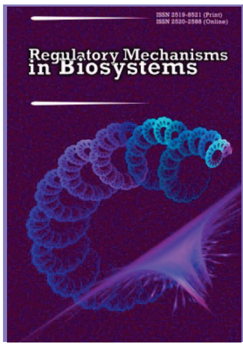

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Soil microbial diversity and activity in different climatic zones of Ukraine

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Soils are dynamic biological matrices featuring a complex microbiome that has an integral role in all ecosystem processes. At the system level, microbial communities regulate ecosystem functioning and modulate resistance and resilience to anthropogenic impact. Ecological status of soils depends on the structure and activity of soil microbiome. The aim of this study was long-term investigations of soil microbiome in different climatic zones of Ukraine, namely the structure and diversity of microbial communities, direction of soil microbiological processes in natural and transformed ecosystems. Four types of soil were studied in different natural and climatic zones: Steppe zone – Donetsk region, Forest-steppe – Vinnytsia region, Polissya – Chernihiv region, Carpathian region. Microbiological studies of soil were carried out according to generally accepted methods in soil microbiology. Diversity of soil microbiome was estimated using Shannon and Simpson indices. The direction of microbiological processes in the soil was determined by the appropriate coefficients: mineralization, oligotrophy, pedotrophity, and transformation of organic matter. The results of soil monitoring in various natural and climatic zones of Ukraine showed a correlation between the agroecological conditions and activity of microbiocenosis. The soil of natural ecosystems was characterized by a high total number of the microorganisms with a balanced structure of various ecological-trophic groups and balanced mineralization-immobilization processes, organic matter decomposition, and humus accumulation. The chernozem soil was characterized by more stable and balanced structure of microbiocenosis than soddy-podzolic, brown and grey forest soils. The growth of the proportion of micellar organisms occurs during the long-term application of mineral fertilizers. Data of functional communities and functional processes helped estimate specific microbial responses to anthropogenic impact. The most significant influence of agricultural activity on the soil microbiota was observed in the poorly soddy-podzolic, brown and grey forest soils, where the cultivation of the crops without fertilization resulted in a decrease of the total number of microorganisms by 2.2–4.5 times. Soil microbial diversity was practically twice lower in these ecosystems in comparison with the natural ones. Soils with low content of organic matter and acidic medium: soddy-podzolic, brown forest and grey forest soils have been characterized by a high number of micromycetes and a relatively low number of eutrophic and nitrogen-fixing microorganisms. This article summarizes important results of long term investigations of soil microbiome: structure, interaction, functioning, activity and diversity in the main types of soils on the territory of Ukraine.

Keywords: biodiversity; microorganisms; ecosystem; community; soil monitoring.

Introduction

Soil microbiome plays a key role in ecological functions such as decomposition of organic matter and nutrient cycling (Wakelin, 2018; Crowther et al., 2019). Agricultural activity primarily affects the soil environment by changing the direction of biogeochemical cycles of biophilic elements, the content and composition of organic matter, density and soil structure, water and air regime, etc. (Liu et al., 2010; Rousk et al., 2010; Deng et al., 2019; Alyokhin et al., 2020). Under these conditions, changes occur in the structure of microbial communities, the direction of microbiological processes and biological activity of the soil (Sun et al., 2016; Deng et al., 2019). Soil microbial biomass, community structure, and microbial diversity are sensitive indicators of soil quality. Changes in the structure of microbial communities and microbial activity can influence plant growth and crop yield (Bending et al., 2002; Zhang et al., 2012; Bender & Van der Heijden, 2015; Yang et al., 2018; Martin et al., 2019). Anthropogenic load on the environment in Ukraine is several times higher than in developed countries of the world. Particularly negative environmental consequences can be traced in the agrosphere, which occupies more than 70% of the territory of Ukraine. The biological activity of soils indicates the ability of the soil to perform its functions and is crucial in ensuring the sustainability of ecosystems (Harwood & Greenberg, 1999; Heijden et al., 2008; Schulz et al., 2013; Ferris & Tuomisto, 2015; Bahram et al., 2018; Nannipieri et al., 2017; Yang et al., 2018; Chen et al., 2020). Stability of the soil microbiome structure is important for the activity of soil processes. For example, such proceses as: nitrification and nitrogen fixation (Hu et al., 2011; Martin et al., 2016). Changing any function of the soil reduces its quality and value, and ability to ensure the productivity of agrocenosis. The ecological status of the soil is characterized by qualitative and quantitative changes in the structure of microbial cenosis and the ratio of the number of microorganisms of certain ecological trophic groups (Andreyuk & Valagurova, 1992; Sharma et al., 2010).

