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IMPORTANCE OF SOIL FAUNA FOR SOIL ORGANIC MATTER DYNAMIC IN AGROECOSYSTEMS - minireview

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Abstract: Soil Organic Matter (SOM) is essential for soil fertility, climate change mitigation, biodiversity conservation and associated ecosystem services. Existing models of SOM dynamics do not take into account the important contribution of soil fauna activity. The explanation for this limitation is given, on the one hand, by the complexity of the interrelationships between the different categories of soil organisms and on the other by the existing gaps in knowledge on the biodiversity of soil fauna. The paper includes a review that underpin the selection of fauna groups which can be used in modeling as a first step for the further development of a soil monitoring systems and also the prediction of vegetal production in agroecosystem.

Key words: *soil fauna, soil organic matter, Soil Quality, soil biological indicators*

INTRODUCTION

Due to their functional roles and the provision of various ecosystem services, soil fauna are important components of agricultural ecosystems. Agricultural practice involves an intense land use (especially through monoculture, use of pesticides, frequent and deep tillage, inadequate soil cover and poor management of organic residues, physical degradation) and need high input of inorganic fertilizers application to restore soil fertility which in turn has negative effects on soil biota (Hendrix et al., 1986; Lavelle et al., 2001; Coleman &Whitman, 2005; Brussaard et al., 2007; Ayuke et al., 2011). The loss of abundance and diversity of arthropod communities under annual crops results invariably in a loss of certain important soil functions (Lavelle, 1996; Giller et al., 1997). A mega study performed across Europe show that among 19 different functional groups of the soil food web the species richness of earthworms, collembolans, and oribatid mites was negatively affected by increased land-use intensity (Tsiafouli et al., 2015). Other recent studies suggest the soil's structure is disturbed, soil organic matter (SOM) is lost and the impact of agricultural intensification on soil ecosystem services can seriously damage the quality of soils (Liiri et al., 2012; Bedano & Dominguez, 2016). The term “soil quality” has been introduced to describe the combination of chemical, physical, and biological characteristics that enables soils to perform a wide range of functions. Because soil arthropods are regulated by anthropogenic impacts this soil organisms are currently used as indicators of soil quality in order to compare different management systems. A direct quantification of soil functions requiring various costly and labour intensive analyses is generally not feasible, so an promising alternative approach could be to use this fauna groups as “biotic indices” (Baveye et al., 2016; Rabot et al., 2017; Schulte et al., 2014). Numerous studies have been done using single taxon groups, for example: Acari, Isopoda, Coleoptera, Araneae, or Collembola (Holland & Reynolds, 2003; Santurofo et al., 2012; Cluzeau et al., 2012) and others are dealing with integrative quality indices (Parisi et al., 2005; Aspetti et al., 2010]. Some agricultural management practices have positive impacts on soils fauna, increasing SOM levels and improving soil functioning and plant productivity.

Existing models of SOM dynamics do not take into account the important contribution of soil fauna activity. The explanation for this limitation is given, on the one hand, by the complexity of the interrelationships between the different categories of soil organisms and on the other hand by the existing gaps in knowledge on the biodiversity of soil fauna. Monitoring soil components plays a key role in acquiring basic data to assess the impact of nutrient application in agroecosystems. In this review we present the current knowledge that underpin the selection of soil fauna groups which can be used in modeling as a first step for the further development of a soil monitoring systems designed for the prediction of vegetal production in agroecosystem.

MATERIAL AND METHODS

Based on a comprehensive searching of available literature, Internet resources and also on personal communications with experts in the field, the main objective of this review was to clarify a series of aspects related to SOM dynamics and two "key" groups: (i) collembolans in the upper soil surface layer and (ii) earthworms for the deep soil layer; well known for their beneficial functions, and considered as biological indicators of soil quality. To accomplish with this objective, this review has been organized into two sections. In Section 1, we are briefly presenting the concept of soil organic matter as a soil quality indicator; in section 2 we introduce general knowledge related to soil fauna and their potential to be used as soil quality indicators in respect with their role for SOM dynamic in agricultural soils.

RESULTS AND DISCUSSIONS

Soil Organic Matter and Soil Quality

SOM is present in all soils all over the world but is heterogeneous in nature and due to the variable biological factors, under which it was formed, does not have any defined physical or chemical structure. It can be described as a complex mixture of organic material (including: plant residues, soil biota and humic substances), present in soils under various stages of decomposition.

Organic matter is an essential component of soils because it: (i) provides a carbon and energy source for soil microbes; (ii) stabilizes and holds soil particles together, thus reducing the hazard of erosion; (iii) aids the growth of crops by improving the soil's ability to store and transmit air and water; (iv) stores and supplies such nutrients as nitrogen, phosphorus, and sulphur, which are needed for the growth of plants and soil organisms; (v) retains nutrients by providing cation exchange and anion-exchange capacities; (iv) maintains soil in an uncompacted condition with lower bulk density; (vii) makes soil more friable, less sticky, and easier to work; (viii) retains carbon from the atmosphere and other sources; (ix) reduces the negative environmental effects of pesticides, heavy metals, and many other pollutants. Soil organic matter also improves tilt in the surface horizons, reduces crusting, increases the rate of water infiltration, reduces runoff, and facilitates penetration of plant roots (www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053150.pdf).

