Use of soil and litter arthropods as biological indicators of soil quality in forest plantations and agricultural lands: A Review

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This article reviewed published papers on the use of soil and litter arthropods as biological indicators of soil quality since the 1970s. Our review shows that soil and litter arthropods are litter transformers and ecosystem engineers. They contribute to the availability of organic matter. Their diversity, abundance, biomass, and density are suitable measures for the assessment of natural and/or anthropogenic effects on soil. However, their use is challenged by difficulties in sampling methods and the identification of soil and litter arthropod diversity up to species level, and few research projects combine both abiotic and biotic factors. We recommend further research to investigate the most suitable methods for sampling soil and litter arthropods, and create a classification of dominant groups up to species level which, along with the use of integrative methodologies, will be valuable steps towards a generalized and accepted method for the assessment of soil quality.
Key words: arthropods, soil quality, indicator, forest plantations, agricultural lands.

Cet article a examiné les articles publiés sur l'utilisation des arthropodes de la litière et du sol comme indicateurs biologiques de la qualité des sols depuis les années 1970. Notre revue montre que les arthropodes de litière et du sol sont des transformateurs de litière et des ingénieurs d'écosystèmes. Ils contribuent à la disponibilité de la matière organique. Leur diversité, leur abondance, leur biomasse et leur densité sont des mesures appropriées pour l'évaluation des effets naturels et / ou anthropiques sur le sol. Cependant, leur utilisation est remise en question par des difficultés dans les méthodes d'échantillonnage et l'identification de la diversité des arthropodes de la litière et du sol au niveau de l'espèce, et peu de projets de recherche combinent à la fois des facteurs abiotiques et biotiques. Nous recommandons que d'autres recherches explorent les méthodes les plus appropriées pour échantillonner les arthropodes de la litière et du sol et créent une classification des groupes dominants jusqu'au niveau de l'espèce qui, avec l'utilisation de méthodologies intégratives, constitueront des étapes précieuses vers une méthode généralisée et acceptée pour l'évaluation de la qualité du sol.
Mots-clés : arthropodes, qualité des sols, indicateur, plantations forestières, terre d'agriculture.

1 INTRODUCTION

Soil is an integral component of ecosystem processes and biogeochemical cycles, comprised of solid, liquid and gaseous components which interact through a multitude of interrelated physicochemical and biological processes (Zornoza *et al*., 2015). Soil is a key resource for agriculture production and is a source of nutrients required for plant growth (Tsiafouli *et al*., 2015). Soil is also the foundation and the essence of all terrestrial life (Lal, 2015). In relation to biodiversity, soil is inhabited by a range of organisms including fungi, algae, bacteria, protozoa, and invertebrates (Koehler, 1992), with soil and litter arthropods representing as much as 85% of all soil fauna (Culliney, 2013).

Through history, soil has been essential to human well-being, and human dependence on soil is direct due to its contribution to food production and importance for economic development (Lal, 2015). However, intensive exploitation of soil can cause considerable decline in soil quality (Eswaran *et al*., 2016). Current estimations show that soil degradation affects around 33% of all soils in the world (FAO, 2017), and has strong consequences on soil ecosystem services and biodiversity conservation due to changes in the concentration of nutrients, loss of soil organic carbon, pollution, loss of soil biodiversity, wind and water erosions, desertification, acidification, salinization, increased greenhouse gas emissions, reduced water infiltration and purification, and perturbations of hydrological cycles (Zornoza *et al*., 2015).

Although some authors consider soil quality to refer to soil functions while soil health represents the finite nonrenewable and dynamic living resource (Doran & Zeiss, 2000), soil quality and soil health are often used interchangeably and are defined as the ability of a specific soil to function within its capacity and within natural or managed ecosystem boundaries, to sustain productivity of plants and animals, maintain water and air quality, and support human health (Arshad & Martin, 2002). However, soil quality assessment has long been a challenging issue because soil presents high variability in properties and functions, and globally acceptable methodologies for assessing the soil quality are not yet in place (Laishram *et al*., 2012).

