Chapter 3

Activity and Variety of Soil Microorganisms Depending on the Diversity of the Soil Tillage System

Karolina Furtak and Anna Maria Gajda

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.72966

Abstract

Soil is an ecosystem capable of producing the resources necessary for the development of the living organisms. Soil microorganisms (bacteria and fungi) are responsible for biomass decomposition, biogenic element circulation, which makes nutrients available to plants, biodegradation of impurities, and maintenance of soil structure. The presence of microorganisms in soil depends on their chemical composition, moisture, pH, and structure. Human activity has an indispensable influence on the formation of ecosystems. Soil tillage has an impact on the chemical and physical parameters of the soil, and thus on its biological properties. The use of inappropriate agro-technology can lead to degradation of the soil environment. Changes in soil properties may cause changes in soil abundance, activity, and diversity. Cultivation can affect microorganisms, causing their mortality and reducing the availability of nourishment in the soil. Therefore, it is extremely important to assess the diversity and microbiological activity of soil in relation to soil-tillage technology.

Keywords: agricultural, biodiversity, soil microorganisms, soil quality, tillage system

1. Introduction

The soil is the most outer layer of lithosphere. It covers almost the entire surface of the land; in it, there is a circulation of nutrients, biotic, and abiotic processes. Soil is a key element of the environment. It performs many functions in the environment (**Figure 1**). The five main ones are listed [1] below:

1. Environmental formation—shaping the local climate, relief of the earth's surface, natural reservoir of water resources retention;
2. Ecological—an element of circulation of biogenic elements and organic matter retention;

3. Edaphic—creation of living conditions for organisms (microorganisms, plants, animals);
4. Protection—counteracting changes in the environment by means of sorption properties, *e.g.*, absorbing toxic compounds;
5. Economic—place of work for man, a farmer.

This is a general separation of soil functions. Each of them can be discussed separately. All soil functions are affected by human farming. This chapter is an attempt to collect information on the influence of man on the edaphic function of soil.

The soil has the capacity to self-produce resources necessary for the development of living organisms [2]. This makes it a living environment for over 30% of the species existing on Earth. Soil organisms are a very important component of soils and are referred to as "*biological engine of the earth*" [3]. Soil quality can be defined as the balance between high activity and high microbiological biodiversity [4]. Soil quality plays an important role in protecting the environment, preserving biodiversity and good agricultural practices [5–7]. Agriculture has an impact on soil, and thus on the qualitative and quantitative composition of soil microorganisms.

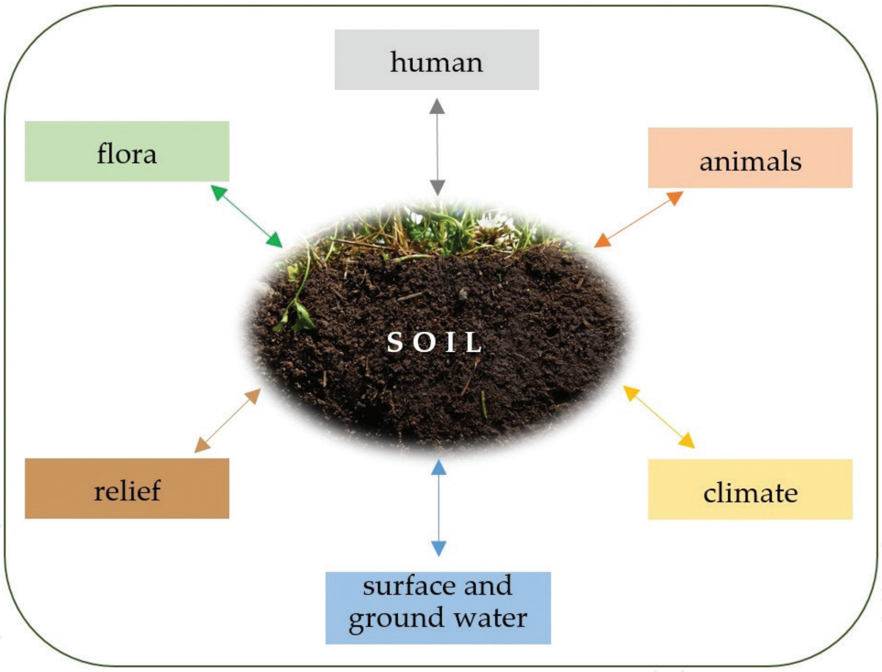

Figure 1. Soil functions in environment.

2. Soil microorganisms

Soil microorganisms are involved in many biogeochemical processes. They are a very important functional group of soil organisms. They are responsible for mineralisation of organic matter, element circulation, synthesis of proteins, and nucleic acids, as well as transformation

http://dx.doi.org/10.5772/intechopen.72966

of phosphorus forms. Rhizosphere microorganisms increase plant health and can protect against pathogens [8, 9] (**Figure 2**).

Agricultural biodiversity concerns with indigenous bacteria, plants, fungi, animals, and their equivalents introduced into the agricultural space by man and is related to the structure of soil and its use [10, 11]. It is estimated that from 1 g of soil, about 4000–6000 different bacterial genomes can be isolated [12]. Classic microbial analyses of microorganisms allow to isolate 0.1–10% of the population of bacteria present in the environment. The other species are not reared, which means that they cannot be reared under laboratory conditions. In research on the presence of microorganisms in soil, it is important not only to evaluate their quantitative and qualitative assessment, but above all to perform their functions, their role in the ecosystem, and their impact on other organisms.

