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BIOLOGICAL INDICATION OF SOILS FOR CONTAMINATION WITH HEAVY METALS UNDER DIFFERENT FERTILIZATION SYSTEMS IN AGRICENOSES OF SOUTH-EAST KAZAKHSTAN

БИОЛОГИЧЕСКАЯ ИНДИКАЦИЯ ПОЧВ НА ЗАГРЯЗНЕНИЕ ТЯЖЕЛЫМИ МЕТАЛЛАМИ ПРИ РАЗЛИЧНЫХ СИСТЕМАХ УДОБРЕНИЯ В АГРОЦЕНОЗАХ ЮГО-ВОСТОЧНОГО КАЗАХСТАНА

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Summary: The article presents the results of studies on the impact of heavy metal pollution on biological activity in agrocenoses in the south-east of Kazakhstan. It is shown that soil invertebrates can be used as bioindicators of the level of pollution.

Ключевые слова: почва, удобрения, тяжелые металлы, загрязнение, индикация, мезофауна, биологическая активность, гумус.

Реферат: в статье представлены результаты исследований влияния загрязнения тяжелыми металлами на биологическую активность агроценозов юго-востока Казахстана. Показано, что почвенные беспозвоночные могут быть использованы в качестве биоиндикаторов уровня загрязнения.

The preservation and improvement of soil fertility is impossible without the introduction of organic and mineral fertilizers in conjunction with the observance of crop rotation, soil cultivation systems, the use of new adapted varieties, and reclamation measures. The evidence of the ecological impact of mineral fertilizers on all components of the agroecosystem and their relationship with each other is undeniable. When using fertilizers, there is a risk of heavy metals entering the soil, which are the most toxic elements for living organisms.

The accumulation of heavy metals in soils has a negative effect on many of the most important soil biological processes, which leads to a drop in fertility, productivity and quality of agricultural products [1,2,3]. In such conditions, the problem of studying the behavior of heavy metals in soils of different properties and in soil-plant-animal systems is severe. Obtaining information about the environment is possible either using chemical methods or based on assessing the state of biological objects - bioindication.

The use of living organisms as biological indicators of environmental changes necessitates the development of several criteria based on which indicator species can be selected. These include the biological activity of soils (mesofauna, enzymes).

The mesofauna, along with other soil organisms, can be used as a bioindicator. In addition to its high abundance, significant biomass and ubiquitous occurrence, the mesofauna is characterized by the ability to respond quickly to changes in the ecosystem, the availability of species identification and the ability to use for comparison of quantitative characteristics associated with the presence of standard generally accepted methods of isolation.

Bioindicators under anthropogenic load on the soil, with prolonged use of fertilizers, can respond to very weak effects due to the accumulation of doses. Moreover, they make it unnecessary to use expensive and laborious physical and chemical methods for measuring biological parameters.

In this regard, it becomes urgent to study and select soil bioindicators for agrocenoses in the southeast of the republic at various levels of application of mineral fertilizers.

The objects of research are long-term fertilized (more than 30-40 years) soils of field stationary experiments of the Department of Agrochemistry of the Kazakh Research Institute of Agriculture and Crop Production of the Ministry of Agriculture, Republic of Kazakhstan (MoA RK), "Agrouniversity" of the Kazakh National Agrarian University and the Department of Agrochemistry of the Kazakh Research Institute of Potato and Vegetable Economy of the MoA RK.

Based on the data of the Kazakh Research Institute of Agriculture with fertilizers, we calculated the amount of heavy metals (HMs) that entered the soil with fertilizers in 42 years in light chestnut soils, in 22 years in meadow chestnut soils and in 14 years in dark chestnut soils, which was 0.5-39.1 g for cadmium, lead - 2.9-281.2 g, zinc - 1.2-190.2 g, copper - 31.5-79.2 g per 1 hectare. At the same time, the largest amount of heavy metals enters the soil with phosphorus fertilizers.

