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PLANT - SOIL FAUNA INTERACTION - BIOINDICATORS OF SOIL PROPERTIES IN AGROECOSYSTEMS

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Abstract

Agricultural systems have a great diversity of functional traits of plants and soil biota. Invertebrates play a key role in determining soil sustainability and crop health. Many species of invertebrates are important in soil fertility and play a vital role in the production and maintenance of healthy soils. Soil fauna have several roles in the functioning of ecosystems: they influence plant productivity, regulate nutrient mineralization, allow decomposition and act as a buffer. The functional groups of invertebrates in relation to plants are reliable bioindicators, as they provide information on soil quality, ecological services and the functioning of the ecosystem as a whole. The conceptual approach of plant-soil interaction research has shifted from plant strategies to more quantitative approaches using plant-specific functional traits and soil food web characteristics. Because plants use nutrients in inorganic form, they depend on the rate of mineralization in the soil. It has often been assumed that nutrient mineralization is mainly the result of soil microflora activity. The appearance of soil fauna population increases the release of nutrients by fragmenting waste, grazing microflora.

Key words: *agroecosystems, bioindicators, plants, relationship, soil fauna.*

INTRODUCTION

Soils are living environments with a great diversity of plant species and invertebrates. The interaction between plants and invertebrates has an impact both in soil fertility and in the provision of ecosystem services. Soil functions as a favourable habitat for many invertebrate species, and invertebrate communities are involved in geochemical cycles (Lemanceau et al., 2014). Soil benefits from a very rich food web on which many of the terrestrial species depend directly or indirectly (Stork & Eggleton, 1992). Climate and land use changes cause modifications to all ecosystems, including to the structure and distribution of invertebrate communities and species distribution. Some studies predict a lack of self-regulation of soil caused by the disturbances of key links in food webs, caused by rising temperatures, loss of humidity, pollution, etc. In addition to changes in the dynamics of the invertebrate community, changes also occur in terms of functional features of plants (Ulrich et al., 2020). Soil fertility represent its capacity to supply the nutrients (including water) to plants (Culliney, 2013) taking into account the optimal ecological requirements of them (Boháč, 1990). A fertile soil can be defined either on the basis of its own properties or according to the production and productivity of plants. Soil fertility is determined by several physical properties (i.e. texture, structure, profile depth, water retention capacity, drainage capacity), chemical (pH, amount of essential elements available for plants, ion exchange capacity, organic and mineral matter content) and biological (soil organisms, abundance-dominance ratio, intraspecific and interspecific relations) (Chiriac et al., 2020). Crop productivity and soil fertility are steadily declining due to the lack of these essential elements in agroecosystems. Sustainable soil management not only improves crop productivity but also increases soil fertility and sustainability (Khalid et al., 2019). Agricultural systems must sustain stable crops and save energy, inputs and natural resources. This is a goal of new and modern agricultural systems that have very few inputs and are more environmentally friendly providing the expected ecosystem services (Lemanceau et al., 2014). The main purpose of this study is the critical analysis of the literature on the relationship between plant traits and functional groups of invertebrates, a relationship used as a bioindicator of soil fertility in agricultural systems.

MATERIALS AND METHODS

A literature search was conducted using Google Academic, Research Gate and Web of Science. In the present study, no restriction on the publication date was set and we considered original studies and reviews. To identify relevant publications about the relationship between soil invertebrates and plants for the management of agroecosystems, we used different combinations of the search terms "soil" and "soil functions" or "soil quality", "soil health". Other keywords used in conducting the critical analysis of the literature were: springtails and collembola, earthworms, earthworms functions, nematoda, nematoda functions, bacterivores species, fungivores species, agroecosystems, characteristics of agroecosystems, biodiversity role in agriculture, relationship between plants and invertebrates in agricultural systems, invertebrates in agriculture, soil - plants - invertebrates, plant - soil feedback in agriculture, using plant - soil feedbacks, plant and invertebrates as indicators. In this study, we focused only on three groups of invertebrates in the soil: springtails (Collembola), earthworms (Lumbricidae) and nematodes (Nematoda). We analysed 140 scientific papers, but we considered to include in the present publication only 77 papers comprising our interest.