The biological activity of the soil depends on the correct number and species composition of microorganisms and their enzymatic activity. Microorganisms mediate 80–90% of all processes occurring in the soil [13]. They create favorable conditions for germination of seeds and growth of the root system of cultivated plants, which is very important for a high yield [5]. Plants emit a large number of various chemical compounds into the soil, which shape the composition of microorganisms in the environment. Microorganisms use these root secretions as a source of food. The rhizosphere is a habitat mainly for bacteria and mycorrhizal fungi. Some microorganisms may produce antibiotics that block harmful microorganisms. In addition, soil microorganisms can also improve the condition of plants by releasing growth regulators (e.g., ethylene, auxin, and cytokine) and making available some nutrients (e.g., phosphorus). Polymer-producing microorganisms can improve the soil structure. Among the significant soil microorganisms, it is worth mentioning the bacteria of the genus *Pseudomonas* sp., bacteria that inhabit the root zone of plants [14]. Bacteria of this kind produce various

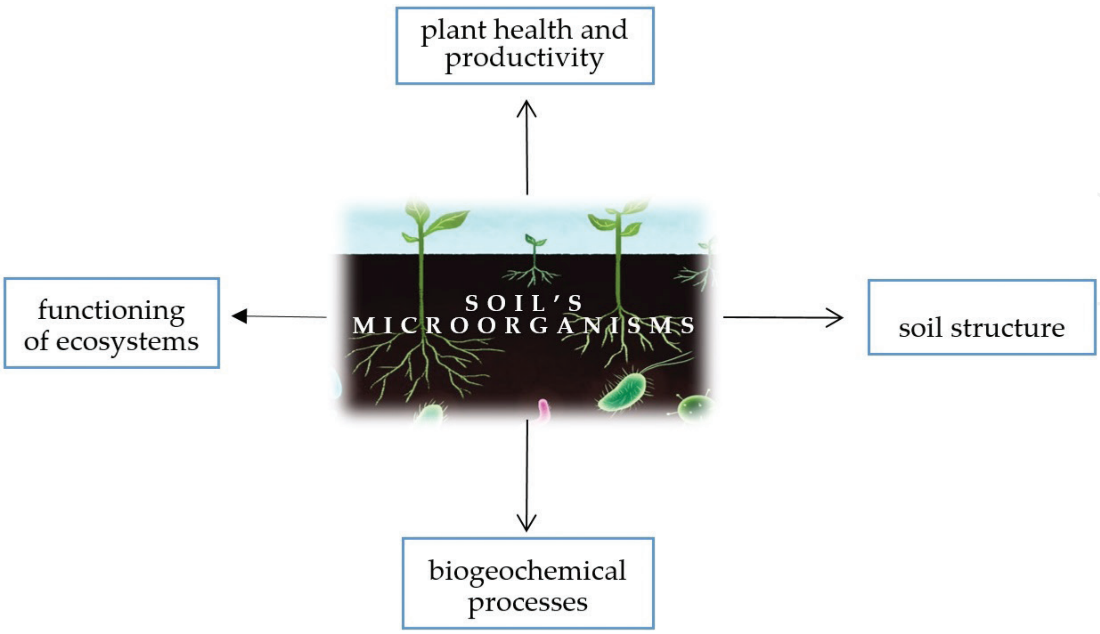

Figure 2. Functions of soil microorganisms.

biologically active compounds such as antibiotics and lytic enzymes, as well as ethylene, auxin, and gibberellin. In addition, *Pseudomonas* compete for nutrients with pathogenic microorganisms, *e.g.* for iron by creating a siderophores. The bacteria binding atmospheric nitrogen are also important for the cultivation of plants such as *Azotobacter*, *Clostridium*, *Rhizobium*, and *Bradyrhizobium* [15].

3. Impact of agricultural activity on the soil quality

Human activities in the natural environment, above all the intensification of agriculture and the use of plant protection products, change the activity and diversity of the soil environment. This can lead to changes in the functioning and sustainability of the ecosystem [9, 16]. Changes in soil quality lead to changes in plant variety and productivity [17]. Human activity is aimed at giving the soil the best possible soil production properties in order to increase the yield of plants.

Proper agricultural management should take into account the microbiological and physicochemical properties of the soil. The activity of microorganisms and their diversity is a sensitive indicator of soil quality, which is the subject of research for many researchers. The cultivation systems applied by man modify the quantitative and qualitative composition of organisms inhabiting the soil environment [18]. In [19], it was found that soil microorganisms are sensitive to anthropogenic factors, in particular agricultural activity.

Numerous studies indicate that agricultural treatments strongly change chemical [5, 20–22] and physical [23, 24] parameters of soil. Changes in soil physicochemical parameters can lead to changes in soil microbial diversity [25, 26]. Some researchers suggest that the agricultural techniques generate a homogeneous soil environment and reduce bacterial diversity [27]. Other studies [5] indicate that the soil has a high capacity to maintain biodiversity. Numerous studies are being carried out to compare the impact of soil-tillage systems on soil microbiology [8, 22, 25, 26, 28]. Some studies confirm that agricultural practices have an impact on the soil composition of microorganisms [29, 30]. Other researchers suggest that changes in the structure of the bacterial population are mainly due to chemical properties and soil structure [5]. The research [31] also reports that the soil has buffering capacity and that composition and functionality of microorganisms depends on the type of soil.

It is well known that the biodiversity of microorganisms varies from untapped soil to land cultivated in agricultural areas. In [20], it was demonstrated that in uncultivated soils, the obtained number of operational taxonomic units was about 1.5 million, 30% higher than agricultural soils. Similar results were obtained by [32] who noted that 140–150 species per 1 g of soil are found in the soil cultivated for agriculture, while in natural soils, this amount is about 1000 species per 1 g of soil. It is estimated that about 40% of the world's agricultural land has already been degraded [22, 33, 34].

