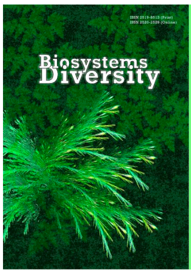

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Effects of different fertilizer systems and hydrothermal factors on microbial activity in the chernozem in Ukraine

O. S. Demyanyuk*, O. V. Sherstoboeva*, A. A. Bunas*, O. V. Dmitrenko**

**Institute of Agroecology and Environmental Management NAAS, Kyiv, Ukraine*
***State Institution "Soil Protection Institute of Ukraine", Kyiv, Ukraine*

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Institute of Agroecology and Environmental Management NAAS, Metrologichna st., 12, Kyiv, 03143, Ukraine.
Tel.: +38-067-680-12-43.
E-mail: demolena@ukr.net, ovsher@ukr.net, bio-206316@ukr.net

State Institution "Soil Protection Institute of Ukraine", Olena Teligha st., 8, Kyiv, 04112, Ukraine.
Tel.: +38-067-442-80-22.
E-mail: ecolab23071964@ukr.net

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Groups of microorganisms in soils perform the role of global biogeochemical membrane which provides metabolism of substances and energy between the pedosphere, lithosphere, hydrosphere and living organisms. Climate change has resulted in a complex combination of unpredictable changeability of the environment, which is a serious test for the stability and productivity for the natural and anthropogenically transformed ecosystems. Changeability of the hydrothermal factors causes serious changes in the structure and metabolic activity of soil microorganisms, the quality and properties of soil. We studied the impact of hydrothermal factors on the content of carbon, microbial biomass and organic substance in deep chernozem of a natural ecosystem (fallow) and an agroecosystem under different systems of fertilization of winter wheat. A close relationship (r = 0.69–0.79) was determined between the content of microbial biomass in soil and hydrothermal factors (air temperature and moisture). Excessive drought and high parameters of air temperature led to decrease in the content of microbial biomass by 1.5–2.8 times compared to the years with optimum parameters of hydrothermal regime (HTC = 1.0). Leveling out the impact of high temperatures on the productivity of the soil microbiota occurs at a sufficient amount of moisture, and also available nutrients. Drought (HTC = 0.4) and excessive moisture (HTC = 2.0) following heightened air temperatures reduce the release of CO_2 from soil. Fallow soil usually has a high content of microbial carbon in the organic compounds of soil (C_{mic}/C_{org} was 2%). In the agroecosystem, there was recorded a decrease by 26–32% of the C_{mic} specific share in the content of the organic compound of the soil compared to the natural analogue. With organic and organic-mineral systems of fertilization, an increase in C_{mic}/C_{org} parameter occurs and the soil parameters become close to the soil of a natural ecosystem. The calculated ecological coefficients of the orientation of microbial processes in soil indicate a possibility of a balanced functioning of the microbial group and introducing organic and organic-mineral fertilizers, creating optimum conditions for the productivity of winter wheat.

Keywords: soil; microbial biomass: C_{mic}/C_{org} ratio; emission of carbon dioxide; hydrothermal coefficient; crop yield of winter wheat

Introduction

Soil is an important natural resource and the key indicator of the balanced functioning of terrestrial ecosystems, which forms the basis for their health. To characterize the ecological condition of soil, different physical, chemical and biological parameters are used (Fahrutdynov, 2010; O'Dell et al., 2014; Malysheva et al., 2017; Bünemann et al., 2018). At the same time, biological/chemical parameters are represented insufficiently, but have a broad potential for assessing the quality of soils and ecosystem functions (Bünemann et al., 2018).

Climate is one of the main factors of the soil-formation process, which forms the hydrothermal regime of soil and determines physical-chemical and microbiological processes in it (Davidson & Janssens, 2006; Ludwig et al., 2015; Mueller et al., 2017). Also, the hydrothermal soil regime, influences to a great extent the level of biological productivity of ecosystems and involvement of organic carbon (C_{org}) in the soil processess (Qi et al., 2016; Shahbazac et al., 2017).