The assessment of soil quality has long been based on various biological indicators (Vasconcellos *et al*., 2013), including indicators of biotic or abiotic conditions, indicators of various human activities (Basedow, 1990), or goal parameters deducted from nature conservation aims and translated into measurable factors such as species diversity (May, 1995). The use of soil invertebrate community as an indicator of soil quality has received more attention in recent years and soil mesofauna are the most studied organisms in soil quality assessment (Lavelle & Spain, 2001). Currently, the focus is on soil and litter arthropods (Bagyaraj *et al*., 2016), although little is known about the advantages and challenges of using these organisms in assessing soil quality.

This paper reviews the use of soil and litter arthropods as biological indicators of the soil quality under forest plantations and agricultural lands. The focus on these land use is motivated by the fact that forest plantations become common landscapes across many parts of the world occupying around 264 million of hectares (7% of the total global forest area) (Jürgensen *et al*., 2014), while agricultural lands occupy around 1.6 billion of hectares (12% of global land area) (FAO, 2011). Planted forests serve to restore degraded lands, to control soil erosion (Mishra *et al.*, 2003), and together with natural forests, they provide benefits to human society such as timber, food, fuel wood, medicinal resources, opportunities for recreation, climate regulation, soil and water protection, biodiversity preservation and carbon sequestration (Campos *et al.*, 2005; Dyck, 2003), while agriculture is the main source of food and money for humans (FAO, 2011).

This review starts with a review of classical methods for soil quality assessment in forest plantations and agricultural lands, continues with a review of the dominant soil biodiversity of arthropods, their role in maintaining soil quality, and types of measures of soil and litter arthropods indicating soil quality. It concludes with recommendations on how soil and litter arthropods can be effectively used as biological indicators of soil quality.

2 LITERATURE

2.1 Classical and recent measures for soil quality assessment

Quality of an indicator must correlate well with ecosystem processes, integrate soil physicochemical and biological processes and serve as basic inputs needed for estimation of soil properties or soil functions which are more difficult to measure directly (Doran & Safley, 1997). Furthermore, according to the same authors, an indicator must be relatively easy to use under field conditions and be assessable by both specialists and producers, be sensitive to variations in management and climate, and be components of existing soil data bases where possible. The need for basic soil quality and health indicators is reflected in the question such as: what measurements should I make or what can I observe that will help me evaluate the effects of management on soil function now and in the future (Doran & Safley, 1997)?

Soil quality is assessed by considering soil properties that are sensitive to changes in land use (Andrews *et al.*, 2004), and it has long been assessed by measuring physicochemical attributes (**Table 1).** The most commonly measured parameters include soil organic carbon and total nitrogen, soil pH, electrical conductivity, available nutrients, bulk density, and soil aggregation (Zornoza *et al.*, 2015). In other studies, the choice of soil quality indicator considered land use and land management (Laishram *et al.*, 2012) due to the interconnections of soil quality with other ecosystem components such as soil fertility, soil productivity and vegetation type (Doran, 2002).

Table 1: Soil physicochemical indicators for screening the condition and quality of soil (Adapted from: Doran & Parkin, 1994; Laishram *et al.*, 2012; Cardoso *et al.*, 2013).

Indicator of Soil Conditions	**Measured soil quality**
Physical indicators	
Soil texture	The capacity of retention and transport of water, minerals, and level of soil erosion.
Depth of soils or top soils	Potential productivity and level of soil erosion.
Infiltration and bulk density	The potential for leaching, productivity, and level of soil erosion.
Water holding capacity	The level of water retention, transport, and soil erosion.
Aggregation	Soil structure, erosion resistance, and soil management effects.
Chemical indicators	
Soil organic matter	Soil fertility, structure, stability, and extent of erosion.
Soil pH	Biological and chemical thresholds.
Electric conductivity	The threshold of plant and microbial activity, soil structure, and level of water infiltration.
Extractable nitrogen (N), phosphorus (P), and potassium (K)	Available plant nutrients and potential for nitrogen loss, productivity, and environmental quality indicators

In agricultural systems, soil organic carbon has been used as the most important indicator of soil quality (Arias *et al.*, 2005), as well as soil pH, electrical conductivity, and nutrient availability (Rahmanipour *et al.*, 2014). Physical indicators are the most commonly used with the measurement of aggregate stability and bulk density (Rouseau *et al.*, 2013). Soil microbial activity and diversity (**Table 2**) are also often used (Li *et al.*, 2014), as they are more susceptible and can therefore clearly indicate changes in the environment more responsively than physicochemical attributes (Masto *et al.*, 2009). Due to agricultural economic development, soil quality in agricultural lands can also be assessed using measures of crop productivity (Zornoza *et al.*, 2015) and direct or indirect impacts of soil degradation on human health (Deng, 2011).