RESULTS AND DISCUSSIONS

Due to the accelerated growth of soil degradation in recent decades, it has been necessary to identify methods to define not only soil quality but also, in a holistic approach, soil health (Menta & Remelli, 2020). Soils are living environments in which particularly abundant and diverse microbiome and fauna are involved. The resulting biological functioning has a direct impact not only on soil fertility but also on a series of ecosystems services (Lemanceau et al., 2014). Soil is one of the most heterogeneous ecosystems on the planet. It plays an irreplaceable role in the biosphere: it governs plant productivity and allows organic matter degradation and nutrient cycles (Santorufo et al., 2012). Soil quality represents the ability to function within the limits of the ecosystem, to support crop and animal productivity, to maintain or enhance environmental sustainability, and to improve human health worldwide (Yang et al., 2020). Invertebrates in soil can be defined as all the ontogenetic stages of organisms that live permanently or temporarily in the soil or on its surface. Soils provide goods and services (production services) that the human population can benefit (Lavelle et al., 2006). Soils provide goods and contribute to ecosystem services, having important functions in the supply of food and fiber (Cornu et al., 2020). It functions as a support for agro-forestry-pastoral ecosystems. It also has a role in regulation services (climate regulation by controlling the flow of greenhouse gases, carbon sequestration, flood control). It also contributes to cultural services, but in a lesser extent due to society's low interest in the sustainable use of this key resource (Lavelle et al., 2006). Soil invertebrates can play two roles in the soil food web: shredding and wetting ingested plant debris thus improving the substrate for bacterial decomposition and ecosystem engineers (organisms that physically modify the habitat by establishing the availability of resources for other species) (Culliney, 2013). Soil invertebrates have a great importance in soil quality and considering their size, can be divided into microfauna (nematodes in general), mesofauna (not large enough to change soil structure; mites, collembolans, enchitraeids, small diplopods) and macrofauna which change the soil structure by their movements (isopods, eartworms beetles, dipterans, ants). The advantage of studying these organisms is that they benefit from a great diversity, appear in large numbers, are easy to take in every season (Stork & Eggleton, 1992; Behan-Pelletier, 1999; Manu et al., 2015). All these groups of soil fauna presented above have an essential role in the soil processes. They improve microbial activity by accelerating decomposition and mediating soil transport processes (Stork & Eggleton, 1992; Stone et al., 2020). Soil invertebrates are critically important for human well-being, contributing to soil function by regulating key ecosystem services such as litter decomposition, nutrient cycling, plant nutrient uptake and climate regulation such as CO_2 fluxes (Bastida et al., 2020).

Invertebrates in the soil, taxonomy and ecology

Individual species have functional traits than can be grouped together to form functional groups. Functional groups create the biophysical traits of ecosystems, through interactions between ecosystems, communities and individual species traits (Zoeller et al., 2020). Regarding the ecology of functional group of invertebrates, they have a global distribution depending on certain factors. Abiotic factors, as altitude and latitude are the most important, determining both the composition and the structure of the trophic networks of invertebrates. In addition to these aspects, anthropogenic activity has a major impact; for instance, low concentrations of heavy metals are not toxic for plants, invertebrates and animals, but they are indispensable for multiple soil functions (Stork and Eggleton, 1992; Manu et al., 2017; Inobeme, 2021). Many soil functions (litter decomposition, nutrient cycling) are influenced by the relationship between the biological activity of soil non-vertebrates and the processes above the soil. Moreover, invertebrates are also used as soil quality indicators (Lavelle et al., 2006; Fiera et al., 2020). The majority of invertebrate groups are sensitive to environmental changes. They present a fact response to soil management and are influenced by environmental characteristics: refuge, breeding or feeding habitats. For this reason they function as a tool for monitoring the quality of the environment (Paoletti et al., 2009; Manu et al., 2019; Manu et al., 2020). Some soil invertebrates can be used as indirect indicators (for the entire soil community), as well as direct indicators (for the provision services of soil ecosystems) (Domínguez et al., 2018).

