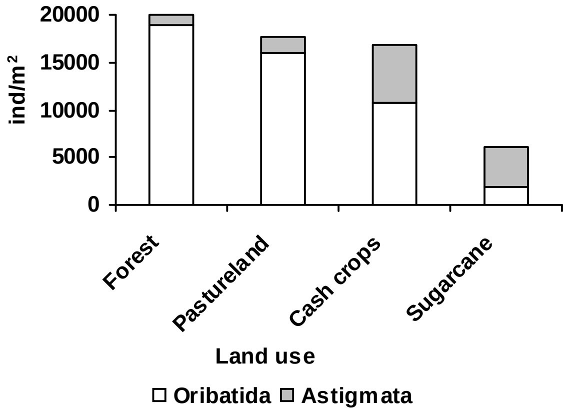

Fig. 1. Oribatida/Astigmata ratio in four land uses in the red plain of Artemisa and Mayabeque.

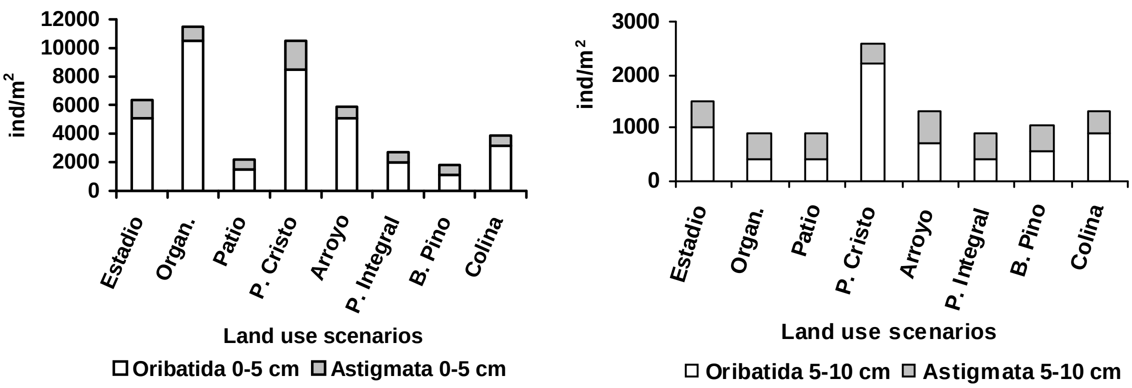

Fig. 2. Oribatida/Astigmata ratio in the eight use scenarios of the Regla municipality.

situation of the soil and its capacity of recovery; as well as to formulate recommendations about the management changes necessary to achieve production in balance with the environment conservation.

CONCLUSIONS

The groups of the soil mesofauna are very sensitive to the changes that occur in the soil environment due to natural or anthropic causes, causing variations in their density and diversity; for such reason they are considered accurate indicators of the soil ecological status. The qualitative analysis of the groups that integrate this zoological category will allow to make an adequate evaluation of the soil environment.

The relations among the different antagonistic trophic and functional groups of the mesofauna should be considered as an index and not a fixed value. The most used ones are Oribatida/Astigmata and Oribatida/Prostigmata. These balances allow to predict and evaluate the transformations caused by the climate change and the application of different mine, agricultural and livestock production methods, under specific soil and climate conditions. In addition, they allow to consider integrally the functioning of the ecosystem.

In the last decade, in Cuba the use of the soil mesofauna as a bioindicator for the evaluation of the edaphic environment has increased; however, there are few specialists and little knowledge related to the topic, for which the practice has not been generalized.

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