The impact of agrotechnologies on the microbiocenosis of the soil can be either direct or indirect due to changes in the physical and chemical parameters of the microclimate and energy sources (carbon), the reorganization of the composition of microbial communities and their functional activity (Celik, 2005; Lauber et al., 2013; Auffret et al., 2016). Organic and mineral manure can significantly affect soil microorganisms (Hartmann et al., 2015; Fernandez et al., 2016; Schmidt et al., 2018). Two factors of microbial community structure, plant type and soil type, exert their effects in a complex manner. This fact may be related to the complex microbial interactions in soil, including interactions between microorganisms and soil and microorganisms and plants. Biological and biochemical studies of soils have a special place in the knowledge of soil fertility, its ecological status and the prediction of the productivity of agrocenosis (Torsvik & Ovreas, 2002; Ferris & Tuomisto, 2015; Qamar et al., 2018). Soil fertility management is, first of all, the management of the microbiological processes occurring in it (Lombard et al., 2011; van der Bom et al., 2018).

It is necessary to conduct in-depth and comprehensive studies of the basic patterns of the formation of microbial communities and their functional activity, depending on edaphic and agrotechnical factors. The objective of this work was to investigate changes in the structure, diversity and activity of soil microbiome in different climatic zones of Ukraine.

Materials and methods

Study sites and soil sampling. The study was conducted in the Laboratory of Ecology of Microorganisms at the Institute of Agroecology and Environmental Management of National Academy of Agrarian Sciences of Ukraine and SR&E Center of Molecular Microbiology and the Immunology of Mucous Membranes. The initial data for the analysis, calculations and mathematical analysis were the results of multi-year studies of soil microbiocenoses in stationary field experiments of the National Academy of Agrarian Sciences of Ukraine during 2001–2015. The soil sampling was carried out by standard methods (ISO 10381-6:1993) in multi-year field experiments, the characteristics of which are given in Table 1. For comparison, soil in natural ecosystems was studied (virgin land).

Table 1
Agrochemical characteristic of soil in stationary field experiments in different climatic zones of Ukraine (0–20 cm, the average 2001–2015, n = 10)

Type of soil Geographic coordinates	pH	Humus, %	Content, mg/kg of soil: nitrogen which easily hydrolises	active phosphorus	exchangeable potassium
Chernozem ordinary 48°05'28" N 37°39'00" E	6.5 ± 0.2	5.2 ± 0.07	114 ± 1.3	98 ± 1.1	143 ± 1.6
Grey forest 49°11'19" N 28°21'16" E	4.2 ± 0.1	1.7 ± 0.04	76 ± 0.9	174 ± 1.4	115 ± 1.2
Soddy-podzolic 51°07'00" N 31°10'07" E	4.9 ± 0.1	1.1 ± 0.02	74 ± 0.7	170 ± 1.4	68 ± 0.7
Brown forest 48°18'67" N 23°44'39" E	5.2 ± 0.1	1.9 ± 0.04	78 ± 0.7	164 ± 1.3	122 ± 0.9

The soil samples of the agroecosystems were selected from the 0–20 cm layer of the plants over the period when the system reached its climax – stable, balanced state. All samples were prepared using the unified procedure: they were air dried and grounded to < 3 mm in size; visible plant and mesofauna residues were removed. Experiments were performed in five replications.