Collembola (springtails)

Collembolans play an important role in decomposition process. Larger species accelerate the mineralization process while smaller species help the soil humidification (Stork & Eggleton, 1992). Some characteristic Collembola species had been identified in agroecosystems where they accelerate decomposition, influence microbial activity and nutrient cycling. Phytophagous species influence the distribution of highly mobile metals (i.e. potassium) and detritivore species accelerate the mineralization rate of less mobile elements (i.e. phosphorus and calcium) (Mulder, 2006; Fiera et al., 2020). Low numbers of collembolans in an ecosystem stimulate the growth of bacterial activity, but when they multiply excessively they affect fungal populations and thus can reduce the process of soil humidification (Stork & Eggleton, 1992). Springtails are known to have a great impact on above and below ground ecosystems (Baird et al., 2019).

Lumbricidae (earthworms)

The role of earthworms in agricultural ecosystems is also increasingly recognized (McTavish & Murphy, 2020). Soils in which earthworms are present have many properties: larger volume pores, higher water retention capacity and infiltration rate and higher nutrients retention rate (Stork & Eggleton, 1992). Earthworms (also termites and ants) have been identified as the most important soil engineers (Spurgeon et al., 2013). In essence, “soil engineer” means the ability of organisms to build organo-mineral structures with certain physical, chemical and microbiological properties through their movements. These structures can be of several types: casts, mounds, fungus-comb chambers and so on (Jouquet et al., 2006). Earthworms can actively or accidentally ingest seeds as they move through the soil (McTavish & Murphy, 2020). Thus, they have an important role in the processes that take place in the soil establishing its quality, influencing the decomposition of organic matter, nutrient cycles, soil structure, and being key species in food webs (Ezeokoli et al., 2021).

Nematoda (nematodes)

Nematodes are the most abundant organisms. Like the other invertebrates, they provide many ecosystem services and maintain the stability of food webs by ensuring the nutrient cycles (Neher, 2001; Zhang et al., 2020). Nematodes are heterotrophic, primary consumers (parasites of plants), secondary consumers (predators) and consumers of decomposers (bacterivores and fungivores) (Wasilewska, 1997; Bonkowski et al., 2009). Nematodes are biological components of multiple functional groups of the soil food web, and can be used as indicator of ecological processes (the maintenance of nutrient cycling and soil suppressiveness against pest or invasive species) (Sánchez-Moreno & Talavera., 2013).

The main function of bacterivores in the food web is to improve the mineralization of immobilized nutrients in organisms contributing more than 80% to nitrogen mineralization (Ferris et al., 2004). Bacterivorous nematodes represent the first group of invertebrates reacting to environmental changes; for example the introduction of a quantity of nitrogen can change this group structure in 24 hours (Wasilewska, 1997). The increase in the number of fungivores offers information about an augment in soil acidity caused either by the excessive use of mineral fertilizers or by an acid rain. For this reason, nematods are considered a good indicator group that can highlight changes occurring in soil characteristics. The increase in the abundance of plant parasites is correlated with the processes of environmental damage caused by excessive use of nitrogen-based fertilizers, intensification of agricultural activities, contamination by acid rain, drying of swampy soils. Predatory nematodes represent the highest trophic level in the soil microfauna. The potential to use this group as a bioindicator is low due to low numbers of individuals, especially in agricultural lands. Increasing the abundance of predatory nematodes may be an indicator of an unaffected environment (Wasilewska, 1997). In food webs, the basal entities usually are not biological species but feeding groups (guilds, trophic species) consisting of groups of species which are assumed to be functionally equivalent (i.e. depending on similar prey and therefore exert similar top-down forces on prey populations) (Scheu, 2002).