Circulation of carbon, one of the most important chemical elements, in the biosphere entirely depends on the origin, composition, stability/lability, rotation velocity of the organic compound, and the structure and activity of soil microbiocenoses. The largest metabolic reservoir of carbon on the planet is soil. It concentrates 2300 Gt of carbon, which is greater than the total content of this chemical element in the atmosphere (800 Gt) and phytomass (550 Gt) (Bardgett et al., 2013; Li et al., 2016; Sinsabaugh et al., 2017). Loss of carbon from tilled soils due to their irrational use leads to loss of fertility and turns agroecosystems into a significant source of greenhouse gas (CO2) (Hu et al., 2018). According to the assessments of scientists, the CO_2 content in the atomsphere can be reduced by at least 16–30% due to its deposition in soil, by increasing the concentration of organic compounds in soil to 5–15% (Baldock, 2007; Maillard et al., 2015; Li et al., 2018).

Climatic factors, including climatic extreme values such as sudden changes in air temperature, droughts, floods and other natural anomalies cause a complex impact on microbiological processes in the soil and its properties, regimes and functions (Kruglov et al., 2012; Ma et al., 2015; Sherstoboeva & Demyanyuk, 2016; Wu et al., 2017; Demyanyuk et al., 2018; Zhao et al., 2018). Depending on the factor which limits the productivity of ecosystems, for example precipitations and accordingly changes in soil moisture, the proportion of number of bacteria and micromycetes can change, as well as the species composition of these groups and their bioecology (Six et al., 2006; Banerjee et al., 2016a). In particular, increase in temperature leads to re-structuring of microbial groups in favour of microorganisms adapted to high temperatures and with high breeding tempi (Orlova et al., 2015; Torres-Sallan et al., 2017).

Microbial biomass is no less important as a living and labile component of the organic compound of the soil and its natural potential, which allows broad use of this parameter for assessing the condition of microbiocenoses and the soil in general (Feng et al., 2014; Weia et al., 2018). The speed of rotation of microbial biomass is 0.5–2.0 years, and that of the organic compound of soil is over 20 years, therefore it allows one to use the values of changes occurring with microbial biomass for assessing the condition of the organic compound of the soil and its ecological condition.

An indicative parameter of the ecological condition of soil and availability of organic carbon is the ratio of carbon of microbial biomass (C_{mic}) and content of carbon of organic compounds C_{org} (Collins et al., 2000; Maillard et al., 2016), which is an indicator of functioning of soil ecosystems (Swenson et al., 2015).

An indicator sensitive to the changes in the condition of biotic and abiotic components of soil, caused by natural and anthropogenic factors, is the tempi of CO_2 production (Benbi et al., 2015). On the one hand, the more substrate is available to the microorganisms, the more active are the processes of its decomposition and mineralization, and the greater is the increase in biomass and microbial breathing and CO_2 production (Maillard & Angers, 2014; Santana et al., 2015; Banerjee et al., 2016b). On the other hand, the more favourable the ecological conditions of the soil environment and the lower the number of barriers limiting the accessibility of the substrate, the more full and effective is its consumption and mineralization by microorganisms (Kaiser et al., 2016; Yang et al., 2017). The objective of the study is the impact of hydrothermal factors (air temperature and precipitations) on the ecological condition of chernozem soil of a natural ecosystem and an agroecosystem under different systems of fertilization and parameters of emission of carbon dioxide, content of microbial biomass and ratio of C_{mic}/C_{org} and the orientation of the microbiological processes which quickly react to the change in ecological and anthropogenic factors and are broadly used as ecological indicators of the soil environment.

Material and methods

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 (NAAS) of Ukraine. The initial data for the analysis, performing calculations and statistical analysis were the indicators of multi-year studies (2001–2015) on the parameters of soil, samples of which were selected in accordance with the current standards (ISO 10381-6:1993) from an agrocenosis of winter wheat and its natural analogue (fallow) in the forest-steppe zone of Ukraine. The experimental ground was situated at the research station of the V. M. Remeslo Myronivka Institute of Wheat of NAAS of Ukraine (Kyiv Region) in a lowland area of the Right Bank of the Dnipro within the Ukrainian Uplands (49º40' N, 31º00' E).

In a field experiment, we studied the impact of long-term usage of different systems of fertilizing on the physiological activity of the microbial grouping and content of microbial and organic carbon in soils. Among the systems of fertilization, we chose variants according to the principle – without using fertilizers (control, Con), introducing only mineral (Min) or organic fertilizers (Org) and combining mineral and organic fertilizers (Min + Org). The soil characteristics of the field experiment is demonstrated in Table 1.

