Chapter 2

The Ecological Role of Biodiversity for Crop Protection

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Additional information is available at the end of the chapter

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Abstract

Agricultural system is a complex community sheltering different ecological units. The units of this complex structure are in balance with each other showing fluctuations to ensure effective regulations from time to time depending on the abundance of both undesirable and beneficial organisms. This balance is a major case for biological activity playing an important role to maintain biological diversity. Once this natural balance is impaired due to abiotic and biotic factors occurring in biosystems, the economic and environmental problems appear becoming significant for the economical dimension in agriculture. The most important components showing deficiencies in systemically agro-ecostructure problems result from soil fertility, pest and disease management. Large interactions, which are concomitantly persisting with biological processes, are on plant and animal biodiversity, which have been affected by miss-treatments in crop protection and plant nutrition. Hence, food-web and biodiversity are indirectly seriously damaged in nature, such as recycling of nutrients and changes of microclimate. In this chapter, we have discussed the major effects of crop protection on biodiversity in detail regarding the persistence of biodiversity that needs to be mediated, considering the preserving of ecological properties and sustainable maintenance of biological integrity in agroecosystems.

Keywords: agroecology, antagonists, biodiversity, biological control, target-oriented nanotechnological approaches, environment-friendly approach, sustainability

1. Introduction

As a main value of the nature, biodiversity refers to all living species existing and interacting within an ecosystem and within each other such as microorganisms, plants, animals etc. [1]. It has also a major role as a source of agricultural production and cultivation of domestic crops. Breeding and hybridization techniques are efficient ways to increase their yield and quality that seems valuable genetic resources for crop improvement, which serves indirectly and directly for many ecological cases. In agricultural systems, this unique property of ecosystem provides food sources and organic fuels besides web of nutrients, regulation of microclimatic conditions, ongoing required hydrological processes, removal of undesirable residues of macro/micro-organisms, and hazardous chemicals. The recycling and renewing processes largely occur biologically being directly dependent on the existence of biological diversity [2]. Once this natural process is impaired, the losses in economic and environmental fields will be seriously significant. The lack of functional components and properties of soil fertility and pest regulation reduces the quality of life due to contaminated soil, water, and food quality by pesticide and/or nitrate accumulations.

For creating an artificial ecosystem through nutrient recycling supplied by only chemical fertilization and control of pest and pathogens by chemical pesticides, results in constant but infertile and not sustainable ecosystems, which are used for agricultural purposes created by human intervention. In fact, it is an inevitable end for the functional regulation of nature by impairment of biodiversity, which will extinct the flows of energy and the nutrients will progressively diminish because of the intensive crop cultivation [3].

In our century, seedling preparation and mechanized planting have replaced the conventional methods. Genetic manipulations have been used in breeding and selection of varieties. Modern agricultural systems bring high incomes depending on external inputs. Many differences of opinions are present concerning the protection of non-renewable resources, the loss of biodiversity, the loss of land by soil erosion and lack of biological property by chemical fertilizers and pesticides that have negative effects on human and animal health, food quality and safety, and environmental pollution [4].

Nowadays, increasing in pollution of environmental conditions enforces us to develop agroecological ecofriendly approaches considering the conservation of biodiversity, soil, water and other resources that is an inevitable requirement for sustainable preservation of environmental structure in the world. Therefore, enhancing of functional biodiversity is a key strategy for living ecosystems including beneficial antagonists and soil microflora dynamism in crop protection and soil fertility [5, 6].

2. Biodiversity in agroecosystems

Modern agriculture enforces the use of all components of nature available to human beings that determine the simplification of nature's diversity considering a diminished number of cultivated plants and domesticated animals. The literature and other knowledge sources indicate that only a few species of grain, vegetable, and fruit crop species are intensively cultivated [7] besides the huge diversity of plant species found in tropical rain forest containing nearly 100 species of trees (**Figure 1**) [4, 8]. Genetically, modern agriculture is under the pressure of major crops limiting varieties in cultivated areas [9] that creates genetic uniformity and determines day-by-day losses in biodiversity.