Microbiological study of soil microorganisms. For the microbiological analyses, we selected the soil samples from each variant of the experiment and an abandoned field in 5-fold replication and prepared an average sample. Batches of 10 g each were put on sterile mortar and then the microorganisms were separated from the soil particles using the method of Zviahyntsev (1991). We prepared tenfold solutions of the output soil suspension, which were used for inoculations to the elective media for each ecological-trophic or taxonomic group of microorganisms. The quantitative compound of the microorganisms of the main ecological-trophic and taxonomic groups in soil was determined using the methods of inoculating the soil suspension to standard growth media, which are generally accepted in soil microbiology (Zviahyntsev, 1991): the total number of microorganisms – on peptone-glucose agar with soil extraction (PGA), bacteria which use organic nitrogen (N_{org}) – to meat infusion agar (MIA), *Streptomyces* and bacteria which use mineral nitrogen (N_{min}) – to starch-and-ammonia agar (SAA), the number of pedotrophs – to soil agar (SA), nitrogen-fixing microorganisms – on the non-nitrogenous media of Ashby and Vinogradsky, oligotrophs – on purified agar (PA), micromycetes – to Czapek-Dox agar. After the inoculation to the media, the bacteria were incubated at the temperature of 28 °C during 5–14 days. The colonies which grew in these media were calculated assuming that one colony is formed from one vital cell. The results of assessments of the number of microorganisms grown on the nutrient media were expressed in Colony Forming Units (CFU) per 1 g of dry soil. For this purpose, we determined the moisture of the soil samples for the experiments using the thermostat-gravimetric analysis, and recalculated the obtained number of colonies taking into consideration the coefficient of moisture and solution of the soil suspension. The inoculations were repeated three times, the obtained data were analyzed using mathematical statistics, calculating the confidence interval in the number of microorganisms.

The taxonomic structure of the microbial communities was determined as a percentage of such taxa: bacteria, *Streptomyces* and micromycetes (Zviahyntsev, 1991; Strickland & Rousk, 2010).

Direction of soil microbiological process. The direction of microbiological processes in the soil was determined by the appropriate coefficients (Andreyuk & Valagurova, 1992):

– coefficient of mineralization (K_{min}) was calculated by the ratio of the number of microorganisms immobilizing the mineral forms of nitrogen (CSAA) to the number of organotrophs (CMIA) by the formula: K_{min} = CSAA/CMIA;

– coefficient of oligotrophity (K_{ol}) was calculated by the ratio of the number of microorganisms, which are able to absorb nutrients from very rarefied solutions to the total number of eutrophic microorganisms by the formula: K_{ol} = CPA / (CSAA + CMIA);

– coefficient of pedotrophity (K_{ped}) were calculated as the ratio of the number of pedotrophic microorganisms (CSA) to the number of microorganisms using organic nitrogen (CMIA): K_{ped} = CSA / CMIA;

– coefficient of transformation of organic matter (K_{tom}) was calculated by formula: K_{tom} = (CMIA + CSAA) × (CMIA / CSAA).

Diversity of soil microbiome. Diversity of sol microbiocenosis was calculated according to the Shannon index and the Simpson index (Shannon index, Simpson's index) (Magurran, 1988).

Data analysis. We determined the mean values (x) and their standard deviations (SD). The level of significance in the study was P < 0.05. Dispersion analysis and the Tukey test were used to compare the averages of the independent samples. Logistic transformation was applied to the data expressed as a percentage.

Results

The results of many years of research have shown that the total number of microorganisms in the soil depends on the type of ecosystem (Table 2). At the same time, significant fluctuations in the structure of microbiocenoses of soils of natural ecosystems have not been observed. In soddy-podzolic soils, the pool of microorganisms was the smallest, correlating with low content of organic matter and stocks of biogenic nutrients, acidic reaction of the soil environment.

Table 2
Total pool of microorganisms in different types of soils of natural and transformed ecosystems of Ukraine (×10^6 CFU/g of dry soil, x ± SD, n = 10)

Type of soil	Natural ecosystems (Virgin land)	Transformed ecosystems – agroecosystem (arable soil): I*	II**
Chernozem ordinary	28.6 ± 0.4	14.9 ± 0.3	19.3 ± 0.3
Grey forest	6.2 ± 0.2	2.8 ± 0.2	5.2 ± 0.2
Soddy-podzolic	5.4 ± 0.2	1.2 ± 0.1	4.9 ± 0.2
Brown forest	7.4 ± 0.2	3.7 ± 0.2	5.9 ± 0.1

Note: I – without fertilizers; II – a variant with balanced doses of fertilizers and other agrotechnical measures that ensure maximum productivity.

