Pollution of Soil Cover of Steppe Zone of the Altai Region by Heavy Metals and its Effect on Chernozem Properties and on Producing Power of Agricultural Crops

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Abstract

The results of the studies on the spatial distribution of heavy metals in the soils in the natural and soil zones are presented. The effect of some regional sources of environment pollution by heavy metals is shown. It is revealed that with heavy-metal pollution of chernozem soils the number of bacteria and microorganisms growing on meat-and-peptone and starch-and-ammonia agars decreases, and the amount of fungi microflora grows. The study of the phytotoxic activity of the chernozem soils' microflora revealed the possibility of soil toxication caused by anthropogenic impacts. The research involved a number of agricultural crops in vegetation-field experiments, which enabled comparing their resistance to heavy-metal pollution. Buckwheat proved to be the most resistant; rape, alfalfa, millet, soft wheat, and durum wheat followed in resistance (listed in descending order of resistance).

The problem of environmental pollution by heavy metals is caused by their high toxicity and expanding scales of their inflow into the biosphere. Because they are involved in the biological cycle, and enter the soil-plant-human, and soil-plant-animal-human systems, they have a significantly negative effect on human health. Hence, the evaluation of plant development on polluted soils and of the possibility of heavy-metal accumulation, as well as a search for soil detoxification methods, are of great interest. To evaluate the territorial distribution of heavy-metal content in the top humus soil horizons, we processed statistically a universal data set with specific types of heavy metals in order to define the background levels of the surveyed territory. The background content of heavy metals was defined by the median value of the universal set (Chemical Pollution ..., 1991; Satayeva, Satayev, 1994) and the values were as follows Pb – 16.0; Cd – 0.20; Cr – 69.0; Ni – 29.8; Zn – 72.0; Cu – 22.6; Co – 8.0; Hg – 0.012 mg/kg.

The percentage of heavy metals comparatively to the regional background makes it possible to conclude on relative soil pollution in the districts and by specific metals. The spatial distribution of lead in the surveyed area is characterized by pronounced confinement to the natural-soil zones. The area of the leached chernozems and gray forest soils zone of the middle forest-steppe of the Altai Region and the chernozems zone of the meadow steppe of the piedmont plains is characterized by low levels of lead in the range of 0.5-1.0 of the median background. Higher levels of lead from 1 to 2 background values are observed in the Prialeyskaya Steppe. The highest level of lead is recorded in the Zmeinogorskiy District in the chernozem zone of the piedmont plains.

Cadmium content in soils varies throughout the area. For example, some certain areas of different natural and soil zones with high cadmium content are found. That is typical of the Rubtsovskiy, Kuryinskiy, Smolenskiy, Sovetskiy, and Pervomayskiy Districts. The most part of the surveyed area is of low cadmium content.

Chromium accumulation is expressed in the chernozems of temperate arid and forest-outlier steppes, in the piedmont plains, and locally in the middle forest-steppe of the Zarinskiy District. In general, the chromium content in the soils does not exceed two background values. A similar distribution is characteristic for nickel.

Zinc content in the soils of the surveyed area reveals insignificant fluctuations from 64% to the background value in the dry steppe of the Uglovskiy District and to 127% in the Sovetskiy District in the piedmont plains.

The maximum copper content is monitored in the Talmenskiy District, as high as 186% of the background value. Higher content of up to 1.5 of the background value is typical of the piedmont plains of Altai.

Cobalt accumulation is observed in the Prialeyskaya Steppe, in the piedmont plains and locally in the Zarinskiy District.

The maximum mercury content comparatively to the background value is observed in the foothill plains in the Zmeinogorskiy, Kuryinskiy Districts, and also in the Biyskiy District located in the middle forest-steppe. The areas of temperate arid steppes and forest-outlier steppes and the most part of the middle steppe are characterized by low mercury content.

The maximum value of the cumulative index of the pollution by heavy metals is characteristic of the chernozem zones of the arid steppe and the Altai piedmont plains; the highest cumulative pollution is observed in the Kuryinskiy, Zmeinogorskiy, Pospelikhinskiy and Rubtsovskiy Districts. Accumulation of metals is investigated by O.I. Antonova (2000), indicates the highest cumulative pollution level of the soils of the Yuzhno-Prialeyskaya (the south of the Aley River area) zone.

The higher levels of heavy metals in the soils of the chernozem zone of the piedmont plains, foothills and low mountains of Altai is most likely due to the effect of the dispersion halo of the metals of the multi-metal deposits and ore occurrences of the Rudniy Altai (Mining Altai) (Korbalikhinskoye pyrite and multi-metal deposit; Stepnoye, Zolotushenskoye, Novo-Zolotushenskoye, Orlovskoye zinc-copper and pyrite deposits). According to B.N. Luzgin (1997), in the Rubtsovsk ore deposit area of the Stepnoye deposit, the main ore minerals are sphalerite (ZnS), galenite (PbS), chalcopyrite (CuFeS2), and pyrite (FeS2). The ratio of the key components in those minerals is as following: Zn: Pb: Cu = 6.5: 3.5: 1.

The comparison of median contents of heavy metals calculated for specific administrative districts with the regional background of the surveyed territory enabled us to determine the areas of relative pollution of soils by heavy metals. The highest total heavy-metals pollution is observed in the Kuryinskiy, Zmeinogorskiy, Pospelikhinskiy and Rubtsovskiy Districts. In the cities and district centres with developed industry the environment (air, water, soil) is impacted greatly by the toxic substances. In that connection the soils of the city of Barnaul and its suburban zone, the soils of the district centre Shipunovo and its vicinities; as well as the soils of private homestead lands in some rural communities of the Prialeyskaya Steppe were studied to determine their heavy metals levels.