3.1. The ecological farming systems

Sustainable agriculture is based on supporting natural biological processes without interfering with the environment [35]. In simplified systems, the cultivation procedures are minimised. They consist mainly in loosening of the external soil layer, leaving crop residues and the use of stubble intercrops. Leaving harvest residues has an impact on soil nutrient management, which can be beneficial for the biological properties of soil [36]. Among the organic systems, there is also the use of no-tillage, which is limited to the creation of a seed groove for sowing. Studies have shown that simplifications lead to an increase in the number of microorganisms of the genera *Cladosporium* and *Mucor*, which may inhibit the development of pathogens in soil. In addition, two to three times higher biomass of earthworms in the soil under direct sowing was recorded [37]. Tests carried out by [38] demonstrated that organic farming contributes to preserving soil biodiversity. In addition, the beneficial effect of organic fertilisation on soil microbiology is well known and documented [39, 40].

3.2. The conventional and intensive farming systems

Traditional cultivation systems are based on specialised agricultural machinery that directly interferes with the soil structure. The deep ploughing up to 35 cm deep into the soil can cause negative consequences in the physical, chemical, and biological properties of the soil [41, 42]. Numerous studies have shown that conventional soil tillage and monoculture can have a negative impact on soil quality [28, 43, 44]. Intensive ploughing leads to a more compact soil, which may result in lower yields. Intensive plant production and multiarea farms very often fail to take environmental protection into account and can have a detrimental effect on soil quality [44]. In intensive agriculture, many mineral fertilisers, antibiotics, and hormones are used, which leads to degradation of the soil environment. At the same time, it carries a risk of biodiversity loss. The intensive mixing of the soil with the spacing plough causes losses of organic matter by accelerating the humus mineralization process. Such systems aggravate the network of interactions between soil organisms and aggravate disease-related problems [25, 45]. Many years of conventional long-term soil cultivation may also contribute to the decline of microbial population in soil.

4. Methods for analysing the impact of human agricultural activities on soil quality

Research on soil quality is very important in terms of the quality of the yields obtained and the environmental impact assessment of agriculture. Soil as a habitat for many organisms and a place where many biochemical processes occur is sensitive to natural and abiotic factors, including agricultural activities. Soil quality assessment is based on an analysis of the physical-chemical and microbiological parameters of the soil (**Table 1**).

Parameter	Method	Literature
Soil microbial biomass carbon (MBC) and nitrogen (MBN) contents	The fumigation-extraction (F-E) and fumigation-incubation (F-I) method	[46]
Potentially mineralizable nitrogen (PMN)	The short-term (waterlogged) anaerobic incubation method	[47]
Dehydrogenases activity	Method with 2,3,5-triphenyltetrazolium chloride (TTC) as a substrate	[48]
Acid and alkaline phosphatases activity	Method with p-nitrophenyl phosphate (PNP) as a substrate	[49]
Urease activity	Measuring the concentration of an ammonium	[50]
3,6-diacetylfluorescein (FDA) hydrolysis activity	Measuring the concentration of fluorescein	[51]
Soil organic carbon (SOC)	Oxidation with a mixture of potassium dichromate and sulphuric acid	[52]
Strength of soil aggregates	Strength testing device	[53]
Community level physiological profiling	Biolog ECOplate (Biolog Inc., Hayward, USA)	[54]

Table 1. Selected soil quality parameters and methods of their evaluation.

Research on soil quality analysis:

- Determination of enzymatic activity, e.g., dehydrogenases, acidic and alkaline phosphatase, protease;
- Identification of soil microorganisms by molecular and immunological means through sequencing, hybridisation analysis, Elisa test, PCR-based reactions;
- Analyses of soil physical-chemical parameters e.g., pH, EC, granulometric composition, water volume;
- Evaluation of functional diversity of soil microorganisms by the CLPP method—*Community Level Physiological Profiling.*

However, despite many studies and the variety of methods used, there is still no single, universal parameter that would allow the quality of the soil to be determined quickly. In addition, it is necessary to carry out long-term studies, because only in this way can changes in the environment be noticed.

5. Impact of different farming systems on selected soil quality parameters

5.1. The enzymatic activity

Enzyme activity is considered to be one of the main parameters expressing the overall microbiological activity of the soil. The activity of dehydrogenase, peroxidase, phosphatase, protease

http://dx.doi.org/10.5772/intechopen.72966

and urease, β-glucosidase, catalase, cellulase, and invertase is commonly indicated. These enzymes are mediators and catalysts in many biochemical processes in soil, including formation and decay of humus, molecular nitrogen fixation, nitrification and denitrification, phosphorous compounds transformations, or detoxification of xenobiotics. The presence of enzymes and their activity are evidence of soil metabolism, while being sensitive to environmental changes.

Simplified systems have a high dehydrogenase activity [55–57]. Restriction of plough use has a positive effect on the activity of these enzymes [58]. In direct sowing soils, dehydrogenases also have a higher dehydrogenase activity than conventional crops [59].

Phosphatases catalyse the hydrolysis of organic phosphorus compounds once again responsible for its management in plants. They can be used as an indicator of the potential rate of phosphorus compounds mineralization. They are also very sensitive to heavy metal contamination. For acid phosphatase, higher values are recorded in soils from conventional crops and monoculture, e.g., the United States of America. Areas of the European Union's main agricultural holdings are covered by the so-called maize and alkaline phosphatase in simplified crops [36, 60–62].

The FDA hydrolysis is related to the transformation of organic matter into soil. Many studies have shown that its value is higher in soils than in simplified, organic crops [43].