Table 2: Microbial indicators of soil quality: soil cycles they are involved in, and methods for assessment (Adapted from: Doran & Parkin, 1994; Cardoso *et al.*, 2013).

Indicator	**Soil Cycle**	**Measured indicator**
Microbial biomass nitrogen (N) and carbon (C)	C, N and P	Microbial catalytic potential, repository for C and N, and effects of organic matter on land management.
Soil respiration, water content, and temperature	C	Microbial activity, process modeling, and estimate of biomass activity.
Metabolic quotient (qCO_2 index)	C	The metabolic quotient of soil microbial communities.
Microbial functional group	C, N and P	Levels of phosphate solubilizers and diazotrophic, nitrifying, denitrifying and ammonifying bacteria

Researchers have applied biochemical indicators to assess soil quality (**Table 3**). Simple ratio measures including C:N ratios, metabolic quotient, enzyme activities/microbial biomass ratios, fungal/bacteria biomass ratios, soil organic carbon and nitrogen stratification ratios were commonly used (D'Hose *et al.*, 2014; Zhao *et al.*, 2014). Ratios are considered more effective than physicochemical and microbiological indicators for the assessment of soil quality in forest plantations due to their high correlations with soil organic carbon and higher response to changes in soil use and soil management (Miralles *et al.*, 2009).

Table 3*:* Enzyme indicators of soil quality and functions played in soil cycles (Adapted from: Cardoso *et al.*, 2013).

Enzyme	**Soil Cycle**	**Enzyme function**	**Microorganisms**
Dehydrogenase	Carbon	Electron transfer	All aerobic microorganisms
ß-glucosidase	Carbon	Carbon oxidation	Several microorganisms
Cellulase, amylase	Carbon	Cellulose degradation	Mainly fungi, but also bacteria
Urease, glutamase, and asparaginase	Nitrogen	Organic N mineralization to ammonium salts and ammonia	Several microorganisms
Phosphatases (acid and alkaline)	Phosphorus	Organic phosphorus cycling	Microbial and several microorganisms
Aril-sulphatase	Sulfur	Organic sulfur cycling	Several microorganisms

Recently, more emphasis has been given to soil fauna as indicators of soil quality in forest and agricultural land use (Eggleton *et al.*, 2005). Their diversity, abundance, biomass, and density have been proven to be suitable indicators of natural or anthropogenic impacts on terrestrial ecosystems due to their correlation with physicochemical and microbiological properties and ecological changes (Paula *et al.*, 2010). Soil fauna produce galleries, pores, and tunnels in soil that facilitate the flow of air and water in soil (Lavelle *et al.*, 2006). Soil fauna are good decomposers of organic matter and participate in nutrient cycling (Moore & De Ruiter, 1991). The aggregation of soil particles and litter feeding processes enhance soil structures and accelerate dynamic production of organic matter through mineralization processes (Barrios, 2007).

Protozoans, nematodes, and annelids are soil fauna of great importance in maintaining soil quality. Protozoans participate in the stimulation of mineralization of organic matter through microbial activities (Moore & De Ruiter, 1991). Nematodes including oligochaetes and enchytraeids are good litter transformers, and through their pellets, mineralization is enhanced in a short time, while annelids including earthworms are good ecosystem engineers, participating in the production of organomineral structures and formation of soil pores (Lavelle, 1996). The role of structures created by earthworms are essential to soil ecosystems as they offer the mineralization of C and N, denitrification, and facilitate water and air infiltration (Lavelle *et al.*, 1997).

