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Research paper

Sustainability of Agro-Gray Soil to Pollution and Acidification, and its Biodiagnostics

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Abstract

The aim of investigations is to study the resistance of agro-gray heavy loamy soil to heavy metal pollution and acidification on the basis of determining corresponding parameters of buffering, as well as microbiological activity, as a biological diagnosis of fertility potential under stress conditions.
The object of investigations is the agro-gray soil of different cultivation degrees: fertile and infertile. In fertile soil, the humus content in barren soil was 2.2-2.5 % and that in fertile soil was 5.4 %.
A model of soil resistance to heavy metals and acidification has been developed. The low level of stability of the agro-gray soil appears when the maximum Langmuir adsorption value is less than 91 mM / kg for zinc, less than 104 mM / kg for copper, less than 93 mM / kg for lead, and less than 61 mM / kg for cadmium. The average level of stability is provided for zinc, copper and lead in the range from 91 to 143 mM / kg, 104 - 130 mM / kg and 61 - 132 mM / kg, respectively. A high level of soil stability is guaranteed if the maximum adsorption value exceeds 93 - 143 mM / kg.
Bio diagnostics included a series of experiments with imitation of pollution and acidification. Soil pollution was modeled by adding 200 and 600 mg / kg of copper to it (experiment 1). In experiment 2, soil was polluted by cadmium at the rate of 10, 30 and 100 MAC. The exposition was 1, 10, 35 and 57 days.
Acidification of the soil was simulated by adding dilute sulfuric acid at a rate of 0.018, 0.044, and 0.120 mM / l (experiment 3).
In experiment 4, the effect of zinc on the activity of azotobacter in barren and fertile soil was studied. The dose of zinc was 50 and 100 mg / kg.
It was established that when the content of humus is not less than 5 %, the average decrease in activity for all groups of microorganisms was not more than 20 % as compared with clean samples. When the humus content was below 3 %, the microbiological activity decreased by more than 30 %.

Keywords: *agro-gray soil, pollution, acidification, bio indication, microbiological activity, stability.*

1. Introduction

The basis of biological diagnostics of soil is microbiological investigations. The nature of the response of soil microorganisms to external influences depends on the soil state, its simultaneous ability to provide microorganisms with life factors and minimize contact with stressful agents, for example, heavy metals. This is the essence of the bio protective function of the soil, which is a derivative of soil fertility and its expression. A large role in the bio protective function belongs to humic substances, which are one of the main components in binding heavy metals in a wide range of soil acidity (Shimeng Peng et al., 2018). They increase the negative potential of clay fractions, which contributes to an increase in the sorption of cadmium, copper and lead (Ting-Ting Fan et al., 2015).
High molecular organic matter increases the sorption capacity in relation to cations of heavy metals due to the presence of acidic functional groups. Due to heavy metals binding in solid-phase organic matter, their activity is reduced and their participation in the biological cycle is limited.
Currently, there is an almost universal decrease in organic matter of agricultural soils (Glazunov et al., 2016; Sychev et al., 2017; Iñigo Virto et al., 2015).
Most soils of southern Europe have less than 2 % soil organic carbon (Jones, R.J.A et al., 2005). Soils of France has least of all. The loss of soil carbon in England and Wales from 1973 to 2003 was in the range of 0.5-2.0 g / kg of soil per year. In Austria, soil carbon loss per year was 24 g / m^2 (Capriel, P, 2013). In Belgium, carbon loss from agricultural soils for 1955-2005 exceeded 0.12 t / ha per year (Goidts, E et al., 2007).
According to V.G. Sychev et al. (2018), based on the analysis of long-term experimental data from 19 stationary field experiments of the Geographic Network, it was found that fertilizer systems on the main types of soils in Russia did not provide the necessary reproduction of humus, or soil fertility in general.