Table 1
Agrochemical characteristic of soil in field experiments (0–20 cm)

Type of soil	pH	Humus, %	Content, mg/kg of soil		
			nitrogen which easily hydrolises	active phosphorus	exchangeable potassium
Deep low-humus chernozem	5.2–6.5	4.18	109–133	128–189	95–127

To characterize the hydrothermal regime of the period of study, we used the mean values of monthly air temperatures and amount of precipitations. For fuller analysis of thermal resources and atmospheric precipitations, we calculated the hydrothermal coefficient of H. Selianinov (HTC), which is adequate to the ratio of sum of precipitations to 0.1 of sum of temperatures over the period of study with values over 10 ºC (Chirkov, 1979; Gathara et al., 2006). To assess the hydrothermal conditions by the HTC parameter, the following gradation of the parameters was accepted: HTC below 0.5 – sharp deficiency of precipitations (severe drought); 0.6–0.7 – insufficient humidity (extremely dry), 0.8–0.9 – droughty (drought is not intensive), 1.0–1.2 – insufficient moisture, 1.3–1.6 – moderate moisture, > 1.7 – excessive moisture, HTC > 2.0 – highly excessive moisture (Lyalko et al., 2014). This parameter has an advantage over others and characterizes not only the incoming part of the water balance (precipitations), but also the unproductive discharge of moisture (evaporation) from the soil surface or plants and allows assessment of the impact of two abiotic factors at the same time. To determine the impact of hydrothermal factors on the condition and activity of the soil microbiocenosis, we analyzed the results of microbiological studies over the years characterized by contrasts of sudden changes in the temperature in summer and total amount of precipitations (HTC 0.4, 1.0, 2.0).

For microbiological analysis, we selected soil samples from each variant of the experiment and the natural ecosystem (fallow) in the period when the system reached climax – stable, balanced condition (late June – early July) in 5-times replication and prepared a mean sample. Weighed 10 g amounts of soil with bacteria were dispersed using physiological solution in sterile mortars (Zviahyntsev, 1991). We prepared 10-times dissolved solutions of the initial soil suspension, which were used for inoculations on the elective media for each ecological-trophic group of microorganisms (Zviahyntsev, 1991; Volkohon et al., 2010): microorganisms which used organic nitrogen (organotrophs) – on beef-extract agar, bacteria consuming mineral nitrogen and streptomycetes – on starch-and-ammonia agar, a number of pedotrophs – on soil agar, micromycetes – on Chapek's medium. After inoculations to growth media, they were incubated at the temperature of 28 ºC over 5–14 days depending on the tempi of growth of microorganisms in particular groups. The colonies which grew on the media were estimated on the assumption that one colony is formed out of each vital cell. The number of microorganisms was expressed in colony-forming units per 1 g of absolutely dry soil. For this purpose, using the thermostat-weight method, we determined the moisture of the soil sample taken for the experiment and recalculated the obtained number of colonies taking into account the coefficient of moisture and diffusion of soil suspension. The inoculations were made in 5 times replication, the data obtained were analyzed using methods of mathematical statistics, calculating the confidence interval of the number of microorganisms.

The orientation of microbial processes in soil were characterized by the corresponding coefficients: coefficient of mineralization (K_{min}) which was calculated according to the ratio of number of microorganisms which immobilize the mineral forms of nitrogen to the number of organotrophs, and coefficient of pedotrophy (K_{ped}), calculated as a ratio of the number of pedotrophic microorganisms to the number of organotrophic microorganisms (Volkohon et al., 2010).

The content of general microbial biomass (C_{mic}) in the soil was determined using the rehydration method through gentle drying of soil samples at temperature of 65–70 ºC over 24 h with further extraction of 0.5 M with K_2SO_4 solution (Anderson & Domsh, 1978; Blagodatskyj et al., 1987). The content of carbon of organic compounds of the soil (C_{org}) was calculated with consideration of humus content using 1.724 coefficient, accepting that humus contains 58% of carbon on average (ISO 10694:1995; State Standards of Ukraine 4289:2004).