Our studies have shown that the most significant impact of agricultural activity on soil microbiota took place in the brown forest, podzolic and grey forest soils, where prolonged cultivation of non-fertilized agricultural crops led to decrease in the total pool of microorganisms by 2.2–4.5 times. In chernozem the total number of microorganisms was reduced only by 1.9 times. That is, soils with a high content of organic matter, having a higher buffering capacity, are more resistant to the different agro-technical measures. Functioning of an ecosystem before and after disturbance is largely regulated by soil microbial population dynamics. Microbial biomass and activity can provide advance evidence of subtle changes in the content long before it can be accurately measured against the background organic matter levels present in the soil. In agroecosystems, nutrient cycling, residue decomposition, soil structure have great importance to the productivity and sustainability of that system. If the soil is to be used as a waste repository, then infiltration, porosity, structure, and degradation capacity are of greatest importance. Soil microorganisms constitute a large dynamic source and sink of nutrients in all ecosystems and play a major role in plant litter decomposition and nutrient cycling.

Use of a combination of different types of mineral, organic and biological fertilizers took positive effect on the soil microbiota. Increase in the total number of microorganisms was observed on average by 1.3–4.1 times in comparison with the controls without fertilization. The greatest positive effect of agromeasures on microbiocenosis was seen in soddy-podzolic soils. That is, such soils are most susceptible to any anthropogenic impact. The ability of an ecosystem to withstand extreme disturbance may depend partly on the diversity of the system. Diversity investigations are needed to increase our knowledge of the diversity of genetic resources and understand the distribution of microbial diversity in soil.

Soils of agroecosystems were characterized by decrease in the general pool of microorganisms and impoverished microbial diversity (Table 3). As with the assessment of the taxonomic diversity of microbial community, the Shannon index showed greater diversity of soil mirobiome in the natural ecosystems, and hence higher resistance to various environmental factors. The ability to self-regulate and efficient use of energy resources of natural ecosystems is ensured by the numerous trophic levels and high adaptive potential of microorganisms that are part of the microbiocenosis, that is, conditions are created for compensatory reactions in the event of disturbance in certain chains in the system. The results of the study of the taxonomic structure of soil microbiome are presented on Figure 1.

Table 3
Diversity indices of microbial community in different types of soils in natural and transformed ecosystems of Ukraine (x ± SD, n = 10)

Type of soil	Natural ecosystems (virgin land)		Transformed ecosystems – agroecosystem (arable soil)	
	Shannon (H)	Simpson (D)	Shannon (H)	Simpson (D)
Chernozem ordinary	6.21 ± 0.29	0.020 ± 0.002	3.11 ± 0.12	0.123 ± 0.005
Grey forest	3.43 ±0.12	0.153 ± 0.007	1.96 ± 0.10	0.211 ± 0.006
Soddy-podzolic	2.64 ± 0.11	0.178 ± 0.008	1.64 ± 0.10	0.253 ± 0.006
Brown forest	4.56 ± 0.10	0.097 ± 0.007	2.12 ± 0.10	0.180 ± 0.006

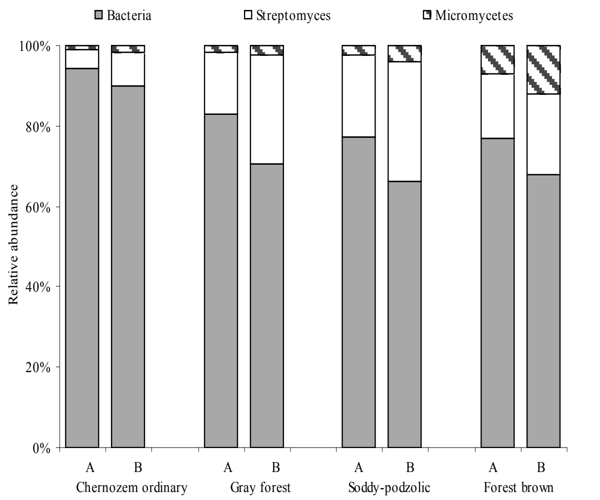

Fig. 1. Community composition of soil bacteria, streptomyces and micromycetes in different types of soils in natural and transformed ecosystems of Ukraine: A – natural ecosystems (virgin land), B – agroecosystem (arable soil); The data are statistically significant, $P < 0.05$, x ± SD, n = 6