The study of heavy metals for 3 years (2016-2018) showed that in light chestnut soils with triple doses of fertilizers, an increased content of heavy metals (table 1).

Table 1 - Influence of fertilizers on the content of heavy metals in irrigated light chestnut soils, mg/kg of soil (3-year average)

Experimentoptions	Heavy metals (HMs)			
	Cd	Pb	Zn	Cu
$N_0P_0K_0H_0$	0,17	1,64	0,70	0,36
$N_1P_1K_1\ H_1$	0,21	3,35	1,42	0,59
$N_2P_2K_2\ H_2$	0,27	4,49	0,86	0,37
$N_3P_3K_3\ H_3$	0,33	4,96	1,44	0,39

In meadow chestnut soils, an increase in the content of HMs is observed with an increase in the doses of applied phosphorus fertilizers. At the same time, the content of heavy metals, along with the norms of fertilizers, is also influenced by culture. So, under corn crops, the content of heavy metals is higher and there is a direct dependence on fertilizer rates. Under soybeans, there is a decrease in heavy metals, and on more fertilized options, their amount is noticeably reduced (Table 2).

Table 2 - Influence of fertilizers on the content of heavy metals in meadow-chestnut soils, mg/kg soil (average for 2016-2018)

Experiment options	Cd		Pb		Cu		Zn	
	Soy	Corn	Soy	Corn	Soy	Corn	Soy	Corn
Control	0,25	0,42	3,25	3,84	0,40	0,44	2,45	2,4
P_{150}	0,23	0,29	4,32	5,98	0,57	0,60	3,25	3,30
$P_{150} + N_{60}P_{60}$	0,36	0,31	5,99	6,17	0,79	0,79	3,67	5,27

It has been established that a higher yield and a powerful root system are formed on the fertilized variants, which, most likely, reduces the negative effect of heavy metals despite the high level of fertilizer use - 210 kg a.i. phosphorus per hectare.

According to the content of heavy metals in dark chestnut soil, it can be said that against a natural background, the content of the determined elements is lower than against a background with the introduction of rotted manure, which indicates the entry of small amounts of heavy metals into the soil with manure.

Mineral fertilizers applied separately do not have a significant effect on the change in the content of heavy metals in the soil. The introduction of mineral fertilizers contributed to the change in the content of heavy metals (Table 3).

Table 3 - Content of moveable forms of heavy metals in the dark chestnut soil of vegetable crop rotation, mg / kg (3-year average)

Experiment options	Cd	Pb	Cu	Zn
Background - natural				
$N_0P_0K_0$	0,33	1,34	0,30	1,54
$N_{30}P_{60}K_{30}$	0,43	3,17	0,54	1,39
$N_{60}P_{90}K_{60}$	0,45	3,14	0,47	1,53
$N_{90}P_{120}K_{90}$	0,53	5,75	0,71	3,54
Background - rotted manure				
$N_0P_0K_0$	0,47	2,40	0,33	1,47
$N_{30}P_{60}K_{30}$	0,45	3,58	0,55	1,50
$N_{60}P_{90}K_{60}$	0,38	3,23	0,59	1,20
$N_{90}P_{120}K_{90}$	0,80	2,64	0,66	1,24

According to the grouping of soils by the level of pollution, the content of cadmium in soils ranges from low to medium levels, lead from medium to high, the level of zinc and copper pollution is low. That is, elements such as cadmium and lead, being dangerous HMs, when fertilizing increase the level of soil contamination from low to moderate and very high, respectively (0.80 and 6.17 mg/kg soil), which must be taken into account when intensifying agriculture and increasing the amount of fertilizer applied. The application of the bioindication method to determine the effect of heavy metals on soil biocenoses in our studies involved the determination of such characteristics as the biological activity of soils (mesofauna, enzymes).