2.2 Soil arthropods and their role in maintaining soil quality

Major groups of soil and litter arthropods including Acarina, Collembola, Myriapoda as well as various orders of the class Insecta are of significant importance in terrestrial ecosystems (Ogedegbe and Egwuonwu, 2014). They are recognized for their active role in organic matter decomposition, nutrient cycling, agricultural productivity, plant growth and improving physicochemical and biological soil conditions (Vasconcellos *et al.*, 2013). By their digestive actions, soil and litter arthropods form stabilized aggregates and decompose resisting chemical substances, thereby improving nutrient availability for plants and microorganisms (Lavelle, 1997). Saprophagous arthropods affect decomposition through feeding on litter, mixing litter with soil and through the regulation of soil microflora (Suift *et al.*, 1979).

The class Insecta is the most dominant of all soil and litter arthropods. It is very diverse and highly susceptible to changes in soil characteristics, making it a good indicator group. The order of Diptera is among these insects. The main natural environmental factors affecting the distribution of Diptera are the inputs of dead organic matter into soil, changes in soil moisture content, litter depth and temperature as well as seasonal variation, and for agricultural systems, tillage, use of manure, fertilizers, and pesticide (Frouz, 1999). The community of soil-dwelling Diptera can serve as indicators of soil quality and environmental stress through an assessment of their distribution and abundance of their species in the community (Krebs, 1989). Lower taxonomic levels such from species to families are recommended to be used in this assessment (Frouz, 1999).

Soil termites also form a very important group of the class Insecta, used as indicators of soil quality due to their effects on soil profiles and soil texture, distribution of organic matter, and plant nutrients and their construction of subterranean galleries (Stork & Eggleton, 1992). Termites' foraging and activities create conditions promoting microbial populations and the mineralization of organic compounds (Culliney, 2013). Soils modified by termites showed higher microbial activity and were significantly more concentrated in ammonium, calcium, magnesium, and potassium cations and inorganic phosphorus (Ndiaye *et al.*, 2004), available phosphorus, total nitrogen, bicarbonates, chloride and sulfate anions (Badawi, *et al.*, 1982). The reduction of C:N ratios by fungi provide organic matter enriched in nitrogen to termite colonies and, by feeding on fungi, nutrients from the litter are incorporated into the biomass of termites with highly efficient assimilation of nitrogen (Lee, 1983).

Hymenoptera, particularly ants, form another dominant group of the class Insecta in most terrestrial environments (Culliney, 2013). Mounds of ant species contain higher exchangeable cations including calcium, magnesium, potassium, sodium cations, and they are rich in trace elements including iron, manganese, and zinc (Wali & Kannowski, 1975). Ant mounds also contain higher concentrations of nitrate and ammonium salts (Amador & Görres, 2007), available phosphorus and potassium and showed higher levels of microbial activities than in uninhabited control soils (Czerwiński *et al.*, 1971). The increase in soil nutrient and soil organic matter content in ant mounds are factors influencing the variation of soil pH (Frouz & Jilková, 2008).

In habitats with high anthropogenic activities, Coleoptera insects including carabid beetles are good indicators of changes in soil properties (Kromp, 1999), namely pH, sodium chloride levels and calcium content (Avgan & Luff, 2010). For sustainable agricultural systems, carabid beetles play the role of predators and prevent outbreaks of several pest insects (Luff, 1996). Scarabaeidae beetles are important in the breakdown of dung, carrion and leaf litter, and return nutrients to the soil (Greenslade, 1985). Communities of staphylinid can be used as bioindicators of human influence on soil ecosystems (Bohac, 1999), through the use of species diversity indices, and individual relative abundance in the sample (Ruzicka & Bohac, 1994).

Besides insects, collembolans form another group of soil and litter arthropods used as indicators of soil quality. They contribute to the decomposition of plant residues, increase mineralization by selective feeding on fungi, and help in the formation of humus by mixing organic material and mineral soil particles (van Amelsvoort *et al.*, 1988). They form water-stable aggregates in the soil and strong inter-particle cohesive forces within fecal pellets (Siddiky *et al.*, 2012). Stimulatory effects of collembolans on fungal growth and respiration through grazing (Filser, 2002) results in mobilization of available nitrogen and calcium in soils (Ineson *et al.*, 1982), and their feces contain more nitrate ions, increasing their availability on the forest floor (Teuben & Verhoef, 1992).