Determining the production of CO_2 by the soil was done in laboratory conditions with temperature, and moisture control using the adsorption method – after alkaline adsorption, and using titration method, we determined the amount of CO_2 released from the soil (Anderson & Domsch, 1990; Volkohon et al., 2010).

The results of the experimental studies were statistically analyzed using the Microsoft Excel program package. The tests were performed in 3–5 times replication. We determined the mean values (x) and their standard deviations (SD). The level of significance selected for the study was $P < 0.05$ (Bailey, 1995).

Results

The experimental data indicated that in the soil of the natural ecosystem (fallow), the activity of the microbiocenosis, its productivity and accumulation of biomass was related to the changes of such ecological factors as air temperature and moisture. Maxima and minima of its content coincide with the values of hydrothermal regime (correlation coefficient r = 0.69–0.79) (Table 2). At insufficient amount of precipitations and high air temperatures (HTC = 0.4), the productivity of the microbial grouping was quite low – 2.8 times lower than over the years with favourable weather conditions at HTC = 1.0.

Table 2
Parameters of activity in microbial group in soil of the fallow and the agroecosystem at different hydrothermal conditions (x ± SD, n = 5)

Treatment	Emission of CO_2, mg CO_2/kg of soil per day	Content of C_{mic}, mkg C/g of soil	Coefficient	
			K_{min}	K_{ped}
HTC = 0.4				
Natural ecosystem (fallow)	53.5 ± 2.4	250.4 ± 5.2	0.89	2.84
Agroecosystem:				
Con	10.3 ± 1.1	203.2 ± 2.3	1.01	2.63
Min	28.9 ± 1.5	254.1 ± 2.6	1.00	2.48
Org	19.1 ± 1.4	289.5 ± 2.1	0.91	0.66
Min + Org	33.4 ± 1.5	290.3 ± 2.1	1.01	0.92
HTC = 1.0				
Natural ecosystem (fallow)	67.7 ± 1.6	680.6 ± 5.8	0.94	2.50
Agroecosystem:				
Con	39.4 ± 0.8	358.3 ± 4.2	1.12	3.12
Min	59.7 ± 1.2	425.2 ± 4.1	1.12	3.08
Org	65.1 ± 1.7	560.5 ± 4.9	0.96	0.61
Min + Org	68.8 ± 1.7	586.1 ± 5.3	1.12	1.04
HTC = 2.0				
Natural ecosystem (fallow)	56.0 ± 0.8	704.0 ± 5.9	1.11	2.63
Agroecosystem:				
Con	24.3 ± 0.3	370.6 ± 3.1	1.33	3.42
Min	48.6 ± 0.9	430.1 ± 3.7	1.34	2.96
Org	42.1 ± 0,6	590.6 ± 5.0	1.10	0.90
Min + Org	45.1 ± 0.7	612.3 ± 5.3	1.15	1.41

Note: data are statistically significant ($P < 0.05$).

In contrast to the years with drought and deficiency of moisture, a sufficient amount of precipitations contributed to active development of soil microorganisms and accumulation of microbial biomass. This is seen in high content of total microbial biomass – 680.6–704.0 µg C/g of soil over the years with normal and high level of precipitations, which indicates active development of microorganisms and general productivity of the microbiocenosis. Heightened temperatures contributed to a stronger negative effect on the microbial productivity both in the natural ecosystem and in the agroecosystem under different systems of fertilizing the plants.

Generalized data of multi-years studies on emission of carbon dioxide from soil of the natural ecosystem indicate that the level of CO_2 emission in different hydrothermal conditions ranged insignificantly within 53.3–67.7 mg CO_2/kg of soil per 24 h, and the variablity of the parameters was 0.7–26.3%. That is the impact of hydrothermal factors on this parameter was not decisive, and the soil biosystem of the fallow plot was characterized by stability. In the agroecosystem, the CO_2 release from the soil was low compared to the natural conditions. The variation coefficient of this parameter (variability – 28.7–56.4%) depends on the impact of hydrothermal and anthropogenic factors.