Urease activity is also sensitive to the way soil tillage is cultivated. It participates in the conversion of nitrogen compounds in soil [63]. In [64], it was showed that the soils from simplified crops show up to two times higher urease activity than those from conventional crops. Similar results were obtained by [65].

5.2. The soil organic carbon content (SOC)

Soil organic carbon content is a sensitive soil quality indicator [66, 67]. The soil microbial biomass carbon (MBC) and nitrogen (MBN) represent a small fraction of the total soil organic C (1–5%) and N (2–6%) [68].

Intensive monoculture of rice causes a decrease in SOC [44]. Less intensive soil tillage improves the stability of soil aggregates and increases the SOC concentration [69]. Researchers also observe higher SOC values in soil, where ploughing is not used and plant residues are left on the surface [70]. In the case of maize, researchers have found that conventional cultivation reduces the amount of SOC in soil compared to zero tillage [71]. Similar results were obtained in the case of winter wheat cultivation, where the SOC content in the upper soil layers was up to 23% higher than in the case of conventional seedlings [28, 72]. Conventional cultivation increases SOC sequestration [71]. Research [73] has shown that in agricultural soil can contain 20% less SOC and MBC than in soil under indigenous grassland.

5.3. The microbial biomass carbon (MBC) and nitrogen (MBN) content

Determination of the soil microbiological biomass content is one of the basic parameters for monitoring soil changes. Soil management has a large impact on the size of the biomass pool of microorganisms [61, 62].

There is a negative effect of conventional crops on the carbon and nitrogen content of microbial biomass [55, 62]. Whereas, the soil under simplified and organic cultivation has a high MBC and MBN content [55, 57, 64]. The MBC and MBN in direct sowing soil are also higher than in conventional sowing [74]. In several years of research [75], the number of MBC in conventional soil cultivation decreased, with a steady level of biomass in reduced tillage and direct sowing.

5.4. The functional analysis

Soil microorganisms are complex, multispecies communities. The processes taking place with their participation should be analysed as a sum of functions of the entire population and not as individual species [54, 76]. Using the Biolog Ecoplate, the [43] observed a greater metabolic diversity in soil than in reduced tillage compared to conventional tillage. Similar results were obtained by [77, 78]. In soils from urban ecosystems, the highest microbiological activity was observed in roadside-tree soils, while the lowest activity was observed in forest sites. At the same time, the authors did not notice any significant differences among long-term maize production, park sites, and street green sites [79].

The higher average utilisation intensity (AWCD) values were recorded in soil under conventional tillage with residue retention, than zero tillage and residue removal, after 15 years of cultivation. At the same time, it has been shown that the higher functional diversity of microorganisms is in soil under wheat cultivation compared to soil under maize cultivation [74]. Research [80] showed that ability of the microbial communities to utilise substrates on ECOplate was affected by fertilisation, but not by crop rotation treatments. At the same time, it has been demonstrated that the long-term use of manure can contribute to increase the beneficial functional diversity of microorganism in agricultural soils. It was demonstrated that the functional diversity of microbial community depended on the presence of plant species [81]. The CLPP analysis also showed that the soil under cultivation of transgenic rice did not differ significantly in functional diversity of microbial communities compared to control [82].

5.5. The biodiversity in soils with different uses

The agricultural activity of mankind affects many of the physical and chemical properties of soil and its microbiological activity. Depending on the manner of soil utilisation, there are differences in the composition of the population of microorganisms inhabiting the soil. The [83] concluded that the species diversity of soil microorganisms is primarily influenced by the abiotic soil properties independent of location or land-use type. They demonstrated that location and land-use type together explained more than 33% of the variation in soil biota diversity. However, the [84] have shown that soils with low human participation rate (cork-oak, forest, and pasture) were characterised by a more stable bacterial environment than soils with a high human participation rate (vineyards and managed meadow). Research conducted by [21, 22] also shows that soils used for agricultural use are degraded, which is noted in lower microbiological parameters when compared with uncultivated soils. Changes in soil communities and loss of soil biodiversity threaten the multifunctionality and sustainability of the ecosystem [17].

Large variations in *Proteobacteria* composition are observed in soils with different uses. There were also changes in the composition of bacterial communities in the case of a change in the

http://dx.doi.org/10.5772/intechopen.72966

way forest soil are used to cultivate crops and grazed pastures [84, 85]. Studies conducted in Poland showed that in soils used for agricultural use, there was a significantly lower amount of ammonifying bacteria in comparison with soils not used for agricultural purposes [21, 22]. Similar results were obtained in other studies on agricultural soils [86, 87].

It is well known that more intensively managed soils often contain less fungi biomass [88]. Lack of ploughing while leaving plant residues on the soil surface may increase the amount of fungi pathogenic to plants (*Fusarium* sp.). At the same time, a long-term economy without ploughing leads to a deep diversification of microbial communities and also develops high fungal biomass in surface soil [89]. Other researchers have shown that cultivation practices had little impact on the diversity of microbial communities [90].

Nitrogen fertilisation of soil influences the number of individual groups of microorganisms in soil. High nitrogen doses may lead to the accumulation of toxic substances, e.g., ammonia in soil, which does not have a beneficial effect on the *Actinobacteria* [91].

Collections of microorganisms decomposing cellulose and hemicellulose change the composition of the population in response to changes in the composition of organic fertilisers [39]. The use of manure as a fertiliser in rice fields increased the activity of microorganisms, with a simultaneous decrease in this activity in the case of chemical fertilisers [92].

Higher mite density, *Collembola* and *Myriapoda*, were observed in forest ecosystems, but on grasslands more earthworms were observed [88].

The examples given above show that soil is a complex ecosystem, and the cultivation method has an impact on many soil parameters (biological, chemical, physical), and thus also the organisms that inhabit it. Changes in populations of soil organisms may have an impact on plant growth and thus on yields.