The concept of soil stability should be quite multifaceted and flow from the entire complexity of its structural and functional organization, mode, openness and features of response reactions to external factors, both evolutionarily determined and others not related to soil formation factors. Therefore, for soils close to native, having the natural character of their development, the concept of stability can be reduced to the ability to preserve traits within the classification divisions (type, subtype, etc.). For anthropogenically transformed agro genic soils, affected by strong external influences, including unfavorable ones, the meaning of the definition of soil stability should be close to homeostasis, a phenomenon typical for biological systems. The following particular definition of soil stability suits this better, as the ability to resist external influences, maintain the existing mode of operation, and also maintain the relative constancy of individual characteristics with a slight change in its composition (buffering), and not reduce some level of fertility (Fried et al., 2013; Khitrov, 2002).
In the light of current trends of anthropogenic impact, its strengthening on natural systems, agricultural soils in particular, is inevitable. Therefore, the negative consequences are becoming more and more obvious. Some anxiety is caused by heavy metal pollution (Motuzova, 2011; Bamborough, 2009) and acidification of the soil solution (Yu T.-Y, 2014; Warby, 2009; Singh et al., 2008; Bouwman et al., 2002; Kandeler et al., 1996). In Russia, the areas with excess acidity is about 36 million hectares, or 32 % of the total area of arable land (Kuznetsov et al., 2002).
Unlike organic pollutants, most HMs are not subject to microbiological or chemical degradation and can accumulate in soils for a long time (Lasat, 2002; Kasitskiy et al., 2017). The total number of polluted sites in Europe varies, according to various estimates, from 0.3 to 1.5 million, covering up to 52 million hectares or 16 % of the land area (Montanarella, 2003).
Soil is a habitat for microorganisms. Therefore, studying the activity of microorganisms will make possible to evaluate the fertility of the soil. This is especially important against the background of adverse factors such as acidification and pollution. Their effect on soil microflora has been the subject of many scientific papers (Hoang Nam Pham et al., 2018; Hamed Azarbad et al., 2016; Niemeyer et al., 2012; Renella et al., 2007; Ananyeva et al., 2002; Walia and et al., 2002; Brookes et al., 1984, 1995; Doelman, 1986). There is little information in scientific literature about the role of fertility in the stabilization of microbiological activity, on the one hand, and bio indicative evaluation of soil resistance, on the other hand. Fertility is a fundamental feature of soil. To evaluate soil fertility in ensuring its stability, it is advisable to use various methods of bio-diagnostics using soil microflora as an object, as it is a sensitive system to respond to adverse effects. By their comparative activity, one can register the appearance of negative initial (earliest) signals in the soil (Devyatova, 2006; Glebova, 2011; Terekhova et al., 2013).
The aim of investigations is to study the resistance of heavy loamy soil to heavy metal pollution and acidification on the basis of determining appropriate parameters of buffering, as well as microbiological activity, as a biological diagnosis of fertility potential under stress conditions.