Another group of soil and litter arthropods of interest in the assessment of the soil quality is Isopoda. They are sensitive to the application of pesticides and herbicides which can cause a rapid decrease of these soil and litter arthropods in intensively managed agricultural and forest plantations (Fischer *et al.*, 1997). Isopoda biomass contributes to the storage of potassium, sodium, phosphate ions, and nitrogen and calcium ions in soil (Teuben & Verhoef, 1992). They constitute an important nutrient pool which immobilizes ions and prevents leaching from the soil (Zaady *et al*., 2003). Due to their tolerance to high-level metals, Isopoda indicate soil contamination by heavy metals especially copper (Hopkin *et al.*, 1993), zinc, lead and cadmium (Prosi & Dallinger, 1988).

Soil quality assessment has been also done using mites, which are among the most species-rich and numerous soil and litter arthropods, having a positive influence on the decomposition rates of organic matter, bacterial and fungal colonizers. They produce fecal pellets which enhance further decay and contribute to improved soil structures by assisting the distribution of bacterial and fungal propagules through the soil and leaf litter (Maraun *et al.*, 1998). In agricultural lands, the processes of cultivations, rotations, monocultures, and application of pesticides are the activities with negative effects on the community of mites (Tomlin & Miller, 1987). Mites give good results of soil status once the cause of the change in soil properties is known in advance (Linden *et al.*, 1994).

Diplopoda and Symphyla, the most important myriapods in soils, form another group of soil and litter arthropods used in the assessment of soil quality. They influence the distribution of microbial populations in soil (Szabó *et al.*, 1983) and participate in the decomposition of plant material, which increases nutrients on the surface area and makes them available for bacteria and fungi (Paoletti *et al.*, 2007). Diplopoda and Symphyla contribute to the decomposition of leaf litter by fragmentation and the addition of microflora through fecal pellets, and they release mineral nutrients into the soil by feeding and defecation which is essential for soil as this brings down C:N ratios. Furthermore, their feces have a relatively high pH which facilitates the growth and concentration of nitrogen-fixing bacteria (Bagyaraj *et al.*, 2016).

2.3 Types of measures of soil and litter arthropods indicating soil quality and their challenges

Many soil and litter arthropods including collembolan, Oribatida, Isopoda and Diplopoda live a rather sedentary life and therefore reflect local conditions of a habitat (Van Straalen, 1998). These facts have been recognized for a long time, and relationships between soil types and soil and litter arthropods have been established in various studies (Rusek, 1989). Use of soil and litter arthropods as indicators of soil quality has commonly been done by measuring soil and litter arthropod biomass, density, abundance, species richness, and biological indices (Yeates & Bongers, 1997; Foissner, 1994) of either single taxon groups (Santarufo *et al.*, 2012), or of the entire community (Aspetti *et al.*, 2010).

Recently, a simplified ecomorphological index (EMI) based on the morphology of micro-arthropods has been introduced (Parisi & Menta, 2008). It is used to evaluate soil quality based on which groups are present in soil samples, where taxonomic groups receive an EMI score from 1 to 20 (**Table 4**), according to its adaptation to the soil environment. Deep soil living forms are given an EMI score of 20, intermediate forms are given a score proportional to their degree of specialization, while surface-living forms are scored with an EMI equal to 1 (Parisi *et al.*, 2005). The Biological Quality of Soil Index (BQS) is calculated as the sum of EMI scores and soil quality correlates with the number of groups of arthropods with high EMI scores.

Table 4: Ecomorphological indices (EMIs) of edaphic microarthropod groups (Adapted from: Parisi *et al.*, 2005).