The characteristics of an agroecosystem

An agroecosystem consists of land cultivated with cereals or other plants that depend on fossil fuels and agricultural products. Agroecosystems totally depend on human input and are functional units of the man-made biosphere (dos Santos et al., 2021) covering as much as a quarter of the global land (38% of global land use) located near human settlements (Rapidel et al., 2015). These simplified systems with low diversity and simplified trophic network (mono-specific crops) may be more complex systems (pastures, poly-specific crops and agroforestry systems) with the ability to support greater biodiversity (Estrada et al., 2012). Agricultural ecosystems are anthropogenic systems (ecological systems modified by humans), their origin and maintenance are associated with the activity man, who transformed nature to obtain mainly food and fibres (Altieri, 2002; Sans, 2007) and other agricultural products (dos Santos et al., 2021). Agricultural systems also produce other goods and services essential for human beings (climate regulation, flood protection) (Rapidel et al., 2015). In agroecosystems, soil health can change due to anthropogenic activities, such as intensive cultivation practices and land use management, which can have an additional impact on soil functions (Manu et al., 2018; Yang et al., 2020).

Soil functions important for agro-ecosystems

The nature of the soil is determined by its chemical, physical and biological properties. It plays a key role in setting growth, productivity and reproductive success of plants (van der Putten et al., 2013). The quality of a soil can be defined as its metabolism, the ability to support plant growth and animal productivity, to maintain or improve water and air quality (Maikhuri & Rao, 2012), participates in nutrient cycling through mineralization, has a role in energy transfer and functions as a buffer (Neher, 2001). The function of soil production has long been recognized but others that support the provision of ecosystem services such as water purification, pathogen control, nitrogen fixation and biodiversity conservation have been discovered more recently (Maikhuri & Rao, 2012).

Soil invertebrates can participate both directly and indirectly in processes of decomposition and its genesis and can influence soil characteristics (porosity, aeration, fertility, infiltration) (Manu et al., 2019). Soil quality determines the sustainability of agriculture and the quality of the environment in general (Maikhuri & Rao, 2012).

Soil food web

A food web is a map of the feeding relationships between species in which energy flows and dynamics are highlighted. The trophic level represents the energy flow that occurs when one organism feeds on another organism (Walter et al., 1991; Neher, 2010). The structure of trophic interactions determines the sensitivity of food webs to perturbations, but rigorous assessments of plant diversity effects on network topology are lacking (Giling et al., 2019).

The food web can also be defined as an ecological network whose nodes are the species in the ecosystem and in which the links are the prey-predator relations. The direction of the connection represents where the energy comes from and where it is going. This network illustrates the complete architecture of the ecosystem functioning as a whole (Conti et al., 2020). The researches on the plant-invertebrate relationship in soil has changed to a more quantitative approach that uses functional features of the species and characteristics of the food web related to the provision of ecosystem services (Mariotte et al., 2018). An important step in this approach is the inclusion of energy flow between species in the food web (i.e. the construction of an energy flow network) (Scheu, 2002). The flow of the energy network can provide clues about the control between species (prey - predator). Some invertebrate species are flexible in their diet. It is difficult to place a certain species in a certain trophic category (Scheu, 2002). Depending on the resources available, some invertebrates (i.e. mites) can eat algae, fungi, detritus or other invertebrate species (Scheu, 2002; Manu et al., 2013). Plants and organic waste provide habitat for soil invertebrates. Plants influence the soil biota directly by providing organic matter and indirectly through the physical effects of shading, soil protection, water and nutrients supplies. Plant energy and nutrients are incorporated into the detritus that provides the resource base of a complex food web (Neher, 2001). Soils host an unprecedented diversity of organisms that are interconnected through numerous trophic bonds and complex trophic networks (Brose & Scheu, 2014; Erktan et al., 2020). In the soil, the basic structure of the food web contains primary producers, consumers and detritivores. The number and biomass of organisms are correlated with the volume of soil and decrease from the bottom up in the food web. Unlike surface networks, soil networks have a longer length and complexity (Neher, 2001). In communities with many species as in the case of those in the soil, the formation of trophic groups is very likely to happen (Scheu, 2002). Trophic interactions are essential for soil functioning and are considered key factors in biogeochemical cycles. Trophic interactions play a major role in waste decomposition and the C and N cycles (Erktan et al., 2020). Mesofauna is found in all levels of the soil trophic network and directly influences both primary production by feeding the roots and indirectly by their contribution to the decomposition and nutrients mineralization (Neher, 2001). Although mites are essential in the food web, enchytraeids are probably "key elements" for the decomposition process. All of these invertebrates are dependent on each other and compete with each other (Mulder, 2006; Manu et al., 2016). Soil organisms play an important role in the dynamics of the above-ground community and the functioning of the terrestrial ecosystem. However, most studies considered soil biota as a black box or focused on specific groups, while little is known about entire soil networks (Morriën et al., 2017).