SOM plays a critical role in the global C cycle due to its role as both a major source and sink for C in the biosphere. It is estimated that the total soil C pool is three times greater than the atmospheric C pool (Krull et al., 2014).

The dynamic of SOM is dependent on the complex interaction between soil parent material, vegetation, landscape complexity, soil biota, climate, and human intervention over time. Paul et al. (2015) show that the amount and quality of SOM are dependent on the amount and type of plant inputs as well as their turnover before stabilization. Depending on landscape position, vegetation, and management intervention SOM in surface horizons ranges from less than 10 to more than 30 g C kg−1 (Syswerda et al., 2011). The soil biota (microorganisms together with their associated products, and soil fauna) account for 1-3% of total soil Carbon (C) and complete the terrestrial C cycle by mineralizing the SOM to carbon dioxide (CO_2) (Robertson & Paul, 2000; Paul et al., 2015).

The concept of soil quality (SQ) has been developed by soil scientists to describe the fitness of soils to perform particular ecosystem functions (Karlen et al., 2001). Glenk et al. (2012) define soil function as "soil processes that underpin the delivery of ecosystem services". Because many soil ecosystem functions are difficult to be directly measured; SQ must often be inferred from easily measurable soil properties named "the soil quality indicators". Doran and Safley (1997) and Pankhurst et al. (1997) suggested that an indicator, regardless of its nature, must comply with following criteria: (i) be easily interpretable; (ii) correlate well with ecosystem processes; (iii) integrate soil physical, chemical, and biological properties and processes; (iv) be accessible to many users; and (v) be sensitive to changes. In addition, an indicator must have reproducibility, low temporal and spatial variability, and simple sampling and analytical methods.

A recent review of SQ concept (Bunemann et al., 2018) point out the fact that an important component of soil quality assessment is represented by the identification of a set of sensitive soil attributes that reflect the capacity of a soil to function and can be used as indicators of soil quality. The same authors mention that a number of elements are mandatory in soil quality assessment: (i) a clear definition of the objectives depending on the assessment aim (e.g. as a part of a monitoring program, a basis for management recommendation or an educational tool); a clear definition of the target function that will further determine the soil depth that is to be evaluated and (iii) the target users of the result (some time participants to this effort) should be named from the beginning. All of these should be related with the ultimate purpose of the soil quality index which is to inform farmers, land managers and others stakeholders about the consequences that human decisions and interventions can have on soil-based ecosystem services.

Soil fauna and Soil Quality

Soil biota also responds rapidly to soil anthropic management and land use changes and can be candidates for soil quality indicators. Soil fauna (particularly nematodes, springtails, mites, earthworms, and insects) play key role in the initial breakdown of complex and large pieces of organic matter, making it easier for soil microorganisms to continue the process of decomposition (Jenny, 1980). They not only stimulate microbial activity and accelerate the organic matter decomposition and nutrient transformation but also enhance soil aggregation, soil pollutant degradation, stimulate the succession of species and pest control.

Earthworms are one of the few soil macro-fauna groups that have been often considered usable as biological indicators since standardized sampling methods are available, their taxonomy is well known and practicability of their use is demonstrated in determining the influence of different anthropogenic land use forms (Rombke et al., 2005). Recently developed methods like Stable isotope ratio analysis of light elements (C, N and S) that is a powerful research tool to reveal and quantify trophic relationships of earthworms in soil food webs, and molecular techniques can further enhance our understanding of the interactions between earthworms and microorganisms and their functional significance (Curry & Schmitt, 2007).

Frund et al. (2010) detailed how earthworms can indicate soil quality by (i) the abundance and species composition of the earthworm fauna at a particular site, (ii) the behavior of individual earthworms in contact with a soil substrate (preference/avoidance/activity), (iii) the accumulation of chemicals from the soil into the body, and (iv) the biochemical/cytological stress-biomarkers in the earthworm.

There are plenty of research papers about the role of earthworm on soil properties, concluding that earthworms enhance the fertility of soil by enhancing the physical, chemical and biological properties of soil (Ojka & Devkota, 2014).

Earthworms are extremely important especially in the upper 15-35 cm of soil where their feeding and burrowing activity influence plant growth, nutrient turnover and seedling development (Asshoff et al., 2010) and because some species play important role in bioturbation have been described as “ecosystem engineers”(Lavelle et al., 1997; Hale et al., 2005; Rombke et al., 2005; Ojka & Devkota, 2014). Based on their feeding strategies, earthworms can be separated into two groups: (i) detritivores, which feed on plant litter and mammalian dung (surface feeders) and (ii) geophages which feed in the deeper layers of soil on plant material. These two groups can be further subdivided depending on which soil horizon they feed in (Curry & Schmitt, 2007). Another classification, based on their habitat divided earthworms into three ecological groups: (i) epigeic or litter-dwellers because they inhabit litter, organic rich surface layers, ingest plant residues; but worms may be absent in plowed, litter-free soil; ii) endogeic (or mineral soil-dwellers) which live in topsoil that is rich in organic matter, they burrow narrow channels and feed on a mixture of soil and plant residues and mix mineral and organic soil layers together; and (iii) anecic which are deep soil-burrowers that dig long, large burrows into deep soil layers and carry with them litter and plant residues and feed on them and on soil.