6. Conclusions

It is well known that the agricultural activity of man has an impact on the soil environment, while changes in the soil shape changes in the whole accompanying ecosystem. Agriculture is an indispensable part of the economy and production, but it is up to man to decide whether he is cultivating the soil in order to increase harvests for only 1 year or for further perspective. The condition of the soil and its quality are deteriorating over time. Many effects of human activity are visible not sooner than in a few or even several years. For this reason, it is worthwhile to carry out monitoring of agricultural land in order to observe how quickly and to what extent changes occur. It is important to manage the environment sensibly so that it does not degrade and at the same time allows to obtain good production results. An additional problem is the difficulty in interpreting and comparing results of biogeochemical parameters with new methods of microbial identification (e.g., sequencing). Therefore, the subject of changes in agricultural soil is a challenge and objective of agricultural science research.

Acknowledgements

Supported by the Task 1.3 of the Multi-Annual Programme of the Institute of Soil Science and Plant Cultivation—State Research Institute, Puławy (IUNG-PIB) and by the Statute Project Nos. 2.26 and 2.38.

Author details

Karolina Furtak* and Anna Maria Gajda

*Address all correspondence to: kfurtak@iung.pulawy.pl

Department of Agriculture Microbiology, Institute of Soil Science and Plant Cultivation—State Research Institute, Puławy, Poland

References

[1] Degórski M. Geografia gleb jako dyscyplina fizycznogeograficzna. Przegląd Geograficzny. 2004;**3**(76):273-274

[2] Russel S. Znaczenie badań enzymów w środowisku glebowym. Acta Agrophysica, Rozprawy i Monografie. 2005;**3**:5-9

[3] Haygarth PM, Ritz K. The future of soils and land use in the UK: Soil systems for the provision of land-based ecosystem services. Land Use Policy. 2009;(26):187-197

[4] Li P, Zhang T, Wang X, Yu D. Development of biological soil quality indicator system for subtropical China. Soil and Tillage Research. 2015;**126**:112-118

[5] Girvan MS, Bullimore J, Pretty JN, Osborn AM, Ball AS. Soil type is the primary determinant of the composition of the total and active bacterial communities in arable soils. Applied Environmental Microbiology. 2003;**69**:1800-7809

[6] Lemaire G, Franzluebbers A, Carvalho PC, Dedieu B. Integrated crop-livestock system: Strategies to achieve synergy between agricultural production and environmental quality. Agriculture Ecosystems and Environment. 2014;**190**:4-8

[7] Martinez-Selgado MM, Gutierrez-Romero V, Jannsens M, Ortega-Blu R. Biological soil quality indicators: A review. In: Mendez-Vilas A, editor. Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology. Microbiology Series N 2. 1st ed. Badajoz: Formatex Research Center; 2010. pp. 319-328

[8] Abigail A, Salyers D, Whitt D. Ziemia: Planeta mikroorganizmów. In: Markiewicz Z, editor. Mikrobiologia. Różnorodność, chorobotwórczość, środowisko. Warszawa: PWN; 2005. pp. 3-5

[9] Nannipieri P, Ascher J, Ceccherini MT, Landi L, Pietramellara G, Renella G. Microbial diversity and soil functions. European Journal of Soil Science. 2003;**54**:655-670

[10] Arias ME, Gonzales-Perez JA, Gonzales-Vila FJ, Ball AS. Soil health-a new challenge for microbiologists and chemists. International Microbiology. 2005;**8**:13-21

[11] UNEP/CBD/SBSTTA/7/12. Developing indicators for national-level monitoring of biodiversity. Draft prepared by the expert group on indicators of biological diversity including indicators for rapid assessment of inland water ecosystems [dissertation]. Montreal; 2003

[12] Torsvik V, Torsvik VL, Sørheim R, Goksoyr J. Total bacterial diversity in soil and sediment communities: A review. Journal of Industrial Microbiology. 1996;**17**:170-178

[13] Nannipieri P, Badalucco L. Biological processes. In: Bembi DK, Nieder R, editors. Handbook of Processes in the Soil–Plant System: Modelling Concepts and Applications. Binghamton: The Haworth Press; 2003. pp. 57-76

[14] Sørensen J, Nybroe O. Pseudomonas in soil environment. In: Juan-Luis R, editor. Pseudomonas: Genomics, Life Style and Molecular Architecture. Boston: Springer; 2004. pp. 369-401. DOI: 10.1007/978-1-4419-9086-0

[15] Gałązka A, Bigos J, Siebielec S. Plant growth promotion by bacteria of the genus *Azospirillum* and their application in agriculture. Polish Journal of Agronomy. 2015;**23**:48-62

[16] Gajda AM. Microbiological and Biochemical Indices of Quality of Soils under Winter Wheat Grown in Different Tillage Systems. Puławy: Monografie i Rozprawy Naukowe, IUNG; 2015

[17] Wagg C, Bender SF, Widmer F, Van der Heijden MGA. Soil biodiversity and soil community composition determine ecosystem multifunctionality. PNAS. 2014;**111**(14): 5266-5270

[18] Kladivko EJ. Tillage systems and soil ecology. Soil and Tillage Research. 2001;**61**:61-76

[19] Kuffner M, Pinar G, Hace K, Handschur M, Haslberger AG. DGGE-fingerprinting of arable soils shows differences in microbial community structure of conventional and organic farming systems. Journal of Food Agriculture and Environment. 2004;**2**:259-267

[20] Wolińska A, Górniak D, Zielenkiewicz U, Goryluk-Salmonowicz A, Kuźniar A, Stępniewska Z, Błaszczyk M. Microbial biodiversity in arable soils is affected by agricultural practices. International Agrophysics. 2017;**31**:259-271. DOI: 10.1515/intag-2016-0040