The most intense sources of pollution of the investigated ones were in the city of Barnaul and its suburban zone, with heating stations. From Heat Station No. 1 (TETs-1), the soil is intensively polluted by lead, cadmium, mercury (above the maximum permissible concentration (MPC)). From the Heat Station No. 3 (TETs-3), soils are polluted in the northern, western, and eastern directions. Even at a distance of 5000 m, the soil is polluted (close to MPC and above) by chromium and nickel. To the south from the Heat Station No. 3 (TETs-3), at a distance of 1000 m, the contents of all investigated heavy metals are reduced and they are close to their background value.

The distribution of heavy metals in soil, depending on the relief, was traced. In the soils of slopes of NW and SE exposures along the direction of the prevailing winds from the Heat Station No. 1 (TETs-1), the tendency of heavy-metal to accumulate over a distance of 10 km was observed.

The motorway (Barnaul – Novosibirsk) pollutes the soil with lead over a distance up to 100 m, and, with cadmium, which is a more volatile element, pollution occurs up to distance of 200 m from the motorway.

Soil samples taken in the center of the rural community of Shipunovo contain values of chromium, zinc and copper close to the MPC. The content of lead, nickel and cadmium in the soils is below the MPC. In the distance away from the center of the community lead, zinc and copper content in the soils naturally decreases.

Heavy-metal content in the vegetable-garden soils in rural communities in the arid steppe does not exceed the MPC; higher zinc content is observed. The analysis of the total heavy-metal content in raw vegetables grown in private homestead lands reveals pollution of some vegetables by cadmium at a level close to the MPC and in some cases above the MPC. Cases of high chromium and copper content are revealed. The higher heavy-metal contents in plants, when the soil has small concentrations, may be related to their aerial inflow as the result of anthropogenic emissions into the atmosphere. In a vegetation-field experiment, chernozems were leached by heavy metals. A decrease in the number of bacteria and microorganisms growing on meat-and-peptone and starch-and-ammonia agars was found.

With an increase of heavy-metal pollution of soil, the quantity of fungi microflora grows. The maximum number of fungi was observed in samples with lead introduced at the level of 10 times the MPC, copper – 1 times the MPC, and cadmium – 5 times the MPC and 10 times the MPC. The changes in microbiological community can have effects on the decomposition and synthesis of soil organic matter, humus formation, i.e., on the chernozem soil formation process.

Our study of the phytotoxic effect on the activity of microflora in chernozem soils reveals the results of toxic compounds from anthropogenic sources.

Maximum phytotoxicity on the microflora is evident in low fertility soils. The following soil factors are listed in descending order of their importance as far as phytotoxicty is concerned: humus content – less than 3%, mobile phosphorus (P2O5) – less than 30 mg/100 g, total nitrogen (N) – less than 0.2%, total phosphorus (P) – less than 0.2%, humus horizon thickness – less than 30 cm, easily accessible phosphorus (P2O5) – less than 1 mg/100 g, exchangeable ammonium nitrogen (N/NH4) – less than 10 mg/kg, total fraction of mechanical elements sized less than 0.01 mm – less than 30%, nitrate nitrogen (N/NO3) – less than 5 mg/kg, exchangeable potassium (K2O) – less than 20 mg/100 g.

Using a crop rotation with grain crops promotes high phytotoxic action on soil microflora. Heavy-metal pollution of soils increases to a phytotoxic level on microflora at lead concentrations of 5 and 10 times the MPC, copper at 5 times the MPC, and cadmium at 1 and 5 times the MPC.

Thus, the research results reveal that the most important factors that affect phytotoxicity are the following (in the degree of importance): humus content (H), mobile phosphorus content (P2O5), thickness of humus horizon, total phosphorus content (P) and nitrogen content (N). Low humus content and, low content of total and mobile forms of nutrient elements promote phytotoxic conditions for the soil microflora.

The research involved a number of agricultural crops in vegetation-field experiments, which enabled us to compare their resistance to heavy-metal pollution. Buckwheat proved to be the most resistant; rape, alfalfa, millet, soft wheat, and durum wheat followed in resistance (listed in descending order of resistance). Buckwheat plants tolerated pollution relatively easily and formed biomass and grain yield at level of soil pollution by Cu up to 3 times the MPC (300 mg/kg), Zn – 1 times the MPC (300 mg/kg), Ni – 1 times the MPC (100 mg/kg), Cr – 5 times the MPC (500 mg/kg), and Cd - 10 times the MPC (30 mg/kg). A statistically significant decrease in buckwheat grain weight only occurred at a Pb level of 1000 mg/kg of soil.

References

Antonova O.I. Heavy metals content in the soils of the Altai Region and the quality of farm products // Improvement of Sustainability of Agricultural Industry of the Altai Region: Proc., 3rd Regional Scientific and Practical Conf. - Barnaul: Izd-vo AGAU, 2000. – P. 95-96. [In Russian].

Luzgin B.N. Metallogeny of the main ore deposit areas of Altai. - Barnaul: Izd-vo AGU, 1997. – 419 pp. [In Russian].

Satayeva L.V., Satayev Ye.A. Statistical structure of the pollution fields of soils and snow cover close to industrial atmospheric discharge sources // Geochemical methods in ecologic research / Rus. Academy of Sciences, Institute of Mineralogy, Geochemistry and Crystal Chemistry of Rare Elements. – M., 1994. - P. 43-54. [In Russian].

Chemical pollution of soils and soil protection: Glossary / D.S. Orlov, M.S. Malinina, G.V. Motuzova, et al. – M.: Agropromizdat, 1991. - 303 pp. [In Russian].