2. Materials and Methods

The object of the research was agro-gray, heavy-loamy soil of different degrees of cultivation: fertile (cultivated) and barren (uncultivated). These options are represented by territorial sites of one geochemical facies. The humus content in barren agro-gray soil was about 2.2-2.5 % and the nutrients were average. The cultivated soil had 5.4-5.6 % humus, mobile phosphorus and exchangeable potassium were high. The cultivated version reflects the potential of the soil to ensure stability.
Soil resistance to pollution was evaluated by the parameters of ion-exchange adsorption of heavy metals — maximum adsorption (Q_{max}) and buffer capacity for heavy metals (BC^{HM}) in the concentration range from 0 to 50 mM / l with a ratio of soil : solution equal to 1:10. Some intersection points of the tangent, held at an equilibrium concentration of cations of heavy metals, were found. The intersection points were found at an equilibrium concentration of cations of heavy metals equal to 5, 10 and 20 mM / l. Buffer capacity was determined as a slope.
To determine the buffering capacity to acidification, the method of continuous potentiometric titration (CPT) was used. The buffering capacity to acidification (BC_A) was judged by the amount of titrant necessary to change pH by a predetermined value.
To study the effect of agro-gray soil fertility on resistance to acidification, some soil samples differing in humus were used. Soil acidification was simulated with dilute hydrochloric acid, having changed the starting point of titration. Acid load was $4.7 \cdot 10^{-6}$ M / 100 g (pH_1), 11 (pH_2) and $30 \cdot 10^{-6}$ M / 100 g (pH_3), which is equivalent to 5.33, 4.96 and 4.52 pH. The control is the background acidity (pH_0).
Bio-diagnostics included a series of experiments with imitation of pollution and acidification. Soil pollution was modeled by adding diluted $CuSO_4 \times 5H_2O$ in the amount when the dose of copper was 0, 200 and 600 mg / kg (experiment 1). Modeling high levels of copper contamination is aimed at studying the bio protective function of soil fertility.
The experiments had cases of simulating acidification and contamination with heavy metals. Soil pollution with cadmium at the rate of 10, 30 and 100 MAC took place in experiment 2. The exposition was 1, 10, 35 and 57 days.
Soil acidification was simulated by adding dilute sulfuric acid at the rate of creating an acid load of 0.018, 0.044, and 0.120 mM / l (experiment 3).
The effect of zinc on the activity of azotobacter in barren and fertile soil was studied in experiment 4. The dose of zinc was 50 and 100 mg / kg. Azotobacter content was determined on Ashby medium by the soil lumps method.
To study soil resistance to acidification and HM pollution (using copper as an example) of different lands (arable land, meadow, forest plantation), acidification was modeled by adding acid at the rate of $2.5 \cdot 10^{-5}$ mole / l and copper at the rate of 30 MAC and 50 MAC (experiment 5). The soil without load (background) served as a control in all experiments. High (stressful) levels of soil pollution and acidification are determined by the law of limiting the adaptive ability of an organism within the normal range of its response to environmental conditions.
Soil moisture was maintained at 30 % of dry soil. Microbiological activity was determined by generally accepted methods. Substrate-induced respiration (SIR) was determined using the method proposed by J. Anderson and K. Domsch (Anderson and Domsch, 1978). The method is based on measuring the initial respiration rate of microorganisms after soil enrichment with an additional source of carbon and energy (glucose). Microbial biomass (C_{mic}) was determined by recalculating the speed of SIR according to the formula (Anderson, Domsch, 1978):

$$C_{mic}(\text{mkg} \cdot g^{-1} \text{ of soil}) = (\text{mql } CO_2 \cdot g^{-1} \text{ of soil per hour}^{-1}) \cdot 40.04 + 0.37 \quad (1)$$

Basal (background) respiration (BR) was determined by the rate of CO2 release by the soil in 8-10 hours of its incubation at 22° C and 60 % moisture. Determining the rate of CO_2 production was carried out as described for determining SIR, but water was introduced into the soil instead of glucose solution. The microbial metabolic coefficient was calculated as the ratio of BR rate to microbial biomass according to the formula:

$$BR/C_{mic} = qCO_2(\text{mkg } CO_2\text{–}C \cdot mg^{-1} C_{mic} \cdot \text{hour}^{-1}) \quad (2)$$

Microbiological studies at Institute of Biochemistry and Physiology of Microorganisms Named after G.K. Scryabin and at Institute of Physical, Chemical and Biological Problems of Pedology RAS (Puschino).

3. Results and Discussion

The model of agro-gray soil resistance to heavy metals and acidification. The overall buffer capacity of agro-gray soil for acidification between the variants with barren soil (BS) and fertile soil (FS) differed by 30 mM eq / kg despite the close values of pH 7.3–7.5. Higher interval values of buffering indicate a better state of soil components of the fertile soil, responsible for processes of hydrogen ions neutralization (Fig. 1).