In favourable weather conditions (HTC = 1.0), the value of the mineralization coefficient below one ($K_{min} < 1.0$) indicates the prevalence of processes of synthesis over destruction in the soil, particularly in the fallow soil K_{min} = 0.94 and in the variant with introduction of organic fertilizers K_{min} = 0.96. For all other variants of the experiment, values of K_{min} were at the level of 1.12, which indicates prevalence of processes of destruction of the organic compound over their synthesis in the soil. Severe drought (HTC = 0.4) did not contribute to the activation of mineralization processes and K_{min} in soil in the studied variants ranged from 0.89 for the fallow soil to 1.01 in the control and the variant with introduction of organic-mineral fertilizers. In the conditions of significant excessive moisture of soil and high air temperatures (HTC = 2.0), the activity of the microbiocenosis was quite high and in all variants of the experiment K_{min} was significantly higher than 1.0. The processes of mineralization of organic compound in the soil were most active in the control (K_{min} = 1.33) and in the variant with introduction of mineral fertilizers (K_{min} = 1.34). During introduction of organic and organic-mineral fertilizers, the values of coefficient of mineralizetion became closer to the soil of the fallow plot (K_{min} = 1.11).

It was determined that the extent of consumption of the organic compound of soil by microbiota did not depend on the hydrothermal conditions. The coefficient of pedotrophy for the fallow plot (K_{ped} = 2.50–2.84), control (K_{ped} = 2.63–3.42) and the variant with application of mineral fertilizers (K_{ped} = 2.48–3.08) had high parameters, which indicates prevalence of autochthonous microbiota in the microbial biocenosis of these ecosystems, which is able to decompose complex polycyclic compounds or humus compounds in the soil (Andreyuk, 1981). In the variants with application of organic and organic-mineral fertilizers, we observed intense development of zymogenous microbiota which decomposes fresh organic compounds and plant remains, and therefore the values of the pedotrophy coefficient equaled 0.61–0.90 and 0.92–1.41, which also indicates sufficient provision of these variants with nutrients.

Introduction of additional nutrient substrates to the soil of the agroecosystem, despite unfavourable hydrothermal conditions (HTC = 0.4), activated microbiological processes of transformation of organic compound, accompanied by increase in CO_2 release from the soil by 2.8 times with application of mineral fertilizers, by 3.2 times with introduction of organic-mineral fertilizers and 1.9 times – with organic fertilizers. That is the introduction of mineral fertilizers to soil activates processes of decomposition of organic compounds, accompanied by increase in volumes of carbon dioxide released from soil to the air. Also, the parameter of CO_2 emission, in conditions of excessive moisture was the highest in the variant with application of mineral fertilizers.

The impact of hydrothermal factors on microbial productivity in the soil of agroecosystem depended on the fertilizing system. During severe drought (HTC = 0.4), a 1.5–2.0 times decrease in the content of microbial biomass took place. Favourable conditions for accumulation of microbial biomass in soil formed in excessively moistened soil (HTC = 2.0). This again proves the conclusion about the leveling out of the impact of high temperatures on productivity of soil microbiota by presence of sufficient amount of moisture. At the same time, the accumulation of biomass of microorganisms also depended on the provision with nutrients – the lowest content of C_{mic} was observed in the control variant, the highest – in the variant with introduction of organic-mineral fertilizers.

The research on determining the content of C_{mic} in soil of the agroecosystem indicates the destabilisation of the organic compound in the soil under different systems of fertilisation. In general, prolonged application of fertilizers led to decrease in C_{mic} specific share in the content of the organic compound of soil by 26–32% compared to the soil of the fallow plot (Fig. 1). With organic and organic-mineral systems of fertilisation, we observed increase in C_{mic}/C_{org} parameter and approach to the values of the soil of natural ecosystem. The soil of the fallow plot typically had a high content of microbial carbon in the content of carbon of organic compounds of soil and had the highest C_{mic}/C_{org} parameter – 2.0%.

