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RESEARCH ARTICLE

The Use of Diatomite as a Detoxicant on Biological Activity of the Copper Polluted Soil and Spring Wheat Yield

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Abstract

The effect of soil pollution with copper and the use of diatomite as a detoxicant on the biological activity of the soil and spring wheat yield was tested. An average copper supply in the soil up to 4 times higher than maximum permissible concentration did not decrease the activity of cellulose-destroying microorganisms. A further increase in the level of copper (up to 10 times higher than the MPC) was accompanied by significant suppression of the activity of soil biota. Pollution of the soil with copper even at 2 times higher than the MPC led to a yield loss of 0.15 t/ha (8%), i.e., up to 10 times higher than the MPC – to the loss of almost a third of the yield (29%). Diatomite (a high-siliceous rock) as a detoxicant contributed to an increase in the yield of spring wheat grain by 0.23 (11%). It completely blocked the toxic effect of copper pollution of up to 4 times higher than the MPC.

Introduction:

In the last century, pollution of agrocenoses with heavy metals (HM) has been increased in all industrially developed regions of the world, including the Volga region of Russia (Barsova *et al*., 2019). The excess of HM leads to the disturbance of physiological and biochemical barriers that prevent toxicants from contaminating plants and its respective products (Cook *et al*., 1997; Cyrysargyris *et al*., 2019). In this regard, on one aspect, it is necessary to search for ways to increase the rigidity of crops to withstand the uptake of heavy metals, and on the other aspect, to prevent soil getting polluted or causes of existing pollution (Schulze *et al*., 2019; Ryszka *et al*., 2019; Qin *et al*., 2019; Tiller & Merry , 1981). It is advisable to use materials that would not only reduce the contamination of crops from toxicants but also have a comprehensive positive effect on soil properties for improving the conditions for plant growth and nutrition. In this regard, the use of natural sorbents is of undoubted interest, after interaction with which heavy metals turn into hard-to-reach states. The latter, first of all, is represented by high-siliceous rocks such as opal cristobalites (diatomites, gaize, rottenstone), zeolites, bentonites, which are mainly found in silicon, including its amorphous form (in an available form). The above-mentioned rocks have high adsorption, ion exchange, and catalytic properties. Owing to this they are able to retain moisture in the arable layer when applied to the soil. They also prevent nutrients from being removed outside the root layer, including heavy metals, converting them into soluble compounds. In addition, they contain a number of nutrients (potassium, sulfur, phosphorus, manganese, and others). It should also be pointed out that these rocks are proven silicon fertilizers (Kulikova, 2013; Kozlov, 2013).

The foregoing determined the purpose of our study - to identify the role of diatomite, a high-siliceous rock, the reserves of which are huge in Russia, in the detoxification of HM pollution and production of ecologically safe agricultural products taking spring wheat as an example.

Materials and methods:

The experiments were carried out on the experimental field of Ulyanovsk State Agrarian University by conducting a small-plot experiment with artificial soil pollution with copper sulfate ($CuSO_4$ X $5H_2O$) and using diatomite from the Inzensky deposit of the Ulyanovsk region as a detoxicant in growing spring wheat. The experimental design comprised 8 options: i) control, ii) soil pollution at the level of 2 times more than the MPC Cu, iii) soil pollution at the level of 4 times more than the MPC Cu, iv) soil pollution at the level of 10 times more than the MPC Cu, v) diatomite at a rate of 5 t/ha, vi) 2 times more than the MPC Cu + diatomite; vii) 4 times more than the MPC Cu + diatomite; viii) 10 times more than the MPC Cu + diatomite. The area of one registered plot was 1 m2, their lay-out was

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randomized, the repetition of the experiment was four times. The soil of the experimental field where experiments were carried out was typical medium loamy black soil with a humus content of 4.7%, available phosphorus and potassium 185 and 196 mg/kg, respectively, mobile copper 3 mg/kg, pHKCl - 6.9 units. Diatomite composition: SiO_2 total - 81.7%; SiO_2 amorphous - 42.1%; CaO - 0.52%; MnO - 0.01%; K_2O - 1.25%; P_2O_5 - 0.05%; SO_3 0.23%.

All work to apply copper sulfate and diatomite and harvesting were carried out manually. The copper content was determined in duplicate by the atomic absorption method according to State standard (GOST) 30692-2000.

Results and Discussions :

Microbiocenosis is one of the main participants in all biochemical and biological processes in the soil. First of all, ensuring the normal course of decomposition and transformation of various organic substances, and the circulation of mineral nutrients important for plants. Soil microbiota plays an important role in detoxification and reducing the level of contamination with hazardous substances in crops (Foy *et al.*, 1978; Woodhouse & Walker, 1981; Marfenina, 1991).