[21] Wolińska A, Szafranek-Nakonieczna A, Banach A, Błaszczyk M, Stępniewska Z. The impact of agricultural soil usage on activity and abundance of ammonifying bacteria in selected soils from Poland. SpringerPlus. 2016;**5**:565-578. DOI: 10.1186/s40064-016-2264-8

[22] Wolińska A, Szafranek-Nakonieczna A, Zielenkiewicz U, Tomczyk-Żak K, Banach A, Błaszczyk M, Stępniewska Z. Quantified characterization of soil biological activity under crop cultivation. Journal of Advances in Biology. 2016;**8**(3):1655-1665

[23] Ozgoz E, Gunal H, Acir N, Gokmen F, Birol M, Budak M. Soil quality and spatial variability assessment of land use effects in a Typic Haplustoll. Land Degradation & Development. 2013;**24**:277-286. DOI: 10.1002/ldr.1126

[24] Singh K, Mishra AK, Singh B, Singh RP, Patra DD. Tillage effects on crop yield and physicochemical properties of sodic soils. Land Degradation & Development. 2016;**27**(2): 223-230. DOI: 10.1002/ldr.2266

[25] Kheyrodin H, Ghazvininan K, Taherian M. Tillage and manure effect on soil microbial biomass and respiration, and on enzyme activities. African Journal of Biotechnology. 2012;**11**(81):14652-14659. DOI: 10.5897/AJB09.1335

[26] Tintor B, Milošević N, Vasin J. Microbiological properties of chernozem of southern Backa (Serbia) according to different methods of land use. Field and Vegetable Crop Research. 2009;**46**:189-198

[27] Palmer KM, Young JPW. Higher diversity of *Rhizobium* leguminosarum biovar viciae populations in arable soils than in grass soils. Applied Environmental Microbiology. 2000;**66**:2445-2450

[28] Gajda AM, Czyż EA, Stanek-Tarkowska J, Dexter AR, Furtak KM, Grządziel J. Effects of long-term tillage practices on the quality of soil under winter wheat. Plant Soil Environment. 2017;**63**(5):236-242. DOI: 10.17221/223/2017-PSE

[29] Bossio DA, Girvan MS, Verchot L, Bullimore J, Borelli T, Albrecht A, et al. Soil microbial community response to land use change in an agricultural landscape of western Kenya. Microbial Ecology. 2005;**49**:50-62

[30] Imaz MJ, Virto I, Bescansa P, Enrique A, Fernandez-Ugalde O, Karlen DL. Soil quality indicator response to tillage and residua management on semi-arid Mediterranean cropland. Soil and Tillage Research. 2010;**107**:17-25. DOI: 10.1016/j.still.2010.02.003

[31] Grządziel J, Gałązka A. Microplot long-term experiment reveals strong soil type influence on bacteria composition and its functional diversity. Applied Soil Ecology. 2017. Article in press. http://dx.doi.org/10.1016/j.apsoil.2017.10.033

[32] Tscharntke T, Clough Y, Wanger TC, Jackson L, Motzke I, Perfecto I, et al. Global food security, biodiversity conservation and the future of agricultural. Biological Conservation. 2012;**151**:53-59. DOI: 10.1016/j.biocon.2012.01.068

[33] Shrestha K, Stevens S, Shrestha P, Adetutu EM, Walsh KB, Ball AS, Midmore DJ. Characterization of the soil microbial community of cultivated and uncultivated vertisol in Australia under several management regimes. Agriculture, Ecosystems and Environment. 2015;**199**:418-427

[34] Wolińska A, Kuźniar A, Zielenkiewicz U, Izak D, Szafranek-Nakonieczna A, Banach A, Błaszczyk M. Bacteroidetes as a sensitive biological indicator of agricultural soil usage revealed by culture-independent approach. Applied Soil Ecology. 2017;**119**:128-137

[35] Gałązka A, Łyszcz M, Abramczyk B, Furtak K, Grządziel J, Czaban J, Pikulicka A. Biodiversity of Soil Environment: Overview of Parameters and Methods in Soil Biodiversity Analyses. Puławy: Monografie i Rozprawy, IUNG; 2016. 100p

[36] Gałązka A, Gawryjołek K, Grządziel J, Frąc M, Księżak J. Microbial community diversity and the interaction of soil under maize growth in different cultivation techniques. Plant Soil Environment. 2017;**63**:264-270

[37] Lenart S, Sławiński P. Wybrane właściwości gleby oraz występowanie dżdżownic w warunkach siewu bezpośredniego i płużnej uprawy roli. Fragmenta Agronomica. 2010; **27**(4):86-93

[38] Caporali F, Mancinelli R, Campiglia E. Indicators of cropping system diversity in organic and conventional farms in central Italy. International Journal of Agricultural Sustainability. 2003;**1**(1):6772

[39] Dumontet S, Cavoski I, Ricciuti P, Mondelli D, Jarrar M, Pasquale V, Crecchio C. Metabolic and genetic patterns of soil microbial communities in response to different amendments under organic farming system. Geoderma. 2017;**296**:79-85

[40] Zhang QC, Shamsi IH, Xu DT, Wang GH, Lin XY, Jilani G, Hussain N, Chaudhryn AN. Chemical fertilizer and organic manure inputs in soil exhibit a vice versa pattern of microbial community structure. Applied Soil Ecology. 2012;**57**:1-8

[41] Busari MA, Kukal SS, Kaur A, Bhatt R, Dulazi AA. Conservation tillage impacts on soil, crop and environment. International Soil and Water Conservation Research. 2015;**3**:119-129