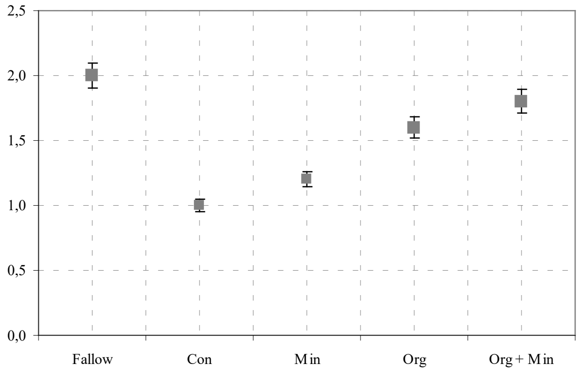

Fig. 1. Share of C_{mic} content in the organic compound (C_{org}) in soil of different ecosystems, mean for 2001–2015 (C_{mic}/C_{org}, %; data are statistically significant $P < 0.05$)

For a full characteristic of the condition of the agroecosystem, the level of productivity of the cultivated crops is used. The highest crop yield of grain of winter wheat at the level of 5.59–6.26 T/ha was obtained in all variants of the experiment at optimum values of hydrothermal regime (Fig. 2). Significant increase in mean values of monthly temperature and deficiency of moisture (HTC = 0.4) caused a decrease in productivity of the plants and the crop yield on average by

1.5–2.0 times. In such conditions, the potential of the plants was used for adapting to unfavourable conditions of the environment. The greatest deficiency in yield was recorded in the control variant (–2.06 T/ha) and with application of mineral fertilizers (–1.81 and –1.85 T/ha).

In conditions of excessive moisture, the productivity of the winter wheat plants was lower in the variants of the experiment on average by 0.55 T/ha. The highest level of crop yield (5.89 T/ha) was observed in the variant with application of mineral fertilizers. A low level of crop yield of wheat, even compared to the control, was observed in the variant with introduction of organic fertilizers (4.74 T/ha). Such decrease in crop yield most likely is related to rapid decomposition of the organic compound as a result of high moisture of the soil and air temperature, which contributed to wash-out of low-molecular soluble compounds to the lower layers of soil and created a deficiency in nutrients for plants and microbiota.

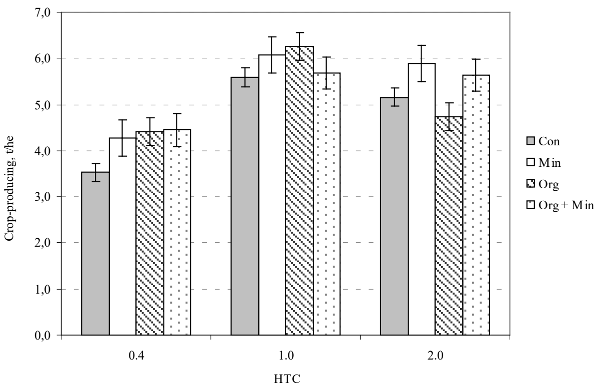

Fig. 2. Crop yield of winter wheat depending on the fertilization system and hydrothermal factors (T/ha; the data are statistically significant, P < 0.05, x ± SD, n = 3)

Discussion

Change in the parameters of the climatic system leave very few opportunities for biological species to adapt to such sudden changes. This may cause extinction of up to 40% of biological species, degradation of ecosystems, loss of soil fertility and reduction of agricultural productivity (Muñoz et al., 2010; Wood et al., 2013; Alaswad et al., 2015; Liu et al., 2018).

Microorganisms perform the role of global biogeochemical membrane, due to which the metabolism of substances and energy occurs between the pedosphere, lithosphere, hydrosphere and biotopes (Pershina et al., 2013; Belyuchenko, 2016; Chernov et al., 2017). Almost 99% of all organic compounds in the biosphere are considered to be formed by autotrophs, and only around 1% – by chemosynthetics (Bates et al., 2010; Eilers et al., 2012; N'Dri et al., 2018). Natural microbiological processes in the soil, along with human technogenic activity is a source of greenhouse gases. Over a half of the amount of annual emissions of CO_2 and N_2O into the atmosphere is a result of activity of soil microorganisms (Myrold et al., 2014; Bichel et al., 2017).

Climatic changes affect soil organisms both directly through the change in environmental temperature regime and indirectly (temperature regime and increase in CO_2 concentration) through changes in physiological and biochemical processes in plant organisms. All this affects the organic compound in the soil and functioning of soil microbiocenoses by activating the processes of destruction of organic compounds, nitrification etc., which increases the amounts of emission of greenhouses gases (Sherstoboeva & Demyanyuk, 2016).