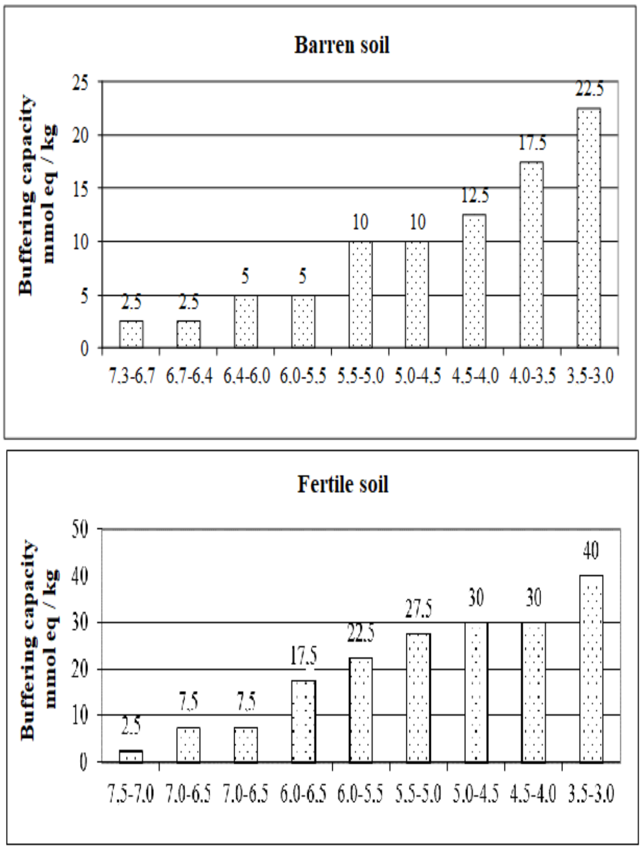


Figure 1: Buffering capacity (mM eq / kg) of agro-gray soil depending on its fertility level

After the action of acid on soil, BC_A decreased in all variants, but most in barren soil: with acid loads of $4.7 \cdot 10^{-6}$; $11.9 \cdot 10^{-6}$ and $30 \cdot 10^{-6}$ M / 100 g. The BC_A was 57, 45 and 48 mM eq / kg, respectively, and that of the fertile one was 175, 165 and 155 mM eq / kg.

The dependence of BC_A on the content of absorbed bases was established and that was $Y = 7.7 + 3.6X$ ($r = 0.77$), the dependence on exchangeable acidity was $Y = - 122.5 + 39.3X$ ($r = 0.89$), the dependence on current acidity was $Y = - 170.4 + 39.5X$ ($r = 0.90$), and that on hydrolytic acidity was $Y = 134.4 - 12.4X$ ($r = - 0.85$).

With humus content of about 2.0 % and pH_{KCl} equal to 5.5–5.7, the BC_A was 7.6 mM eq / 100 g. When acidifying the agro-gray soil to 4.4, the BC_A value decreased 1.8 times to 4.2 mM eq / 100 g. With humus increase in the soil to 3.0 % when pH_{KCl} of 5.9, the BC_A improved and amounted to 10.8 mM eq / 100 g. With further increase of humus to 5.4 %, it is expected the formation of BC_A at 46.3 mM eq / 100 g (differences in comparison with the control variant were authentic at $p < 0.05$).

One of the main criteria for the gradation of stability is the content of humus. In experiments, its content ranged from 2 to 5 %. For agro-gray heavy loamy soil 2 % of humus and below are low values. Apparently, such soils will not have reliable stability, especially against the background of high acidity. In this regard, this resistance is viewed as low.

If the total for pH intervals buffering capacity for acidification (BC_A) is in the range of 9-11 mM eq / 100 g, then the average level of soil resistance is reached. At the same time, the absorbed bases should not be less than 20 mM eq / 100 g. It is not recommended to reduce buffering capacity for acidification to values less than 9 mM eq / 100 g

The results of the studies, adjusted for the content of humus, make possible to distinguish three levels of agro-gray soil resistance to pollution, taking into account specific soil conditions. A low level of soil resistance is manifested when the Q_{max} value according to Langmuir is less than 91 mM / kg for zinc, less than 104 mM / kg for copper, less than 93 mM / kg for lead, and less than 61 mM / kg for cadmium. The average level of stability is provided for zinc, copper and lead in the range from 91 to 143 mM / kg, 104–130 mM / kg and 61–132 mM / kg, respectively. A high level of soil resistance is guaranteed if the Q_{max} value exceeds 93–143 mM / kg in total for the marked elements.

To achieve an average level of stability, the value of the buffering capacity of the agro-gray soil should not be lower than 2 l / kg for zinc, copper, cadmium and lead (according to the adsorption isotherm at a concentration point of 10 mM / l). Exceeding the value of BC^{HM} equal to 2-4 l / kg means transition to a high level of stability (Table 1).