[42] Derpsch R, Friedrich T. Development and current status of no-till adoption in the world. In: 18th Triennial Conference of the International Soil Tillage Research Organization (ISTRO); June 15-19, 2009; Izmir. Turkey: 2009. pp. 1-13

[43] Gajda AM, Czyż EA, Dexter AR. Effects of long-term use of different farming systems on some physical, chemical and microbiological parameters of soil quality. International Agrophysics. 2016;**30**:165-172

[44] Tran Ba L, Le Van K, Van Elsacker S, Cornelis W. Effect of cropping system on physical properties of clay soil under intensive rice cultivation. Land Degradation and Development. 2016;**27**:973-982

[45] Marquad VT, Roscher C, Schumacher J, Buchmann N, et al. Plant species richness and functional composition drive over yielding in a 6-year grassland experiment. Ecology. 2009;**90**:3290-3302

[46] Jenkinson DS, Powlson DS. The effects of biocidal treatment on metabolism in soil V. A method for measuring soil biomass. Soil Biology and Biochemistry. 1976;**8**:209-213

[47] Waring SA, Bremner JM. Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. Nature. 1964;**201**:951-952

[48] Casida LE, Klein DA, Santoro T. Soil dehydrogenase activity. Soil Science. 1964;**98**:371-376

[49] Tabatabai MA, Bremner JM. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biology and Biochemistry. 1969;**1**:301-307

[50] Tabatabai MA, Bremner JM. Assay of urease activity in soils. Soil Biology and Biochemistry. 1972;**4**:479-587

[51] Dick RP, Breakwell DP, Turco RF. Soil enzyme activities and biodiversity measurements and integrative microbial indicators. In: Doran JW, Jones AJ, editors. Methods of Assessing Soil Quality. Madison: Soil Society of America Publication; 1996. pp. 247-272

[52] Walkley A, Black IA. An examination of the degjareff method for determining SOM and a proposed modification of the chromic acid titration method. Soil Science. 1934;**37**:29-38

[53] Dexter AR, Kroesbergen B. Methodology for the determination of tensile strength of soil aggregates. Journal of Agricultural Engineering Research. 1985;**31**:139-147

[54] Garland J, Millis A. Classification and characterization of heterotrophic microbial communities on the basis of patterns of community-level sole-carbon-source utilization. Applied Environmental Microbiology. 1991;**57**:2351-2359

[55] Furtak K, Gawryjołek K, Gajda AM, Gałązka A. Effects of maize and winter wheat grown under different cultivation techniques on biological activity of soil. Plant Soil Environment. 2017;**63**(10):449-454. DOI: 10.17221/486/2017-PSE

[56] Furtak K, Gajda AM. Activity of dehydrogenases as an indicator of soil environment quality. Polish Journal of Soil Science. 2017;**50**(1):33-40. DOI: 10.17951/pjss/2017.50.1.33

[57] Sikora S, Mrkonjic M, Kisic J. Importance of the soil microbial state-experience from the south-east European region. In: Miransari M, editor. Soil Tillage and Microbial Activities. India: Research Signpost; 2011. pp. 145-154

[58] Marinari S, Mancinelli R, Campiglia E, Grego S. Chemical and biological indicators of soil quality in organic and conventional farming systems in Italy. Ecological Indicators. 2006;**6**:701-711

[59] Majchrzak L, Niewiadomska A, Natywa M. Evaluation of dehydrogenase activity of spring barley depending on the tillage system, previous crop and type of crop residua. Annales Universitatis Mariae Curie-Skłodowska Lublin-Polonia. 2014;**69**(4):103-111

[60] Gałązka A, Gawryjołek K, Perzyński A, Gałązka R, Księżak J. Changes in enzymatic activities and microbial communities in soil under long-term maize monoculture and crop rotation. Polish Journal of Environmental Studies. 2017;**26**(1):39-46

[61] Masto RE, Chhonkar PK, Singh D, Patra AK. Changes in soil biological and biochemical characteristics in long-term field trial on a sub-tropical inceptisol. Soil Biology and Biochemistry. 2006;**38**:1577-1582

[62] Winding A, Hund-Rinke K, Rutgers M. The use of microorganisms in ecological soil classification and assessment concepts. Ecotoxicology and Environmental Safety. 2005; **62**:230-248

[63] Izquiergo I, Caravaca F, Alguacil M, Hernandez G, Roldan A. Use of microbiological indicators for evaluating success in soil restoration after vegetation of mining area under subtropical conditions. Applied Soil Ecology. 2005;**30**:3-10

[64] Kabiri V, Raiesi F, Ghazavi MA. Tillage effects on soil microbial biomass, SOM mineralization and enzyme activity in a semi-arid Calcixerepts. Agriculture, Ecosystems and Environment. 2016;**232**:73-84

[65] Mohammadi K, Heidari G, Javaheri M, Karimi-Nezhad MT. Soil microbial response to tillage systems and fertilization in a sunflower rhizosphere. Archives of Agronomy and Soil Science. 2013;**59**:899-910

[66] Tesfay A, Cornelis WM, Nyssen J, Govaert B, Getnet F, Bauer H, et al. Medium-term effects of conservation agriculture based cropping systems for sustainable soil and water management and crop productivity in the Ethiopian highlands. Field Crops Research. 2012;**132**:53-62

[67] Zhao X, Wu P, Persaud N. Soil quality indicators in relation to land use and topography in a small catchment on the Loess Plateau of China. Land Degradation & Development. 2013;**26**(1):54-61. DOI: 10.1002/ldr.2199

[68] Sparling GP. Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. Australian Journal of Soil Research. 1992;**30**(2): 195-207