The organic compound of the soil is one of the largest places of accumulation of carbon on a global scale, and therefore temperature sensitivity of all its fractions is a key factor which determines the reaction of the terrestrial balance of carbon to climatic warming. According to the current views (Baumann et al., 2009; Kurishbayev et al., 2016; Krasnoperov et al., 2018), the organic compound of soil exists from several hours to several thousands of years and gathers the microbial biomass, partly and completely decomposed animal and plant remains, excreta, biomolecules and humus substances. It was proven that one of the most important factors on which the temperature sensitivity of organic compound to mineralization depends is physiological activity of soil microbiota and this determines the effectiveness of utilization of the substrate. At the same time, soil microbiota is functionally stable, which has a strong effect on the organic compound, and the temperature dependence is the main factor which determines the reserves of carbon and their changes in conditions of the global warming (Lutzow & Kogel-Knabner, 2009). The microbial diversity in soil increases as the temperature rises to a certain level (around 26 °C) (Davidson & Janssens, 2006; Zhou et al., 2016).

The productivity and stability of crops in an agrocenosis depend on the species and qualitative composition of the substrate introduced into the soil, which is used both by plants and microorganisms. Our studies showed that in the soil of an agrocenosis of winter wheat without fertilizers, the productivity of the microbial group was low (Table 2). The maximum parameter of the content of microbial biomass in the soil was observed in the variant with an organic-mineral system of fertilizing, which approaches the corresponding parameters of fallow soil. That is, with optimization of the ratio of the content of carbon and nitrogen in the soil, which is achieved by combining organic and mineral compounds, a clearly manifested stimulating effect on the synthesis of microbial biomass was observed. This positively affects the structure and productivity of the microbial group, and allows the balance of physiological processes in the soil of the agroecosystem to approach natural analogues.

Drought (HTC = 0.4) and highly excessive moisture (HTC = 2.0) against the background of high air temperatures have a significant effect on CO_2 emission. The microbial productivity also depends on the introduction of exogenous organic substrate. This can be explained from the perspective of the functional structure of the microbial group. A high level of moisture, optimum temperature and trophic regime have a positive impact on the development and domination of group of mycelial organisms (mycromycetes and streptomycetes) in the microbiocenosis, which leads to significant accumulation of biomass (Ananyeva et al., 2010).

The parameter of CO_2 emission indicates the level of provision and accessibility of the substrate to the microbial group t, and therefore the activity of the processes of its destruction. Therefore, naturally, when hydrothermal factors are unfavourable, the level of carbon dioxide release from the soil was higher in the variants of the experiment with introduction of substrate that is more accessible and balanced in the proportion of C : N of the substrate (Table 2), that is mineral and organic-mineral fertilizers (Sherstoboeva & Demyanyuk, 2003).

This is proven by the data on the orientation of the microbiological processes in the soil. Variability of hydrothermal factors leads to changes in the structure and metabolic activity of soil microorganisms (Sherstoboeva & Demyanyuk, 2016). During extreme conditions (high temperatures, droughts and low soil moisture), the diversity of microorganisms sharply decreases. At the same time, the structure of prokaryote groups changes, which indicates significant change in the activity of microbiota, possible appearance of thermophile forms of microorganisms and intensification of enzymic processes according to the soil temperature gradient, which results in a high emission of greenhouse gases (CO_2, N_2O, CH_4) (Kruglov et al., 2012, Suseela et al., 2012). Increase in temperature affects the change in metabolism over time, at the same time, adaptation of physiological processes of the microbial group to new temperature conditions takes place. Therefore, in predictting the inverse relations between the carbon content in soil, concentration of CO_2 in the atmosphere in conditions of climate changes, one should necessarily take into account the orientation of the physiological processes of soil microorganisms (Bradford & Crowther, 2013; Pereira et al., 2013; Wood et al., 2013).

Microbial biomass is an important component of the organic compound of the soil, and varies quantitatively and qualitatively depending on the impact of different factors, including type of soil, the extent of its cultivation, intensity of the exploitation, usage of agrotechnologies, and climatic factors (Alvarez et al., 1995; Blagodatskyj et al., 2008; German et al., 2011; Wang et al., 2013; Qi et al., 2016; Ghafoor et al., 2017). In tilled soils, compared to their undeveloped analogues, the content of the microorganism biomass was lower (Table 2) and such decrease in the amount of microbial biomass is considered as an indicator of decrease in soil productivity (Jiang et al., 2011).