The conventional crop cultivation system consists of different varieties of domesticated crop species and their wild relatives showing full or partial resistance to diseases that allows farmers to produce crops in different soil types and microclimates [10].

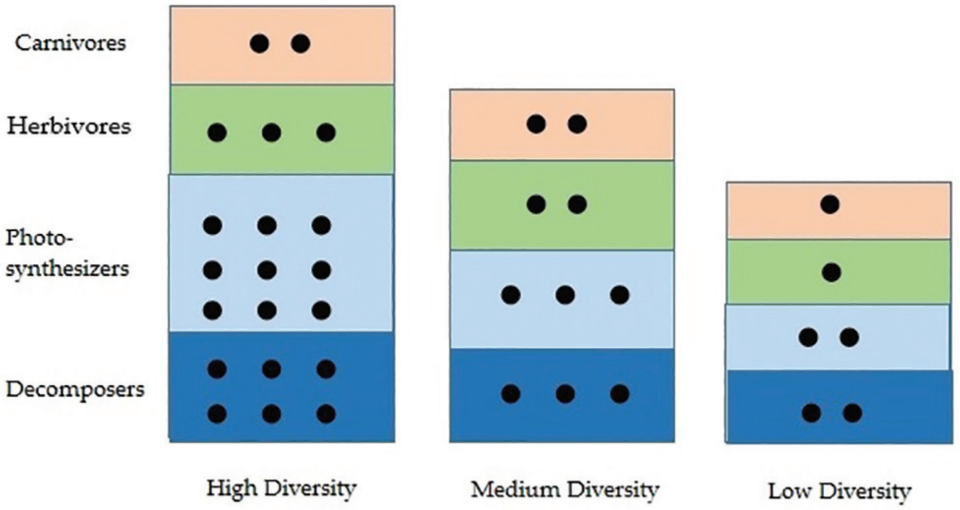

Figure 1. Simple diagram showing the difference between high diversity and low diversity.

In general, the degree of biodiversity depends on four main characteristics of the agroecosystem [4, 11]:

- **i.** The diversity of vegetation within and around the agroecosystem.
- **ii.** The stable maintenance and permanence of various crops.
- **iii.** The intensity of crop cultivation activities and pest control management.
- **iv.** The divergent parts of the agroecosystem from natural vegetation.

The biodiversity part of an agro-ecosystem can be clustered according to their role in cropping systems. It contributes to the productivity through pollination, biological control, degradation besides components such as weeds, insect pests and microbial pathogens. Ecological key is to identify the type of biodiversity that is desirable to maintain and/or enhance the best practices that will encourage the formation of biodiversity components [4]. Many agricultural practices have the potential to enhance functional biodiversity, besides the artificial manipulation that is negatively affecting the ones mentioned above. The main idea is to select the best management practices to enhance or regenerate this kind of biodiversity such as nutrient cycling, water and soil conservation, biological pest management, etc.

3. Biodiversity and pest management

Because of biodiversity reduction, unconscious pesticide applications and mistreatments of soils are shown as main reasons. One problem in agroecosystems is increasingly correlated to monocultures and decreasing of diversity [12]. Plant varieties that are modified to meet the special requirements of consumers are under attack of heavy pests' damage [13]. The characteristic properties depending on trait locus of natural communities are lost by exogenous modifications. The literature on biodiversity suggests that the design of vegetation management strategies must include knowledge on crop arrangement in time and space, the composition and abundance of non-crop vegetation within and around fields, and the soil type including its environment and intensity of management. Extension of the cropping period or planning cropping frequency may allow naturally-occurring biological control agents to sustain higher population levels on alternate hosts and to persist in the agricultural environment throughout the whole season [4, 13, 14].