The activity of such enzymes as invertase, urease, dehydrogenase, the activity of which is sensitive to the presence of various chemical and organic substances in the soil, is successfully used as a biodiagnostic indicator [4]. The high sensitivity of enzymes

makes it possible to effectively use the indicators of their activity to establish the optimal doses of mineral and organic fertilizers applied to the soil to increase its fertility and crop productivity.

Enzyme activity indicators are widely used to characterize the biological state and the level of soil fertility. According to this goal, we considered the activity of soil enzymes in the variants where mineral fertilizers were applied. For light chestnut soils, a decrease in the activity of enzymes is characteristic when applying triple doses of fertilizers compared to the control (Table 4).

Table 4 - Enzymatic activity of light chestnut soil when using various doses of mineral fertilizers (3-year average)

Experiment options	Invertase, mg of glucose per 1 g of soil for 4 hours	Urease, mg NH_3 per 1 g of soil for 24 h	Dehydrogenase, mg TTF per 1 g of soil for 24 hours	Catalase, ml $KMnO_4$ per 1 g of soil	Phosphatase, mg P_2O_5 per 1 g of soil
$N_0P_0K_0H_0$	10,7	1,59	1,43	9,8	2,9
$N_1P_1K_1$ H_1	12,4	1,58	1,35	9,2	4,7
$N_2P_2K_2$ H_2	13,3	1,71	1,43	8,7	4,9
$N_3P_3K_3$ H_3	8,9	1,03	1,32	9,3	5,6

Dehydrogenase and catalase weakly respond to changes in the HM content in the soil. The enzymes invertase and urease react more, where their lowest enzyme activity is observed in the variant with high doses of fertilizers - 8.9 and 1.03 mg, respectively. Phosphatase, on the other hand, in the variants with the introduction of triple doses of fertilizers does not experience suppression of activity, which, apparently, can be explained by its increase in the content of moveable phosphorus in the soil.

As the results of the analyzes carried out to determine the enzymatic activity of meadow-chestnut soils showed, it is largely determined by the level of concentration of biophilic elements and the content of mobile forms of heavy metals in the soil (Table 5).

Table 5 - Enzymatic activity in meadow-chestnut soils, (3-year average)

Option	Invertase, mg glucose per 1 g of soil in 4 hours	Urease, mg NH3 soil/day	Dehydrogenase, mg TFP per 1 g of soil in 24 hours	Catalase, ml $KMnO_4$ per 1 g of soil	Phosphatase, mg P_2O_5 per 1 g of soil
P_0	11,3	0,40	0,39	5,36	4,7
P_{150}	11,1	0,51	0,54	5,25	5,2
$P_{150}+N_{60}P_{60}$	10,8	0,50	0,58	5,86	5,4

In these soils, invertase is an enzyme that responds to changes in soil properties. This can also be explained by the peculiarities of the soil itself - the predominance of restorative soil processes. In dark chestnut soil, when applying single and double doses of fertilizers, the activity of all enzymes increases, except for phosphatase. Triple doses of fertilizers reduce them to the control level and below, that is, the effect of high doses of fertilizers is clearly expressed (Table 6).

Thus, the introduction of high fertilizer rates, along with an improvement in the nutrient regime of soils, is accompanied by a decrease in the activity of soil enzymes.

Table 6 - Enzymatic activity of dark chestnut soil when using mineral and organic fertilizers

Experiment options	Invertase, mg glucose per 1 g of soil in 4 hours	Urease, mg NH3 soil/day	Dehydrogenase, mg TFP per 1 g of soil in 24 hours	Catalase, ml $KMnO_4$ per 1 g of soil
natural background - no manure				
$N_0P_0K_0$	13,5	1,15	2,43	6,4
$N_{30}P_{60}K_{30}$	13,8	0,77	1,42	7,5
$N_{60}P_{90}K_{60}$	14,2	0,75	0,75	6,8
$N_{90}P_{120}K_{90}$	12,8	0,65	0,53	7,7
organic background - 60 tons of manure				
$N_0P_0K_0$	13,7	1,33	2,89	8,2
$N_{30}P_{60}K_{30}$	14,4	0,83	0,81	8,3
$N_{60}P_{90}K_{60}$	15,3	0,74	0,48	7,8
$N_{90}P_{120}K_{90}$	13,2	0,75	0,47	8,1

It should be noted that the relationship between fertilizer rates and yield levels is not always directly proportional. One of the reasons may be the negative impact of high rates of agrochemicals on indicators of biological activity, accordingly, on the level of yield.