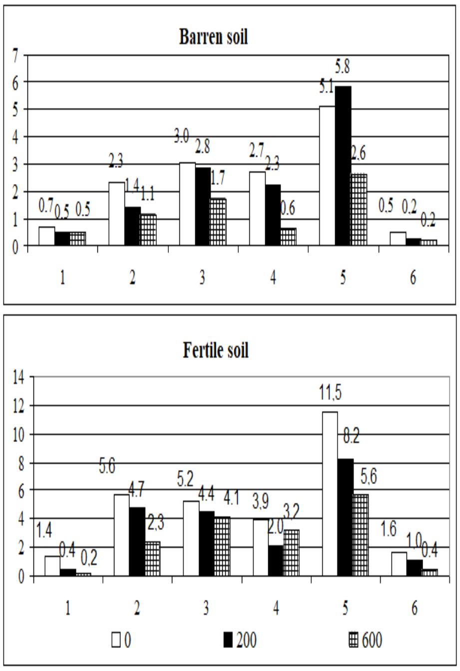
Table 1: The model of agro-gray soil resistance to acidification and contamination with heavy metals

Parameter	Unit	Level of soil resistance		
		low	medium	high
Humus	%	<2,0	2 – 3	> 3,0
Average for pH intervals buffering capacity to acidification (BC_A)	mM eq / 100 g	< 9	9 – 11	> 11
Maximum adsorption (Q_{max}) according to Langmuir:	mM / kg			
Zinc		< 91	91 – 143	> 143
Copper		< 104	104 – 130	> 130
Cadmium		< 93		> 93
Lead		< 61	61 – 132	>132
Buffering capacity to HM (BC^{HM}) according to the adsorption isotherm at a concentration point, mM / l:		zinc		
5	Intensity factor in mM / l	< 4	4 – 7	> 7
10		< 2	2 – 4	> 4
		copper		
5	capacity factor in mM / kg	< 5	5 – 6	> 6
10		< 2	2 – 3	> 3
		cadmium		
5		< 4		> 4
10		< 2		> 2
		lead		
5		< 2	2 – 6	> 6
10		< 1	1 – 4	> 4

Taking into account the dynamic state of soils, the proposed model of resistance is an indicative one for heavy loamy agro-gray soil.

Bio-diagnostics of resistance. In experiment 1, the effect of several levels of agro-gray soil contamination with copper on the number of microorganisms was studied. It was established that due to the fixation of a larger amount of copper by fertile soil, manifestations of the bio-protective function on the activity of most microorganisms in the entire range of pollution was higher than in barren soil (Fig. 2). When no contamination (0 mg / kg) in barren soil, the total number of microorganisms was 14 CFU $\cdot 10^6$ / g, and that in fertile soil was two times more (29 CFU $\cdot 10^6$ / g).

In experiment 2, microbial biomass at all proposed concentrations of cadmium in the soil was highest in fertile soil. At background concentration it was 1,187 µg C / g of soil for 1 day, 1,590 µg C / g of soil for 10 days, 1,005 µg C / g of soil for 35 days and 891 µg C / g of soil for 57 days, which is, respectively 540, 761, 541 and 554 µg C / g of soil greater than in the barren variant (Fig. 3).



Note: 1 - fungi, 2 - ammonifying bacteria, 3 - bacteria using organic nitrogen-containing substances, 4 - bacteria assimilating nitrogen of mineral salts, 5 - cellulose-destroying bacteria, 6 – actinomycetes

Figure 2: The number of microorganisms, CFU $\cdot$ 10^6 / g (y-axis) of agro-gray soil in conditions of pollution (x-axis), experiment 1

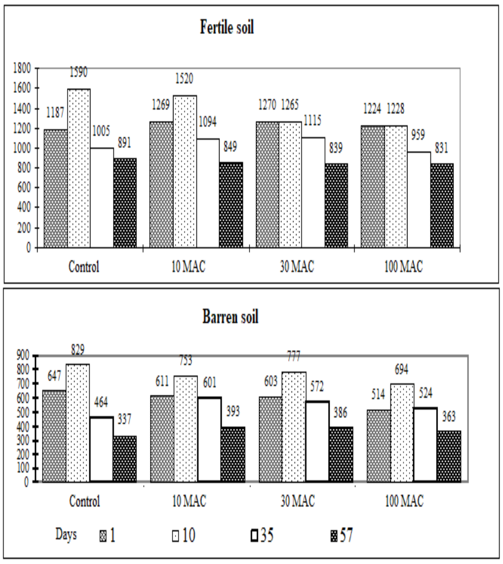


Figure 3: Dynamics of microbial biomass (μg C / g of soil) (experiment 2)