Low pest potentials may be expected in agro-ecosystems if a production area exhibit high crop diversity by mixing crops in time and space. Moreover, good agricultural practices including integrated crop management strategies have positive effect on remediation of characteristic property of microflora. The ecological system in fields provides shelter and alternative food for natural enemies of pests. Pests may proliferate in these environments depending on population dynamism of natural enemies/or presence of alternate hosts in the area. Orchards are, in some extent, permanent ecosystems, and they are more stable than annual crops. They have greater structural diversity, possibilities for the establishment of biological control agents by floral diversity conditions. Increase of crop densities or cultivation of tolerable specific weed species is a bio-remediation tool for biodiversity combined with the use of variety mixtures or crops. These are few prominent properties that are necessary in the planning of a crop management strategy in agroecosystems.

4. Biodiversity, soil fertility and plant health

To understand the main factors of plant biodiversity, climate and geographic properties should be considered at the micro-fauna level. The relationship between plant biodiversity and productivity can also be influenced by other abiotic and biotic factors (**Figure 2**). Soil

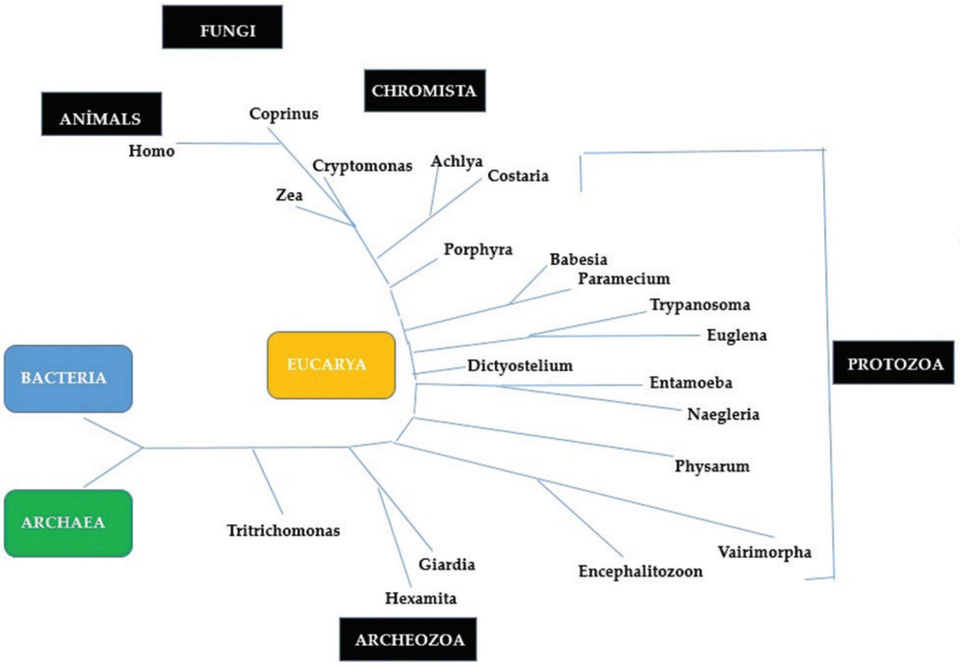

Figure 2. Simple diagram showing biotic factors through the evolutionary approach.

biodiversity reductions occur from negative issues due to recycling of nutrients and improper balance between organic matter, soil organisms and plant diversity. These are necessary components of a productive and ecologically-balanced soil environment [4, 15–17]. Soil biomass consists of beneficial and harmful microbes (fungi, bacteria and actinomycetes) and animals such as nematodes and different insects. One gram of soil contains nearly a thousand fungal hyphae and a million bacterial colonies [3]. Soil organisms provide a number of vital functions [18]: degradation of litter and cycling nutrients converting atmospheric nitrogen into organic forms, and reconverting organic nitrogen besides suppressing soil-borne pathogens through antagonism, synthesize of enzymes, vitamins, hormones, vital chelators altering soil structure through population living in mutualistic, commensalistic, competitive, and pathogenic forms.