Group	EMI Score	Group	EMI Score
Blattaria	5	Acari	20
Coleoptera	1-20	Araneae	1-5
Collembola	1-20	Opiliones	10
Diplura	20	Isopoda	10
Diptera (larvae)	10	Chilopoda	10-20
Embioptera	10	Palpigradi	20
Hemiptera	1-10	Diplopoda	10-20
Hymenoptera	1-5	Pauropoda	20
Orthoptera	1-20	Symphyla	20
Other holometabolous insects (adults)	1	Dermaptera	1
Other holometabolous insects (larvae)	10	Psocoptera	1
Protura	20	Microcoryphia	10
Thysanoptera	1	Zygentomata	10

However, a true theory of community composition of soil and litter arthropods in relation with other environmental factors still remains to be developed. Although diversity indices represent variables that can be measured independently of the difficulties involved in identification of soil and litter arthropods at species level, these measures represent a snapshot in time (Anderson *et al.*, 1985). They give little information about the community structure, and changes in abundance can be related to other factors such as predation, grazing and mutualistic relationships. They can also be related to other abiotic and biotic factors (King *et al.*, 1985), including climate variability and climate change, variations in temperature, moisture, soil salinity, soil pH, the type of vegetation, and land use (Schils *et al.*, 2006).

These are the reasons why measuring abundance, biomass, density, diversity and evenness is not enough for assessing the status of soil arthropods and hence soil quality. Some other factors including the relationship between biological parameters (species composition, life history diversity, feeding type and physiotype) and environmental parameters (soil type, microbial populations, soil pH, humidity, temperature, nutrients, heavy metals and pesticide residues) have to be studied (Van Straalen, 1998). Functional significance including fragmentation, soil aggregation, organic matter and nutrient distribution, mineralization rate, and nutrient mobility (**Table 5**), as well as spatial and temporal scales, have to be considered (Bagyaraj *et al.*, 2016).

Table 5: Classification of soil fauna according to their size and function (Adapted from: Schjønning *et al.*, 2004; Faber, 1991).

**Mites (Acari); spring tails (Collembola); **Spiders (Arachnida), Millipedes (Diplopoda); Termites (Isoptera); Slater (Isopoda); Centipedes (Chilopoda); Ants (Hymenoptera; and Beetles (Coleoptera).*

Function	**Body size**	
	Mesofauna (0.2 – 2.0mm)*	**Macrofauna (>2.0mm)****
Fragmentation of residues	x	x
Stimulation of microbial activity		x
Organic matter and nutrient redistribution		x
Soil aggregation (biopores)	x	x
Carbon sequestration		x
Nutrient cycling, mineralization, and immobilization	x	
Humification	x	x
Feeding on fungal hyphae	x	
Opening channels and galleries		x
Regulation of bacterial and fungal populations	x	
Mixing of organic and mineral particles		x

Variations of soil and litter arthropods in samples may also depend on the sampling method used (Ferrer-Paris *et al.*, 2013). Berlese-Tullgren funnels, pitfall traps, hand collection and Winkler extraction are the most used sampling methods for soil and litter arthropods (Tuf & Tvardik, 2003). However, less is known about the relative trapping efficiency of each of these sampling methods (Krell *et al.*, 2005). The knowledge of the taxa that are most likely collected by each sampling method and the sampling method likely to collect the highest diversity of soil and litter arthropods remain the topic of interest, which has to be studied before generalization of any sampling-dependent findings (Sabu & Shiju, 2010).

2 CONCLUSIONS AND RECOMMENDATIONS

Even though community indicators meet most of the desired parameters to determine soil quality in the habitat under investigation, many other interesting criteria must be met, including soil physicochemical parameters, types of vegetation, soil microbial communities and enzymes (Van Straalen, 1998), soil ecological functions (Laishram *et al.*, 2012) including availability of soil nutrients and soil structures (Culliney, 2013). Changes in these parameters may have varying effects on diversity and abundance of different species of soil and litter arthropods (Lavelle *et al.*, 2006), so that the relationship between soil and litter arthropod biological parameters, and soil ecological functions played by soil and litter arthropods (Table 5) have to be studied (Cardoso *et al.*, 2013) before making a general conclusion on soil status.

Further research should explore the effect of combinations of various sampling and measuring methods. If both species diversity and abundance have to be used for assessing soil quality in different land use, we recommend that they be used together with other physicochemical parameters of soil, microbiological communities and enzymes as well as environmental factors such as seasonal variability and altitudinal variations (Sicardi *et al.*, 2004). These studies should focus on the identification, comparison and testing different sampling methods for sampling soil and litter arthropods and the development of a hierarchy classification system up to species level for dominant soil and litter arthropod species. From our review, we propose that these steps could lead to a generalized and accepted approach for soil quality assessment using soil and litter arthropods.

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