The biological activity of the soil provides operational information on the nature and speed of the processes occurring in the soil since microbiocenosis immediately responds to any ongoing processes. Table 1 shows data on the state of general biological activity of typical black soil obtained by the application of linen canvas.

Table 1: Biological activity of typical black soil depending on the level of pollution with copper, %

Option	A	B1	B2
Control	44	-	-
2 times more than the MPC of Cu	47	+3	+7
4 times more than the MPC of Cu	51	+7	+16
10 times more than the MPC of Cu	40	-4	-9
Diatomite	49	+5	+11
2 times more than the MPC of Cu + diatomite	45	+1	+2
4 times more than the MPC of Cu + diatomite	43	-1	-2
10 times more than the MPC of Cu + diatomite	40	-4	-9
LSD_{05}	3		

A-Decomposition degree of linen canvas, B1- In absolute numbers, B2- In relative per cent (B1 & B2-Deviation from control)

As per the above data, the application of copper in the soil medium up to 4 times higher than the MPC contributed to an increase in the activity of cellulose-destroying microorganisms to 16 relative percent. A further increase in the level of copper pollution to 10 times higher than the MPC of Cu was accompanied by significant suppression of the activity of soil biota and its activity with respect to the control significantly decreased. A certain amount of copper is required for the normal course of physiological processes in both microorganisms and plants. However, if its content goes up above threshold values, their activity sharply decreases, blocking the normal functioning of enzyme systems (Korotchenko & Kiriyenko, 2012). The threshold value of the copper content, beyond which the biological activity of black soils in the Middle Volga region was significantly reduced, so this could be the level of pollution in an amount of over 4 times higher than the MPC of Cu.

One of the limiting factors in the formation of crop yields is the creation of optimal conditions for growth and development, not only in terms of nutrition, moisture but also the absence or presence of negative factors, where heavy metals belong to. Table-2 shows the performance indicators of spring wheat according to the options of the experiment.

Table-2: Spring wheat yield depending on the level of pollution with copper and use of diatomite as a detoxicant

Option	A	B1	B2
Control	2,01	-	-
2 times more than the MPC of Cu	1,86	-0,15	-8
4 times more than MPC of Cu	1,52	-0,49	-24
10 times more than the MPC of Cu	1,43	-0,58	-29
Diatomite	2,24	+0,23	+11
2 times more than the MPC of Cu + diatomite	2,17	+0,16	+8
4 times more than the MPC of Cu + diatomite	2,08	+0,07	+4
10 times more than the MPC of Cu + diatomite	1,79	-0,22	-11
LSD_{05}	0,07		

A-Yield, t/ha; B1-t/ha,+ -; B2- %,+ - (B1&B2-Deviation from control)

While analyzing the obtained data, first of all, it is worth paying attention to a significant increase in the yield of spring wheat grain when diatomite was applied to the soil (by 0.23 t/ha, or 11%). Our study proved that diatomite (as well as other high siliceous rocks, zeolites, bentonite clays) has a multilateral positive effect on the soil-plant system (Kulikova, 2013; Kulikova *et al.,* 2016):

- it has a structuring and loosening effect on the soil when cultivating any crops
- favorably affects the activity of soil organisms
- facilitates water-retaining capacity and improving the nutritional regime of the soil
- has protective properties
- contributes to the production of ecologically safe products, etc.

Despite the fact that copper pollution at the level of 4 times higher than the MPC even stimulated biological activity of the soil and did not lead to noticeable changes in its nutritional regime, it was accompanied by a sharp decrease in the yielding capacity of spring wheat by 0.15 - 0.58 t/ha, or by 8-29 %. Apparently, the influence of copper on the formation of crop yields was regulated by complex biochemical mechanisms due to the fact that it is a constituent element of copper-containing proteins and enzymes, and participates in redox processes.

The use of diatomite as a detoxicant in a dose of 5 t/ha with copper contamination of up to 4 times higher than the maximum permissible concentration of Cu completely blocked its negative effect on the formation of spring wheat

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yield, due to its high absorption and ion-exchange capacity. However, with a sufficiently high pollution level of 10 times more than the MPC of Cu, it was not possible to neutralize the toxic effect of copper on the formation of crop yield and it decreased by 0.22 t/ha.

Conclusively, soil pollution with copper even in the amount of 2 times more than the MPC of Cu could be accompanied by a loss of spring wheat yield by 0.15 t/ha. With a higher level of pollution (up to 10 times higher than the MPC), crop losses could reach 0.58 t/ha (almost a third, 29%). Diatomite as a detoxicant contributes not only to the spring wheat yield increase, due to its beneficial effect on soil properties and optimization of soil conditions for plant growth, but also to obtaining ecologically safe products.

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