The microbial activity of soil directly and/or indirectly affects the nutrient availability and plant nutrition. Decomposition of organic matter by microbial activity is used in cell building and maintenance processes of plants that are sources of available nutrients for plants. Furthermore, because of the microbial competition ongoing at different fractions of the soil organic matter, nutrients in biomass secreted compounds and dead cell of microorganisms are attacked by other competitive microbial communities. The effect of microbial activity has a positive effect on the available form of nutrients and elements that increase plant resistance to pathogens [19].

4.1. Positive reflection of dynamic biota on soil fertility and plant resistance

Many studies show that biologically suppressive activity can be regulated by the physical and chemical characteristic properties of soils [20–22]. Disease-conducive soils are described as a living biomass that is insufficient showing no suppressive effect on pathogens. In biologically balanced microflora, the disease-suppressive effects of microbes are successfully manipulated in order to suppress pathogens and thereby, they reduce disease losses [23]. The mechanisms are in most cases not well known, the manipulation of soil biological activity and enhancing biodiversity appear to be a method by which pathogen invasion on plant can be reduced. Studies have revealed novel antagonistic relationships between soil organisms and soil-borne pathogens [24, 25] and identified methods by which the soil environment can be manipulated to suppress pathogen activity [22, 26]. Pathogen-inhibitory components secreted and released may act against pathogens, which have fungistatic or fungicidal properties [27].

Some studies have reported interactions based on untested and often postulated and/or unstated assumptions; we simply do not have enough information on microbial dynamism and ongoing struggle to survive in soil microflora to successfully use disease-suppressive microbes in a wide variety of cropping environments. However, many researchers have suggested a direct relationship between soil biodiversity and disease suppression depending on dynamic population that will increase suppressive effect of the soil that regulates this dynamism. Such information is critical for the understanding of these relationships and the testing of whole assumptions. Because of the demonstrable dynamism of microbial population on the food supply, soil-borne plant pathogens provide useful models for evaluation of the impact of soil biodiversity on agroecosystems [22].

As a new concept, biological control of plant pathogens can be realized by using of inoculations and introduction of effective microbial species that are protecting our crops from plant pathogens' attacking and establishment of safety microflora based on introduced organisms. Inoculation of seeds with biocontrol agents and/or dipping of roots into solution of antagonistic microbes (*Rhizobia*, *Mycorrhizae*, and *Trichoderma*) have a direct protective effect to enhance plant performance and resistance to pathogens [28]. When pathogens are not inhibited by naturally present antagonists, it is possible to enhance biocontrol by adding more effective ones selected by previous studies and data relying on scientific evaluations. For instance, *Agrobacterium tumefaciens* var. *radiobacter* strain 84 and *Peniophora gigantea* have been successfully introduced and used against crown gall (*Agrobacterium tumefaciens*) in fruit trees. Many other tested microorganisms inhibiting pathogens have positive effect on plant health and induction of resistance when introduced into the soil or plant rhizosphere e.g., *Trichoderma* spp., *Pseudomonas* spp., *Bacillus* spp., *Alcaligenes* spp., *Agrobacterium tumefaciens* and others [4, 25, 29].

The biocontrol aims to introduce antagonistic microorganisms in soil, without considering the nutrient content of soil, to diminish pathogen population thereby adversely affecting infection process. A number of fungal and bacterial parasites can be used to control of most destructive soil-borne nematodes (*Meloidogyne* spp). There are many ways in which an antagonist microorganism can show rapid colonization in advance of the pathogens. Competition between biocontrol agent and pathogen may lead to niche exclusion, secretion of secondary metabolites and/or antibiotics may create an unsuitable medium resulting in cell-wall degradations of the pathogen. In addition, some microorganisms positively induce growth of plants, so that even if disease is present, its symptoms are partly masked. Moreover, ectomycorrhizae promotes phosphorous uptake in plants, forming a physical layer or a chemical barrier to pathogen invasion, thereby preventing pathogens from affecting the root surface of a plant [4, 30]. The literature on soil management recommends the enhancing of existing microbial antagonists, use of organic amendments reported as initiators of disease control processes to provide appropriate conditions for secreting of metabolites with digestive compounds by soil microorganisms [31]. Organic additions have an active role on microbial activity and supply advantages to antagonistic individuals in controlling of pathogens [32].