Analysis of the data on the mesofauna on the studied variants of the experiment and collection showed that the common species are the larvae of insects from the family - *Carabidae, Scarabaeidae, Elateridae, Formicidae*, since these species have plasticity (the ability to inhabit a wide variety of biotopes). The dominant species are insect larvae - *Formicidae, Scarabaeidae*.

More species have been recorded on fertilized options. There are more numerous species from the *Carabidae* family, *Scarabaeidae*. Consequently, the introduction of optimal doses of organic and mineral fertilizers does not have a significant effect on the complex of soil mesofauna. However, it has a positive effect on the state of plants, which leads to an increase in the overall productivity of the agrocenoses and some changes in microclimatic conditions.

The results of our research have established that light chestnut soils have favorable physical properties - the appearance of earthworms, while the genetic feature of light chestnut soils is the absence of earthworms in them, which, according to research, are a diagnostic indicator of the potential fertility of chernozems and dark chestnut soils.

Under the conditions of our experience, it was found that the appearance of earthworms in the experimental plots indicates the duration of the use of organic and mineral fertilizers, which contributes to the improvement of the vital activity of soil invertebrates, which in turn depend on the optimization of many basic agrophysical and agrochemical soil properties (density, specific gravity , soil moisture, soil pH, a sufficient amount of root and crop residues, the maximum permissible indicator of heavy metals and radionuclides). From our observations, it turned out that earthworms, larvae from the family of click beetles Elateridae, are associated with more humus and moisture rich soils (dark chestnut, meadow chestnut soils) (table 7).

Table 7 - Bioindicators of soil mesofauna species in the studied agrocenoses with different fertilization systems

Type, sub-type of soil	Type	Class	Squad	Family
Bioindication indicators				
Dark chest-nut soil	Type annelid worms (*Annelida*e)	Class annelids oligochaetes (*Oligocheta*)	Earthworms (*Lumbricidae*)	Earthworms (*Lumbricidae*)
	Type Arthropod (*Arhtropoda*)	Class Insects (*Insecta*)	Squad Beetles (*Coleoptera*)	Ground beetles (*Carabidae*) Clickers- (*Elateridae*) Predators- (*Staphylinidae*)
Meadow chestnut soil	Type Arthropod (*Arthropoda*)	Class Insects (*Insecta*)	Squad Beetles (*Coleoptera*)	Weevils (*Curculi-onidae*) wireworms (*Te-nebrionidae*)
Light chest-nut soil	Type Arthropod (*Arthropoda*)	Class Insects (*Insecta*)	Squad Beetles (*Coleoptera*)	Redblogs (*Pyr-rhoridae*) Click-ers *Elateridae*

It can be seen from the data in the table that the indicators on dark chestnut soil are *Lumbricidae, Staphylinidae,* and on meadow chestnut wireworms from the family *Tenebrionidae*, which do not inhabit light chestnut soils. The results of our research have shown that the common species are the larvae of insects from the families - *Carabidae, Formicidae*, since these species have plasticity (the ability to inhabit a wide variety of biotopes). The dominant species are insect larvae - *Formicidae*.

It has been determined that larvae from the *Staphylinidae* family are rather hygrophilic and therefore soil moisture is a factor limiting its distribution in xerophytic conditions, namely, on gray soils and in technogenic pollution. Wireworms from the family *Tenebrionidae* of the genus are found only on dark chestnut and meadow chestnut soils, while larvae from the family *Elateridae* are confined to light chestnut soil [5].

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