Significant differences ($p < 0.05$) between the variants increased when increasing pollution. For 1 day it was 658 μg C / g of soil for 10MAC, 667 μg C / g of soil for 30MAC and 710 μg C / g of soil for 100MAC. There was no inhibition of the vital activity of microorganisms in the fertile variant for 1 day, in contrast to the barren variant, as the value of microbial biomass at the indicated concentrations of cadmium was higher than the background concentration. As can be seen from Fig. 3, the magnitude of the microbial biomass in the fertile soil was greater than that in the barren one for the entire period and doses of cadmium contamination.

The stabilization of microbiological activity in the fertile soil due to better provision of environmental factors when cadmium contamination, as well as a decrease in the activity of the element, is proved by the data of basal respiration. In the whole range of pollution and exposure, its value was higher than that in the barren soil. Therefore, in soils with insufficient substrate, microorganisms spend more energy on protective reactions and less energy on biomass formation.

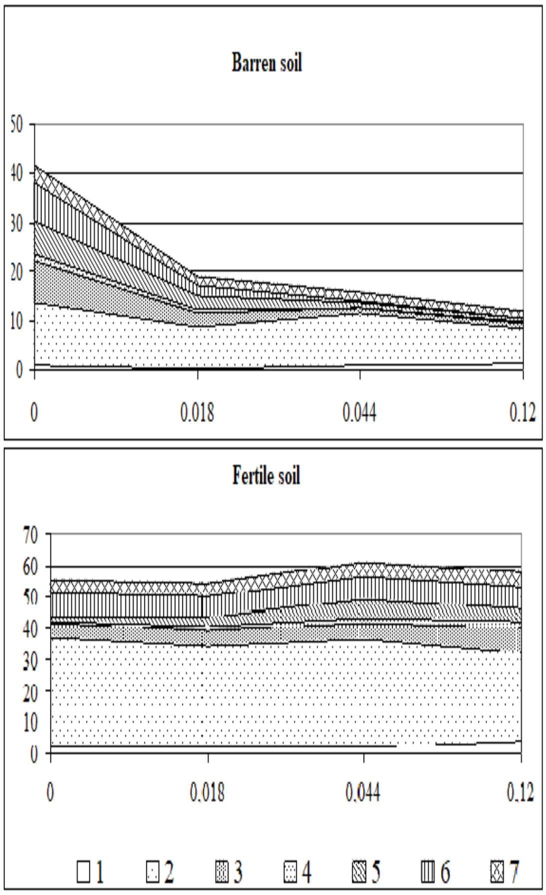
As can be seen from Table 2, the values of the metabolic coefficient in the barren agro-gray soil were higher than in the fertile soil. For the background concentration on average during the exposure, the difference was 0.3 units (21.4 %), it was 0.2 units (15.4 %) for 10 MAC, 0.3 units (26.1 %) for 30 MAC and 0.33 units (33.4 %) for 100 MAC.

Microbiological diagnostics in experiment 3 revealed an improvement in the resistance of the fertile soil to acidification (Fig. 4) and poor soil showed a decrease in total biogenisity on the background of progressive acidification in the barren soil. So, if at background pH of 6.0, the total number of microorganisms was 41.64 $\cdot$ 10^6 CFU / g, then after adding 0.018 mM / l acid (pH 5.3), it decreased to 19.16 $\cdot$ 10^6 CFU / g, then to 15.80 $\cdot$ 10^6 CFU / g and 12.00 $\cdot$ 10^6 CFU / g, respectively with 0.044 and 0.120 mm / l acid.