Plants - invertebrates - soil triangle

Many functions of the ecosystem are based on interactions between primary producers and other trophic levels, such as pollinators, soil decomposers and herbivores. For example, the nitrogen cycle involves complex interactions between plants and soil biota and between plants and herbivores (Moretti et al., 2016). Recent reviews reveale the genetic basis to plant–soil linkages that are critical to demonstrating their evolution due to plant - soil feedback (PSF). Considering plant-soil linkages only at plant species level, had been demonstrating that their feedbacks influence many aspects of plant communities, including invasion by exotic species, plant competitive interactions, and successional dynamics (Schweitzer et al., 2018). PSF can bring improvements to plant succession, invasion and coexistence, processes that have consequences on the nutrient circuit and other ecosystem services (van der Putten et al., 2016). Based on oscillations of structural and chemical root traits, it is demonstrated that plants can accumulate rhizosphere specific soil communities', including mutualist groups, (mycorrhizal fungi and plant growth-promoting bacteria), and antagonist groups (microbial pathogens and nematodes). These organisms affect the performance of their hosts and neighbouring plants, but also of subsequent generations of plant individuals through a mechanism known as plant-soil feedback (Wilschut & Kleunen, 2021). The underground and aboveground communities have most often been studied separately, but lately the vision has changed to a more integrative and holistic (Scheu, 2003). Researches on food webs have been focused only on "who eats whom?" as feeding relationships, but no attempt has been made for extensive studies of the entire network and functional traits of the species as network nodes (Moretti et al., 2016). Soil fauna has an essential role in the homogenization and decomposition of plant residues in the soil, which changes the physical and chemical composition and accessibility of organic matter (Bray & Wickings, 2019). The roots have several roles: anchorage the plant in the soil, transfer nutrients from the soil to the upper parts through the roots, nutrient storage, etc. For this reason they are attacked by herbivores. To defend themselves, they developed a whole arsenal of direct defence compounds, such as terpenoids, as well as indirect tools, involving communication strategies to interact with soil fauna, soil microorganisms and other plant roots to prevent attack (Bonkowski et al., 2009). Detritivorous species can alter the food web, providing large amounts of nutrients through decomposition, accelerating plant growth and performance. There are several mechanisms through which they can do this: mineralization of organic matter, stimulation of microbial activity, pest control and changes in soil porosity (Scheu, 2003; Johnson et al., 2011). Soil invertebrates affect directly or indirectly the decomposition of organic matter, maintain soil structure and can exert a direct influence on plant communities through selective feeding on roots, leaves or seeds (Cifuentes-Croquevielle et al., 2020). Changes in the density and composition of species of mites affect the rate of transformation of soil organic matter and soil fertility (Manu et al., 2018). By affecting plant features, the effect can cascade to higher trophic levels and affect the functions of the above-ground ecosystem (i.e. plant productivity and resistance to pests) (Wurst et al., 2018). Underground communities regulate plant growth and community composition; plants themselves regulate the quantity and quality of resources available for soil biota (Wardle et al., 2004; Wurst et al., 2018). Plant species and their composition change local environmental conditions: light, temperature, soil moisture and chemical quality of the substrate. Plant diversity is positively correlated with invertebrate diversity (Cifuentes-Croquevielle et al., 2020). Plants can influence soil and its properties by the input of chemical compounds and organic matter, by impact on hydrological processes as well as by ensuring habitats and/or resources for microscopic and macroscopic organisms (van der Putten et al., 2013).