Earthworm cast is digested material that is excreted back into the soil. Cast is enriched with nutrients and microorganisms during its passage through the worm’s digestive system. This way, immobile macro nutrients like phosphorous and other micronutrients, which are absorbed by plant through root interception, are easily available to the plants. Earthworms can greatly enhance the mineralization of N and can stimulate other N transformation such as denitrification (Kooch & Jalilvand, 2008). Nutrients are temporally and spatially synchronized with plant needs and so earthworms contribute to decrease the risks of nitrate leaching.

Collembola is one of the most abundant and widely distributed taxa among terrestrial Hexapoda (Hopkin, 1997). The potential use of Collembolans as biological indicators of soil health and ecosystem quality is increasingly and consequently knowledge of the diversity of springtail becomes useful in the development of conservation strategies and environmental monitoring recognized (Stork & Eggleton, 1992; Zeppelini et al., 2008). Soil quality is positively correlated with the abundance and number of Collembola species that are well adapted to soil habitats (Parisi, 2001). Many papers indicated that the abundance of soil mesofauna is higher in places with relatively high organic matter and humus content (Twardowski et al., 2016; Kovac & Miklisova, 1997). In most agricultural soils, organic matter can be increased by leaving residue on the soil surface, rotating crops with pasture or perennials, incorporating cover crops into the cropping rotation, or by adding organic residues such as animal manure, litter, or sewage sludge. Many authors shows that aaddition of organic matter (e.g. vermicompost, compost, manure, sewage sludge and other organic wastes) in the agrosystem was positively correlated with increased populations of mites, collembolan, and other different predacious soil arthropods (Pimentel & Warneke, 1989; Gunadi et al., 2002; Mathews et al., 2002; Brown & Tworkoski, 2004). Battigelli et al. (2004) explained that organic not only supplies nutrients but also improves soil porosity, which creates a suitable habitat for soil mesofauna. Soil-dwelling springtails decompose plant residues (Kiss & Jager, 1987; Takeda, 1988). By their selective feed on fungi, larger species increase mineralization while smaller one contribute to soil humification by non-selective scavenging and by mixing organic material and mineral soil particles (van Amelsvoort et al., 1988). The decomposer activities of springtails depend on their relationship with microbial communities and are very sensitive to various biotic and abiotic stressors. Collembolan species are often selected as model organisms for soil ecology and ecotoxicology, such as species *Folsomia candida* Willem F. that has been used as a "standard" test organism for more than 50 years for estimating the effects of pesticides and environmental pollutants on nontarget soil arthropods, using the protocols published by the International Standards Organization (ISO 1999; Organisation for Economic Co-operation and Development 2009). *Folsomia* is currently used in Ecological Risk Assessment schemes for in-soil organisms exposed to various pesticide application but it has also been employed as a model for the investigation of numerous other phenomena such as cold tolerance, quality as a prey item, and effects of microarthropod grazing on pathogenic fungi and mycorrhizae of plant roots.

Despite of the abundance of the literature on this topic, the ccurrent knowledge is limited about the impacts of fertilizers on soil fauna and subsequently on their functions.

At national level, the researchers regarding the impact of fertilizers on soil fauna are very scarce. Sandor et al. (2016) developed 56 microcosm experiments which were made with four types of fertilizer regime, two soil types and two hydric regimes in order to bring new data on the effect of fertilizers (mineral and organic) on earthworms (*Aporrectodea caliginosa* and *Lumbricus terrestris*) and springtails (*Folsomia candida).* This experiment showed that while mineral fertilizers seem to have a detrimental impact on soil fauna, the use of caw manure and green manure exhibit beneficial effects in terms of biomass and density of soil invertebrates. The effects of various human interventions on soil fauna in agroecosystems should be well studied; the need for more field studies involving the use of selected biological quality indicators is obvious.

CONCLUSIONS

One of the major challenge within sustainable soil management in agriculture is to find a way to optimize agricultural yields while conserve ecosystem service delivery. It is particularly important to understand how fertilizers impacts on soil fauna and subsequently on their functions. SOM and earthworms have been directly and positively related to soil fertility and agricultural productivity potential and can be used as indicators of soil quality. Changes in the activities of springtail communities, as a result of soil management practices, make this soil fauna group a third valuable candidate of a set of biological indicators of the soil quality that can be used in research modeling programs as a first step for the further development of a soil monitoring systems designed for the prediction of vegetal production in agroecosystem.

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