Table 2: The change in the metabolic coefficient when pollution of barren and fertile agro-gray soil

Variant	1 day		10 days		35 days		57 days	
	FS	BS	FS	BS	FS	BS	FS	BS
Control	1.69	2.21	1.10	1.20	1.49	1.51	1.35	1.87
10 MAC	1.50	2.07	1.08	1.29	1.23	1.15	1.32	1.46
30 MAC	1.40	1.73	1.11	1.65	0.95	0.99	not det.	1.45
100 MAC	1.19	1.79	0.97	1.30	0.89	0.98	not det.	1.32

Note: FS - fertile soil, BS - barren soil



Note: 1 - fungi, 2 - ammonifying bacteria, 3 - bacteria using organic nitrogen-containing substances, 4 - bacteria assimilating nitrogen of mineral salts, 5 – nitrobacteria, 6 - cellulose-destroying bacteria, 7 – actinomycetes

Figure 4: The number of microorganisms (CFU $\cdot$ 10^6 / g) in agro-gray soil depending on the acid load and fertility (experiment 3)

No decrease in microbiological activity was discovered in the fertile soil with the marked volume of acid load. Besides, it was higher than the one in barren variants in any cases.

Soil contamination leads to weakening the use of atmospheric nitrogen by soil microflora. This can be judged by the percentage of soil lumps accumulating azotobacter, which significantly decreased in the barren soil (experiment 4). So, if against the background it was 100 %, then with concentration of mobile zinc equal to 30 mg / kg it was 24 % and in a case of 70 mg / kg mobile zinc it was 12 %. The fertile soil had less inhibition of vital activity (Table 3).

Table 3: Azotobacter activity in fertile and barren agro-gray soil when zinc contamination (experiment 4)

Variant of zinc load, mg / kg	Barren soil			Fertile soil		
	Zinc, mg / kg	Number of zinc accumulated lumps	Zinc accumulation, %	Zinc, mg / kg	Number of zinc accumulated lumps	Zinc accumulation, %
0	7	25	100	8	25	100
50	30	6	24	23	20	82
100	70	3	12	50	23	90

Based on understanding the core place of the soil in the agro-ecosystem, inter-component links play a large role in increasing the potential of soil stability. The creation of natural-anthropogenic ecosystems with an enhanced function of the natural component in them can be considered as a necessary measure for the complexity of the positive protective impacts on the soil (Polokhin et al., 2016).

The next experiment simulated the man-made load in the form of acidification and pollution. The differences between ecosystems are authentic at a significance level of $p < 0.05$. In experiment 5, the number of ammonifiers of the soil under the forest plantation was $31.4 \cdot 10^6$ CFU / g more than that of the arable soil. The total number of microorganisms using mineral forms of nitrogen was more by $25.5 \cdot 10^6$ KFU / g, the number of microscopic fungi was more by $0.078 \cdot 10^6$ CFU / g, but the number of cellulose-decomposing organisms was less by $0.0872 \cdot 10^6$ CFU / g. Additional acid load on the soil reduced the pH value of the soil solution in all ecosystems. The response of soil microorganisms to acidification manifested itself in different ways. All groups of microorganisms reacted to soil acidification with a decrease in their number, with the exception of cellulose-decomposing actinomycetes, microscopic fungi, and denitrifiers in the soil under forest plantation. The number of ammonifiers, microorganisms on starch agar (total), nitrifiers and aerobic nitrogen fixers decreased by 8, 7, 53 and 63 %, respectively. In arable soil, the number of ammonifiers, microorganisms on starch agar, cellulose-decomposing organisms, microscopic fungi and aerobic nitrogen fixers decreased by 15, 31, 17, 18 and 63%, respectively (Table 4).

With additional acid load, the total number of microorganisms under arable land was $57 \cdot 10^6$ CFU / g, it was $75 \cdot 10^6$ CFU / g under meadow and $123 \cdot 10^6$ CFU / g under forest plantation. Thus, on the basis of bio-diagnostics, it can be concluded that the gray forest soil under the forest and meadow components of the agricultural landscape is more resistant to acidification.