5. Target-oriented nanotechnological approaches and preservation of biodiversity

In the past decades, chemical pesticides have been widely used for plant protection. Nevertheless, hazardous chemicals are not only affecting the target pest but also other natural enemies modifying the biological balance. The negative effects of chemicals and residues have become also a public concern since they cause health disorders and environmental pollution. Therefore, nano-formulation of these chemicals has received much attention to diminish of these side effects. Target oriented nanoparticles (NPs) syntheses and their application against crop pests and diseases have been suggested since they are cost-effective, non-toxic and environmentally friendly biological approaches [33]. Converting of metallic compounds into nanoparticle forms increases its effect on target pathogen and pest. Hence, we are able to reduce the side effect of hazardous components and source of these chemical components are used for pest and pathogen control. Moreover, nanotechnology has been used for detection of plant pathogens using biosensor-based synthesized products [34]. Different nano-formulations of these molecules have been proposed since they provide efficient identification and effective management considering the biosafety and preservation of biodiversity.

It is essential to understand the biochemical and molecular mechanisms of nanoparticle synthesis. They have been suggested due to its long lasting biological activities compared to conventional pesticides. Besides their multifaceted property enhancing the volume ratio, it reduces the amount of pesticide to be used and provides better contact on target surface. However, recent studies have shown that there are some negative effects on biodiversity [35].

Advanced agronomical methods enforce agricultural production through the use of effective fertilizers and pesticides based on nanotechnology. However, their negative effects in the ecosystem have indirectly influenced the biological diversity and contaminate groundwater and soil [36].

Green nanotechnology has two objectives: creating nanomaterials and items without hurting the Earth or human wellbeing, and delivering nano-items giving answers for ecological issues. It utilizes existing standards of green science and green designing [37] and make nanomaterials and nano-items without poisonous fixings, at low temperatures as less vital and inexhaustible sources by considering lifecycle thinking in all outline and designing stages. Administrative bodies, for example, the United States Ecological Assurance Organization and the Sustenance and Medication Organization in the U.S. and the Wellbeing and Insurance Directorate of the European Commission have begun the managing of potential dangers generated by nanoparticles. Constrained nanotechnology and control are necessary for potential human and ecological wellbeing and security issues related to nanotechnology. It has been contended that the improvement of far reaching control of nanotechnology will be indispensable even we are able to determine of their potential dangers related to the examination and business utilization besides potential advantages [38].

Nanotechnology has diverse applications in precision agriculture. However, toxicity can be a major problem of nanoparticles due to their unique properties. Effects of the unique characteristics of nanoparticles are not well understood; hence more studies on toxicity are required for commercial food crop applications [39]. However, applications of nanoparticles are not always detrimental to plants and they have also positive effects [40–42].

Carbon nanomaterials such fullerenes, carbon nanoparticles, fullerol, and single-walled carbon nanotubes/multiwall carbon nanotubes have been utilized as a part of agribusiness demonstrating positive and unfavorable impacts. Lethality of carbon nano-materials was observed to be to a great extent reliant on their fixations, development/presentation conditions, and plant species. Kerfahi et al. [43] examined the impacts of local and functionalized multiwall carbon nanotubes (0–5000 mg/kg) on soil microbes. They revealed that following 2 weeks, the dirt bacterial group was significantly influenced by the multiwall carbon nanotubes. Following 2 months, there was no impact on the bacterial assorted variety with either kind of nanotubes. They ascribed this early impact to the acidic behavior of multiwall carbon nanotubes that caused a diminishing in soil pH at higher introduction fixations and hence changed the soil bacterial groups [43].