According to the ratio of the number of microorganisms of certain ecological trophic groups, the direction of microbiological processes in the soil was analyzed (Table 4). In chernozem soil of the natural ecosystems, the activity of mineralization processes, oligotrophy and pedotrophy was low (microbiological coefficient < 1). For soil with low SOM content, the mineralization activity (Kmin increases by 5–18%), oligotrophy and pedotrophy increased by 2.2–2.8 compared with chernozem. Transformation of organic matter in chernozem usually was more active by 1.7 times and correlated with SOM content in comparison with soddy-podzolic soil. It was established that irrespective of the edaphic conditions, in the soil of agroecosystems on non-fertilized control, the activity of mineralization processes increased by 1.5–1.7 times, as well as coefficient of oligotrophy and pedotrophy increased by 1.1–3.0 times, indicating a deterioration of the nutritional regime and the development of destructive processes of the organic matter.

Table 4
Direction of microbiological processes in different types of soil of natural (virgin land) and transformed (arable soil) ecosystems of Ukraine

Type of soil	Treatment	Coefficient of mineralization, K_{min}	Coefficient of oligotrophy, K_{ol}	Coefficient of pedotrophy, K_{ped}	Coefficient of transformation of organic matter, K_{tom}
Chernozem ordinary	Virgin land	0.92	0.62	0.93	38.63
	Arable soil I*	1.40	1.61	3.13	15.43
	Arable soil II**	1.13	1.08	2.75	26.72
Grey forest	Virgin land	0.97	1.62	2.38	23.11
	Arable soil I	1.64	1.93	2.75	21.27
	Arable soil II	1.23	1.35	2.58	29.58
Soddy-podzolic	Virgin land	1.09	1.73	2.60	22.20
	Arable soil I	1.69	1.85	2.72	26.41
	Arable soil II	1.20	1.56	2.45	28.81
Brown forest	Virgin land	0.94	1.68	2.10	27.13
	Arable soil I	1.51	1.98	2.59	20.34
	Arable soil II	1.17	1.54	2.31	29.18

Note: I – without fertilizers; II – a variant with balanced doses of fertilizers and other agrotechnical measures that ensure maximum productivity.

Discussion

The use of soil in agriculture and the application of various agrotechnologies disturb the structure of microbial cenosis and its functions (Griffiths et al., 2000; Fierer & Jackson, 2006; Sheibani & Ahangar, 2013; Habig & Swanepoel, 2015). To increase our knowledge of the functional role of diversity and to identify changes in the diversity associated with disturbance or management, it may be important to monitor the diversity as an indicator of change or in response to stress. We need to determine the extinction rate that still can maintain a stable sustainable ecosystem with intact integrity. The extinction rate within a system may be an important indicator of the status of the system and critical in determining the level of the diversity necessary to maintain a sustainable system. Indices of diversity which combine species richness and evenness also have been called heterogeneity indices. Since diversity indices are numerous and varied, it is critical to realize their limitations. A diversity index is a single value; thus, it cannot indicate the total makeup of a community.

The Simpson diversity index was the first index to be used in ecological studies and deals with the probability that two individuals are of the same species. In other words, if the probability that those two individuals are of the same species is low, then the diversity is high. The Shannon diversity index deals with the uncertainty predicting to which species an individual will belong. This diversity index equation is the most widely used. In the soil of agroecosystems there was a decrease in biodiversity and the formation of a homogeneous microbial complex with a high degree of dominance of certain morphotypes. In studies by Zhou et al. (2015) the continued introduction of inorganic fertilizers into chernozem soil led to reduction in the biological diversity and the number of bacteria.