[69] Jacobs A, Rauber R, Ludwig B. Impact of reduced tillage on carbon and nitrogen storage of two Haplic Luvisols after 40 years. Soil and Tillage Research. 2009;**102**:158-164

[70] During RA, Thorsten H, Stefan G. Depth distribution and bioavailability of pollutants in long-term differently tilled soils. Soil and Tillage Research. 2002;**66**:183-195

[71] Meena JR, Behera UK, Chakraborty D, Sharma AR. Tillage and residue management effect on soil properties, crop performance and energy relations in greengram (*Vigna vadiate* L.) under maize-based cropping systems. International Soil and Water Conservation Research. 2015;**3**:261-272

[72] Mühlbachová G, Kusá H, Růžek P. Soil characteristics and crop yields under different tillage techniques. Plant Soil and Environment. 2015;**61**:566-572

[73] He Y, Xu M, Qi Y, Dong Y, He X, Li J, et al. Differential response of soil microbial community to four-decade long grazing and cultivation in a semi-arid grassland. Sustainability. 2017;**9**(1):128-142

[74] Govaerts B, Mezzalama M, Unno Y, Sayre KD, Luna-Guido M, Vanherck K, et al. Influence of tillage, residue management, and crop rotation on soil microbial biomass and catabolic diversity. Applied Soil Ecology. 2007;**37**:18-30

[75] Gajda AM, Przewłoka B. Soil biological activity as affected by tillage intensity. International Agrophysics. 2012;**26**:15-23

[76] Insam H, Goberna M. Use of Biolog® for community level physiological profiling (CLPP) of environmental samples. In: Kowalchuk GA, de Bruijn F, Head IM, Van der Zijpp AJ, van Elsas JD, editors. Molecular Microbial Ecology Manual. 2nd ed. Dordrecht: Kluwer Academic; 2004. pp. 853-860

[77] Habig J, Swanepoel C. Effects of conservation agriculture and fertilization on soil microbial diversity and activity. Environments. 2015;**2**:358-384

[78] Yang Q, Wang X, Shen Y. Comparison of soil microbial community catabolic diversity between rhizosphere and bulk soil induced by tillage or residue retention. Journal of Soil Science and Plant Nutrition. 2013;**13**:187-199

[79] Zhao D, Li F, Yang Q, Wang R, Song Y, Tao Y. The influence of different types of urban land use on soil microbial biomass and functional diversity in Beijing, China. Soil Use and Management. 2013;**29**:230-239

[80] Soman C, Li S, Wander MM, Kent AD. Long-term fertilizer and crop-rotation treatments differentially affect soil bacterial community structure. Plant and Soil. 2017;**413**:145-159. DOI: 10.1007/s11104-016-3083-y

[81] Zhang CC, Ke SS, Wang J, Ge Y, Chang SX, Zhu SX, Chang J. Responses of microbial activity and community metabolic profiles to plant functional group diversity in a full-scale constructed wetland. Geoderma. 2011;**160**(3-4):503-508. DOI: 10.1016/j.geoderma.2010.10.020

[82] Wei M, Tan F, Zhu H, Cheng K, Wu X, Wang J, et al. Impact of Bt-transgenic rice (SHK601) on soil ecosystems in the rhizosphere during crop development. Plant Soil Environment. 2012;**58**(5):217-223

[83] Birkhofer K, Schoning I, Alt F, Herold N, Klamer B, et al. General relationships between abiotic soil properties and soil biota across spatial scales and different land-use types. PLoS One. 2012;**7**(8):e43292

[84] Bevivino A, Paganin P, Bacci G, Florio A, Pellicer MS. Soil bacterial community response to differences in agricultural management along with seasonal changes in a mediterranean region. PLoS One. 2014;**9**(8):e105515

[85] Shange RS, Ankimah RO, Ibekwe AM, Zabawa R, Dowd SE. Distinct soil bacterial communities revealed under a diversely managed agroecosystem. PLoS One. 2012;**7**:e40338

[86] Bhuyan SI, Triathi OP, Khan ML. Effect of season, soil and land use pattern on soil N-mineralization, ammonification and nitrification: A study in Arunachal Pradesh, eastern Himalaya. International Journal of Environmental Science. 2014;**5**(1):88-97

[87] Liu L, Qin S, Lu D, Wang B, Yang Z. Variation of potential nitrification and ammonia oxidizing bacteria community with plant growing period in apple orchard soil. Journal of Integrative Agriculture. 2014;**13**(2):415-425

[88] Birkhofer K, Bezemer TM, Bloem J, Bonkowski M, Christensen S, et al. Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity. Soil Biology and Biochemistry. 2008;**40**:2297-2308

[89] Sipilä TP, Yrjälä K, Alakukku L, Palojärvi A. Cross-site soil microbial communities under tillage regimes: Fungistasis and microbial biomarkers. Applied and Environmental Microbiology. 2012;**78**(23):8191-8201

[90] Bissett A, Richardson AE, Baker G, Thrall PH. Long-term land use effects on soil microbial community structure and function. Applied Soil Ecology. 2011;**51**:66-78

[91] Natywa M, Sawicka A, Wolna-Maruwka A. Microbial and enzymatic activity in the soil under maize crop in relation to differentiated nitrogen fertilisation. Water-Environment-Rural Areas. 2010;**2**(30):111-120

[92] Mahajan GR, Manjunath BL, Singh NP, Ramesh R, Verma RR, Latare AM, et al. Effect of organic and inorganic sources of nutrients on soil microbial activity and soil organic carbon build-up under rice in west coast of India. Archives of Agronomy and Soil Science. 2016;**63**(3):414-426. DOI: 10.1080/03650340.2016.1213813