Table 4 - The number of microorganisms (CFU · 10^6 / g) in gray forest soil depending on the acid load in different ecosystems

Ecosystem	Acid added, mole · 10–5/l	pH	Ammonifiers	Microorganisms using mineral nitrogen	Cellulose-decomposing bacteria	Microsco fungi
			106 CFU / g		103 CFU / g	
Arable land	Background	6.0	27.3	48.7	100	150
	2.5	4.5	23.2	33.6	89.5	122
Meadow	Background	7.1	53.8	43.4	61.8	89
	2.5	5.7	33.5	41.2	36.2	79
Forest	Background	4.8	58.7	74.6	13.6	228
	2.5	3.9	54.1	69.2	43.7	236

In arable soil with a dose of copper corresponding to 30–50 MAC, the number of microorganisms using mineral forms of nitrogen decreased by 78–82 %, cellulose-decomposing and nitrifying bacteria by 58–93 % and 55-89 %, respectively. The total number of microorganisms on controls in arable land, under the meadow and the forest plantation was $75.4 \cdot 10^6$ CFU / g, 69.3 CFU / g and $81.6 \cdot 10^6$ CFU / g, respectively. With soil contamination, the reduction of microbiological activity was 61-67 % under arable land, 11-26 % under meadow and 58-72 % under forest plantation (Table 5).

Table 5: The number of microorganisms (CFU · 106 / g) in agro-gray soil depending on pollution in different ecosystems

Ecosystem	Copper added, mg / kg	Ammonifiers	Microorganisms using mineral nitrogen	Cellulose-decomposing bacteria	Microscopic fungi	Nitrifiers
		10^6 CFU / g		10^3 CFU / g		
Arable land	Background	27.8	47.5	44.7	46.5	31.9
	30 MAC	23.6	10.0	18.5	83.6	4.4
	50 MAC	20.6	8.4	3.2	82.4	4.0
Meadow	Background	31.1	38.1	48.9	40.0	61.6
	30 MAC	25.6	36.1	29.7	95.9	6.9
	50 MAC	24.1	27.4	3.6	48.8	27.8
Forest	Background	42.4	39.1	64.6	61.9	29.9
	30 MAC	13.3	21.3	40.0	73.1	23.5
	50 MAC	12.7	9.8	17.1	103	2.6

When contamination in arable land, the decrease in the total number of microorganisms as compared to the control (background) was 61-67 %, under the meadow - 11-26 %, and under the forest plantation - 58-72 %. When soil was contaminated with copper, the greatest decrease in the total number of microorganisms (by 42-59 CFU / g) occurred in the soil under arable land and under forest plantation. Apparently, the inhibition of the activity by soil microflora under the forest plantation is explained by the high acidity of the soil, against the background of which the activity of heavy metals increases (Blake L. et al., 2002; Renyuan Wang et al., 2018).

The results of our investigations attract attention once again to the need to improve the infrastructure of agricultural landscapes in order to ensure their long-term sustainability, despite the pressure of the economic situation on agricultural production. Our data from the standpoint of considering the physicochemical bases of buffering of the agro-gray soil to acidification and pollution, and microbiological diagnostics of resistance are consistent with the general views of the rational use of agricultural landscapes.

4. Conclusions

The deterioration of soil fertility means an increase in the vulnerability of agro-soil, in general, to acidification ad contamination with heavy metals. Adequate potential for stability of agricultural soils is the basis for the production of ecologically safe food in the future, when man-made pressure on agroecosystems only grows. Thus, the function of soil fertility is multifaceted. It manifests itself in the resistance to adverse factors, which can be evaluated by determining the physicochemical parameters of the buffering ability to acidification and contamination with heavy metals, as well as by respond of resistance parameters - soil microorganisms.

The nature of soil fertility is threefold. In addition to the production function, it performs environmental and bio protective ones. The soil with a sufficient content of organic matter and good fertility is resistant to adverse effects, as indicated by the data of microbiological diagnosis. Simulation of acidification and contamination of agro-gray soil showed that, in the presence of a sufficient amount of humus (at least 5 %), an average decrease in the activity of all groups of microorganisms occurs by a maximum of 20 % as compared with pure samples. When the humus content is below 3 %, the microbiological activity decreased by more than 20 %.

In a case of increasing the risk of acidification and accumulation of heavy metals in the agro-gray soil, it is possible to recommend long-term fallowing of the arable land and increasing the share of the meadow component in the agro landscape.

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