During the application of fertilizers in chernozem of agrotransformed ecosystems, there were no significant differences ($P < 0.05$) between the number of bacteria using N_{min} and N_{org} compared to the natural analogue, although the reduction was 5% and 23% respectively. However, the number of streptomycetes increased by almost 8 times. The highest vulnerability of the soil microbial ecosystem was in the variants without the introduction of any nutrients into the soil. Prolonged soil management without additional fertilization resulted in the decrease in the content of agronomically useful microorganisms, especially nitrogen-fixing microorganisms by 1.6–2.7 times. Under these conditions, in grey forest and soddy-podzolic soils, the number of oligotrophs and bacteria using N_{min} increased almost twice compared with the analogue of the soil in natural ecosystem. This indicates the intensification of the destruction processes of soil organic matter (SOM) and the decomposition of humus substances.

The enrichment of grey forest and soddy-podzolic soils with nutrients led to the intensification of the growth of the number of bacteria using N_{org} by 40%, and micromycetes by 30%, and streptomyces by 6.2–7.9 times. In the soil of agroecosystems, not only were the reduction of the content of organic matter and its redistribution in the soil column seen, but also the changes in the availability of nutrients and the pool of basic nutrients. This creates new conditions for soil microorganisms and leads to changes in the structure of their community (Sun et al., 2018).

Therefore, an important direction is the study of the impact of agricultural land use on the soil microbiome, the dependence of the number and diversity of microbiota on environmental and human factors that determine the stability of agricultural soils (Patyka & Symochko, 2013; You et al., 2014).

It has been determined that the edaphic conditions and factors that determine the soil fertility (SOC, C/N, NPK content in the soil) correlate with the structure of the microbial group, the dependence of the number and diversity of microbiota on the environmental and human factors that determine the stability of agricultural soil (Wu et al., 2011; You et al., 2014).

Taxonomic structure of microbiocenoses of the studied soils showed that the soil of natural ecosystems are characterized by more stable ratio of bacteria, streptomycetes and micromycetes: for chernozem ordinary – 94% : 4.5% : 1.1%, brown forest – 77.0% : 16.1% :7.0%, grey forest – 82.9% : 15.3% : 1.8%, soddy-podzolic – 77.2% : 20.3% : 2.5% respectively. Bacteria are commonly found in soils rich in SOM, while relatively large amounts of saprophytic fungal communities tend to increase when soil fertility is reduced (You et al., 2014). Forests represent one of the largest and most important ecosystems on Earth, covering more than 40 million km^2 and representing 30% of the total global land area. Primeval forests are ideal ecosystems to study the interaction of bacteria, fungi and archaea with their abiotic environment. Virgin forests are essential for the conservation of biological and genetic diversity. They reserve the relict and endemic species of flora and fauna.

The study of primeval forest is a unique opportunity to explore the natural structure, diversity and genetic structure of unmodified forest and ecosystem dynamic processes and relationships that occur in them under the influence of ecological factors. Despite of the intensive exploitation of forests in the last ten centuries, its area decreased by 3.5 times.

Moreover, since most European forest stands have been managed for centuries, very little is known about the diversity, ecology, and distribution of soil microorganisms in natural, undisturbed forest ecosystems in Europe (Patyka & Symochko, 2013). Soil microorganisms have been largely ignored by conservation efforts. However, their role in biogeochemical processes, their diversity and abundance, and their potential as repositories of valuable genetic information and metabolic products make them as important as animals and plants to the biosphere and human welfare.

A number of studies published over the past decade highlighted the role of microbial diversity for ecosystem functioning, including potential consequences of reduced diversity to the stability of microbial communities (Fierer & Jackson, 2006). In ecosystems, the diversity of functional groups undergoing change, within-species genetic diversity, and the diversity of species in functional groups seem to be critical components of the resilience of ecosystem functions (Seybold et al., 1999; Griffiths et al., 2001). Sustainable agriculture must work toward identifying and minimizing energy loss throughout the system. Diversity is the key issue in energy flux. Although diversity and ecological stability may not be concepts that usually coexist in agricultural systems, diversity in crops, cropping systems and management practices will enhance the stability of agriculture; affect the microbial portion of the agroecosystem, and thus, influence sustainability. Changes in the structure of soil microbiome can be caused by two reasons: the influence of external factors and the availability of the resources. Resource availability is also likely to be the fundamental driver of microbial succession, but the limiting resources and environmental factors regulating succession will be more complex given the far greater physiological diversity is present within microbial communities and the breadth of environments in which succession can occur.