Functional features of plants have a strong effect on the rate of soil communities' decomposition. Consequently, the composition of plant species and soil communities are closely linked; any change in plant species communities lead to changes in soil communities and viceversa (Cifuentes-Croquevielle et al., 2020). The functional features of plants influence soil organisms and the functional features of soil organisms influence the direction and power of plant feedback (Mariotte et al., 2018). The approach based on functional features has extended to the study of plant-soil relationships (Bardgett, 2018).

Differences in soil invertebrate communities could be explained, at least in part, through the soil properties, such as soil nutrient content and water infiltration rates, thus revealing a functional link (Cifuentes-Croquevielle et al., 2020).

Using the plant - soil feedback (PSF) relation as a bioindicator

The experience gained from natural systems where there is a great diversity of plant and invertebrate species supports a sustainable management necessary in agricultural systems (Mariotte et al., 2018). Bioindicators are taxa or functional groups that reflect the state of the environment (Manu et al., 2021). They are divided into few groups: *environmental indicator* - reacting rapid (early warning) at any change in the local environment and indicate levels of taxonomic diversity in a site; *ecological indicator* - monitoring a particular ecosystem stress. Invertebrates are commonly used as bioindicators and may accurately reflect certain environmental trends (Borges et al., 2021). Invertebrates, as bioindicators of biodiversity, can reflect trends in species richness and community composition more accurately than vertebrates, having a simpler body structure, being more diverse and abundant. Invertebrates can be used as bioindicators due to their small size making them sensitive to local conditions, while their mobility allows them to move in response to changing conditions. It is also important that they have a short life cycle. Because invertebrates are easy to collect and are very abundant, they are ideal for studies focused on species richness (alpha-diversity), species cycling (beta-diversity) and on comparison of different communities from many ecosystems using similarity indices (Moscatelli et al., 2005; Gerlach et al., 2013).

The main factors that influence PSF are: soil microbial pathogens, herbivorous nematodes, insect, other invertebrate larvae, mycorrhizal fungi, non-mycorrhizal endophytic fungi, endophytic bacteria, nitrogen - fixing microorganisms and decomposers. They can influence plant growth directly and indirectly by influencing the physicochemical properties of the soil, such as pH, organic matter content, water retention capacity, soil temperature and structure (van der Putten et al., 2016). Earthworms influence plant growth through the physical, chemical and biological changes that they produce in the soil. Scheu (2003) reviewed more studies and over 75% of them showed an increase in plant biomass in the presence of earthworms. The author mentioned that earthworms influence plant productivity through both direct and indirect effects. Direct effects include, for example, plant root feeding and seed transport, while indirect effects include impact on soil structure, mineralization processes, dispersal of microorganisms and hormone-like effects (Wurst et al., 2018). Although there are many reasons to use invertebrates in different studies that highlight the plant-invertebrate relationship, also there are some disadvantages (i.e. taxonomic challenges: relatively small proportion of species are known or described taxonomically) (Gerlach et al., 2013).