In another study, Boonyanitipong et al. [44] considered phytotoxicity of zinc oxide and titanium dioxide nanoparticles on rice (*Oryza sativa* L.) roots. The following three parameters were investigated: seed germination rate, root length and number of roots. The outcomes demonstrated that there was no decrease in the percent seed germination from zinc and titanium dioxide nanoparticles. However, zinc oxide nanoparticles demonstrated hindering growth of rice roots at the early seedling stage. This examination demonstrated that immediate introduction without pre-testing of particular kinds of nanoparticles could cause critical phytotoxicity and accentuated the need for biologically controlled transfer of wastes containing nanoparticles and further use in horticultural and ecological setups [44]. Chai et al. [45] considered the impact of metal oxide nanoparticles (ZnO, SiO_2, TiO_2 and CeO_2) on useful microbes and metabolic profiles in horticultural soil. ZnO and CeO_2 nanoparticles led to the obstruction of thermogenic digestion, diminished the quantities of *Azotobacter*, P-solubilizing and K-solubilizing microbes in soil and restrained the enzymatic activities [45].

These studies showed that nanotechnological approaches should be carefully used considering their adverse effect on biodiversity and population dynamism of micro/macro organism besides its positive sides.

6. Outlook and future aspects

In brief, the beneficial opportunities of microorganisms have been mentioned in literature and published reports. Nevertheless, artificially mimicking of their activities by present technology is impossible when estimating turnover time of biomass, which is 1000–10,000 times less than that obtained in optimal *in vitro* conditions [46]. The data suggests only active short periods and dormant state in soil for microorganisms, which are able to survive in harsh conditions [47]. Technical limitations have made difficult to follow and understand the mysteries of microflora, in all cases with any degree of confidence. The recent application of molecular technologies will revolutionize this scientific area and may permit us to gain a more complete understanding of soil biodiversity [48]. With this information, the use of cultural practices to manipulate microbial activity and diversity may become more practical and effective for the management of soil-borne diseases [22]. Further, there is a need for a better understanding of the capacity of soil-borne pathogens to generate new biotypes depending on phenotypic variation (**Figure 3**) in response to selection pressures, to improve effectively the pest control. New molecular technologies such as „metagenomics "provide great opportunities for precise measurement of both soil biodiversity and pathogen variability. These tools can be used to directly test hypotheses concerning the interactions between soil organisms and plant pathogens.

Efficient and effective protocols for extraction, characterization and quantification of soil DNA and RNA, besides new disease-resistant cultivars, including employing new resistance strategies have been developed using modern biotechnology [49]. Particularly, in assessing soil biodiversity which has potential to suppress soil-borne pathogens, e.g., "metagenomics" can be used (**Figure 4**), that these analyses will be beneficial for the comprehensive understanding of the traits of microbes, which are normally very difficult to measure of their biogeochemical property or potential effect of non-cultivated ones at micro-scale using conventional microbiological methods. To our knowledge, such advanced tools have not yet been used to directly compare microbial metagenomes across soils representing a range of different biomes.

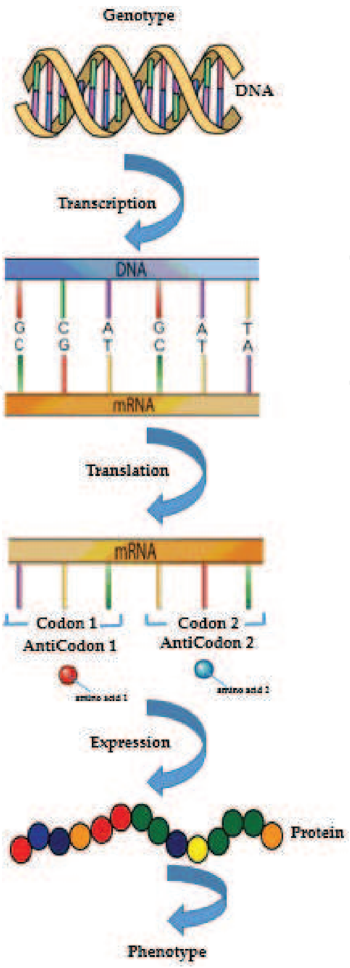

Figure 3. Simple diagram shows that how genetic diversity affects biological diversity based on phenotype formation depending on genotype.