On a regional scale, change in moisture and use of soil are most closely related to the composition of the microbial group and biomass of microorganisms, and such factors as spatial structure, structure of soil, presence of nutrients and species of plants were insignificant (Ma et al., 2015, McDaniel et al., 2013). The habitat of microorganisms in agrarian use of soils obtains carbo-oligotrophic properties which reduce the productivity of the soil by limiting the microbial biomass. Increase in CO_2 concentration in the atmosphere has a so-called "fertilizing effect" on terrestrial ecosystems. The activity of heterotrophic microorganisms involved in mineralization of the organic compound contributes around 70% of emissions of dioxide from the soil (Kudeyarov et al., 2006; Pandey et al., 2009; Malysheva et al., 2017). Changes in bioproductivity of plants and some of their physiological processes can cause changes in the structure and functioning of both natural and cultivated plant groups, and also affect the soil carbon balance (Coppens et al., 2006; Munoz et al., 2010; Pereira et al., 2013; Shangguan et al., 2014).

Prolonged agricultural usage of soils with and without introducing fertilizers has led to both a significant decrease in the content of total biomass of microorganisms, and in the C_{mic}/C_{org} ratio, which indicates decrease in the specific share of carbon of microbial biomass in the total content of organic carbon of soil (Fig. 1). With inefficient use of soils in cultivating agricultural crops, particularly the decrease in the amount of organic fertilizers applied and irrational usage of mineral fertilizers, the degradation processes in the soil increase, leading to mineralization of the organic compound, decrease in agrochemical properties and reduction of soils' productivity (Kruglov et al., 2012; O'Dell et al., 2014; Ghafoor et al., 2017). This is also indicated by our studies: in the variants of the experiment without introducing fertilizers under different hydrothermal conditions, the content of microbial biomass was low, and the activity of processes of mineralization and transformation of the organic compound was high (Table 2), and the crop yield was low (Fig. 2). Combining organic fertilizers with mineral fertilizers has a positive effect on the activity of the soil microbiocenosis, balance of the processes of transformation of the organic compound of the soil, which indirectly ensures the high productivity of the agrocenosis of winter wheat even under unfavourable hydrothermal factors. The negative effect of high air temperatures on soil microorganisms and their activity were leveled out by the presence of a sufficient amount of moisture in the soil. The effect of moisture manifests also in the changes in the activity in the plant organism and provision of microorganisms with the substrates (Chymytdorzhyeva & Chymytdorzhyeva, 2012, 2014).

Conclusion

A statistically reliable relationship (r > 0.70) was determined between the content of microbial biomass in the soil of the studied ecosystems and hydrothermal factors. Drought and high air temperature parameters reduced the content of microbial biomass by 1.5–2.8 times compared to the years with optimum parameters of hydrothermal regime (HTC = 1.0). Leveling out of the impact of high temperatures on the productivity of soil microbiota occurred when there was sufficient amount of moisture, and also of nutrients.

Compared to the soil of the natural ecosystem, in the agroecosystem soil, the content of total biomass of microorganisms significantly decreased, reducing the share of C_{mic} in the soil organic compound to 30%. Usage of organic and organic-mineral fertilizers caused increase in the content of microbial biomass on average by 1.1–1.3 times. With introduction of organic and organic-mineral fertilizers in the soil, we observed increase in the C_{mic}/C_{org} parameter of up to 1.2 and 1.8 times respectively and the tendency towards approaching the values of the fallow soil. Soil of the natural ecosystem is characterized by insignificant fluctuation of the parameters of CO_2 emission. Change in ecological conditions of the soil environment under different systems of fertilizing leads to increase in the activity of the mineralization processes, which is accompanied by loss of the organic compound in soil and decrease in the share of C_{mic}. The highest level of productivity of the agroecosystem by the indicator of crop yield of winter wheat was observed during HTC = 1.0 for all variants of the experiment. In that period of the study, the parameters of microbial biomass were higher by 0.9–2.0 times. This indicates that the hydrothermal conditions provided balanced functioning of the soil microbial cenosis, which therefore contributed to the formation of a high level of productivity of winter wheat.

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