Limits and future research perspectives

With all these aspects presented above, there is still a lack of an explicit understanding of the mechanisms that regulate the relationship between plants - invertebrates - soil, especially in the context of global environmental changes. Solving these problems will improve the predictions about the changes that await us in the future (van der Putten et al., 2016). The mechanisms that manage the relationship between biodiversity and ecosystem functioning are still poorly understood, despite growing evidence of the importance of trophic interactions. Plant chemical composition and the soil community are known to influence litter and soil organic matter decomposition. Although these two factors are likely to interact, their mechanisms and outcomes of interaction are not well understood (Carrillo et al., 2011). There are scarce studies considering multitrophic systems taking into account species diversity rather than functional components of biodiversity (Moretti et al., 2016); the ecosystem services provided by a wide range of organisms whose effects are still relatively little explored, especially for smaller taxonomic groups. There are limited knowledge about soil nematodes, largely due to their microscopic size, distribution, and trophic variation (Lavelle et al., 2006). Few expertises yet exist about the complex interactions of the community and the trophic relationships between soil organisms. The use of plant-invertebrate soil feedback improves agricultural sustainability, increases resource efficiency, reduces the amount of applied fertilizer and fights against pests and diseases (Mariotte et al., 2018). A quantitative and explicit analysis of the physical structure of the soil in the ecology of the soil food web is needed. An interdisciplinary study opens the perspective to understand the structure and functioning of underground systems allowing a more holistic understanding of terrestrial ecosystems (Erktan et al., 2020). Soil biodiversity represents a major part of global biodiversity, but its drivers, threats, and possible future changes are still untapped and not well understood (Phillips et al., 2020). Another big question in soil ecology is whether the food web of an ecological system is regulated by resources (bottom-up) or predators (top-down) (Neher, 2010). Although there are a large number of publications that highlight aspects related to PSF, few of them have been focused on agricultural systems. Trait-based crop rotation could improve the efficiency of land use and thereby promote sustainable agriculture by reducing the excessive use of fertilizers and pesticides (Mariotte et al., 2018). Further future research is needed on the functional features of plants that could expand knowledge about how plants adapt to declining invertebrate density within and between species and how it can shape ecosystem functions (Ulrich et al., 2020). To predict the consequences of global change on multitrophic interactions in terrestrial ecosystems, more studies are needed. Another research challenge is controlled or small-scale laboratory studies that have shown that soil macrofauna, such as earthworms, can mobilize or transfer substantial amounts of nutrients to plants. One limitation is that the information we have about key organisms or soil biota groups that contribute to the nutrient cycle and crop production in different sets of management practices is limited. Future research should focus on their impact in a broader context, for example at the level of the agricultural field. Regarding the growing demand for sustainable agricultural practices, more knowledge is needed on the functional role of soil macrofauna in agroecosystems (Wurst et al., 2018). The challenge is to conduct field studies to show where, when and how PSF influences the real world to explain and predict community and ecosystem responses to a constantly changing world (van der Putten et al., 2016). The need to discover new methodologies to characterize and evaluate the performance of agroecology in a holistic way is a reality and a challenge for all, especially due to the multidimensional nature of agroecology (Petersen et al., 2020).

CONCLUSIONS

For a better understanding of the plant-soil invertebrate relationship, it is necessary to detail: the role and importance of soil invertebrates, the interactions and synergistic effects of soil invertebrate populations on specific diversity and biomass of soil surface plants, and the influence of plant species on the diversity and biomass of soil invertebrates. Also, the structure and functions of invertebrate communities are of particular importance because they can vary considerably, both inside (i.e. in urban areas: lawns, gardens, open land, green roofs) and between different habitats. The soil invertebrates communities can be also used as assessment and prediction tools of ecosystem services. The diversity of soil invertebrate is influenced by the specific diversity of soil surface plant communities, soil type and natural or anthropogenic environmental factors. In terms of human well-being, soil invertebrates are very important because they contribute to soil functions by regulating key ecosystem services: litter decomposition, nutrient cycling, nutrient uptake by plants and climate regulation (CO_2 flows).

In agriculture, the result of the expected research will lead to: reducing the artificial entry of nutrients into the soil (reducing the use of chemical fertilizers), increasing the availability of nutrients; increasing crop resistance to agricultural pests, increasing crop production and productivity. Success in healthy development of a crop requires knowledge from farmers preparing the soil, selecting nutrient inputs, planting the crops, managing the crops from emergence to harvest. The farmers should use the basic principles of soil fertility and plant nutrition that change over time, for instance, procedural practices should adapt to new products, the system of crop management procedures and plant genetics.

An accentuated economic problem in recent years is represented by invasive species and the result of our research might contribute to the development of new methods for eradicating them.

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