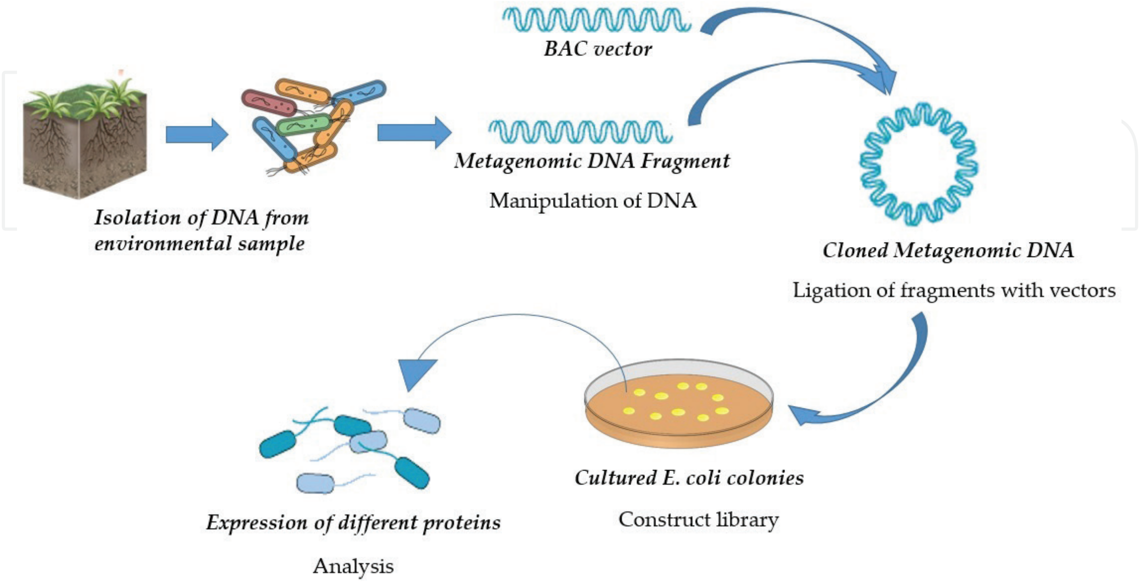

Figure 4. Simple diagram showing the workflow of metagenomics.

“Metagenomics” is a systematically investigation method for classifying and manipulating the entire genetic material isolated from environmental samples. This contain a multi-step process that relies on the efficiency of four main steps consisting of the isolation of genetic material, manipulation of the genetic material, library construction, and the analysis of genetic material in the metagenomics library. Information from metagenomics libraries has the ability to enrich the knowledge and applications of many aspects of environmental sustainability and remediation of soil property. This information can be applied to create a healthy and dynamic microbial population that lives in balance with the environment. Metagenomics is an efficient tool and an exciting field of molecular biology that is likely to grow into a standard technique for understanding the biological diversity at advanced level.

7. Conclusion

We propose several methods with a measurable aspect that can provide benefits for soil biodiversity and may provide information for maintaining biodiversity. This information has also positive effect on plant pathology bringing a new improvement of by using molecular tools such as PCR and microarrays to quantify microbes and monitor gene expression and metagenomics. We believe that future data will provide more information than the previously available ones. Novel agro-ecological approaches will aim at breaking the negative effects of miss-applications related to integration of new plant protection techniques that enhance complex interactions and synergisms and optimize ecosystem functions and processes, such as biotic spontaneously regulation of harmful microorganisms, nutrient recycling, and biomass production and accumulation.

In short, considerable efforts and new technologies are needed to access not only DNA pools but also an entire metagenome for unbiased microbial ecology studies for both understanding and decipher the ecosystem mechanisms and for learning the most effective and eco-friendly control measurements to deal with pest and pathogens.

Conflict of interest

The authors have no conflict of interest.

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