In autotrophic succession, nutrients and light (or the availability of inorganic electron donors) are likely to be the primary resources limiting biomass accumulation. However, in the earliest stages of autotrophic succession, heterotrophs may also be relatively highly abundant, utilizing trace levels of available carbon.

During endogenous heterotrophic succession, labile substrates will be consumed first, supporting copiotrophic microbial taxa that are later replaced by more oligotrophic taxa that metabolize the remaining, more recalcitrant, organic C pools in the later stages of succession. Endogenous heterotrophic succession cause increase in biomass of oligotrophic bacteria and decrease in phylogenetic diversity. Diversity indicates how the microbial communities have changed during succession.

Knowledge of functional communities and functional processes may help to assay specific microbial responses to antropogenic impact. Soil microbial activity, organic matter decomposition and nitrate oxidation have been used as soil quality indicators in studies on the stability of soil microbial communities. Functional resilience, defined as recovery of a soil microbial process, is often observed in soil microbial communities, but the degree to which resilience is possible depends on the functions measured and the type and dose of the impact (Griffiths et al., 2004; De Ruiter et al., 2002). The chernozem soil of the agroecosystem has a more stable and balanced structure of microbiocenosis than soddy-podzolic, brown and grey forests. The percentage of bacterial organisms in it is at the level of 90%, and only the use of mineral fertilizers reduces it to 88%. The growth of the proportion of micellar organisms occurs in the long-term application of mineral fertilizers, both individually and in combination with organic fertilizers. This is due to increase in the acidity of the soil, but micromycetes prefer acidic soils (Grantina-Levina et al., 2011; Cheng et al., 2015; Zhang et al., 2016).

The share of micromycetes and streptomyces in the taxonomic structure of soddy-podzolic soils with acidic reaction and low content of SOM was higher, respectively, by 2.3 and 4.5 times in comparison with chernozem. Due to the lack of organic matter in the soil, the microbial community has restructured in the direction of the growth of the micellar organisms, being more resistant to the environmental and anthropogenic factors.

The application of balanced doses of fertilizers reduced the activity of mineralization of organic matter in the soil by 19–29%, and the oligotrophy by 16–33%. Also, there was active development of zymogenic microbiota which decomposes fresh organic compounds and plant remains, the value of the coefficient pedotrophy decreased by 8–12%.

At the same time, the transformation of organic compounds increased by 10–70% compared with the non-fertilized variant, and this process depended on the type of soil and the type of fertilizer. In particular, as our studies have shown, the application of mineral fertilizers into chernozem soils activated the development of pedotrophic and oligotrophic microorganisms and microorganisms using N_{min} by 1.3–1.5 times (Demyanyuk et al., 2019). At the same time, increase in the values of coefficients K_{min} and K_{ped} was 18% and 9% respectively. That is, the application of exogenous mineral substances activates the processes of soil mineralization. The organic fertilizer system in the soil increased the number of organotrophic microorganisms, and K_{min} decreased by 26–29% and the content of organic matter of the soil increased by 33–37%, which indicates favourable conditions for the accumulation of humus in the soil. Further investigations of other management systems and temporal changes will be necessary for better understanding of the effect of management on the microbial community and soil quality.

Conclusions

The soil of natural ecosystems is characterized by high content of the total number of microorganisms with a balanced structure and high microbial diversity, as well as the balance of mineralization, pedotropy and the transformation of organic matter. Regardless of climatic zone and type of soil in the transformed ecosystem, due to the application of agro-measures, significant changes in the structure and diversity of soil microbiome were observed. Common chernozem was characterized by high stability and phylogenetic diversity of the soil microbial community compare with soddy-podzolic, grey and brown forest soils. The most important impact of agricultural activity on soil microbiota could be traced in soils with low content of SOM. High level of microbial diversity and complex linkage structure provides greater resistance and resilience of soil microbiome to negative changes driven by anthropogenic effects.

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