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Effect of the Physicochemical Properties of the Soil of Western Transbaikalia on the Level of Cadmium Translocation into Plants at Different Pollution Levels

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Abstract

Buffer capacity of the main types of soil of Western Transbaikalia with respect to cadmium under different levels of pollution is studied. The dependence of cadmium intake into plants on the buffer capacity of soil is established. The species ability of watercress to accumulate high cadmium concentrations on the soil of different types in the absence of any pollution source is revealed.

INTRODUCTION

Cadmium is considered to be one of the major pollutants of the biosphere with respect to the degree of ecological risk, toxicity, mobility and the ability to get accumulated in food chains [1–4]. Involvement of the excess amounts of cadmium of industry-related origin into the biogeochemical cycle brings about essential threat to the functioning ecosystems, in particular to human health.

Soil as the depositing component of the landscape is able to accumulate cadmium and transform it into the forms unavailable for the biota, thus removing the excess amount of this element from the environment for a definite time interval. However, the capacity of soil in this process is limited; it is determined by its physicochemical properties (acidity, humus content, the concentrations of fine fraction, exchangeable cations, carbonates, sesquioxides *etc*.). Soil accumulating cadmium serves as its source for plants and soil biota. The behaviour of cadmium in the system soil–microbiota–plant strongly varies depending on the physicochemical properties of soils and on the biological features of soil microbial and plant communities.

Because of this, we made an attempt to investigate the level of cadmium translocation into plants under the conditions of increasing cadmium concentration in soil. The plants were grown on the soil of five types differing from each other in genesis and in physicochemical properties, and dominating in the structure of agricultural land in Western Transbaikalia. This territory is the major part of the buffer ecological zone in the Baikal region where the catchment basin of Lake Baikal is concentrated. Some large industrial centres functioning at this territory are the sources of heavy metals including cadmium for the environment [5, 6].

EXPERIMENTAL

Vegetation field experiments were carried out in 2005 on the soil of five types: forest sands, chestnut, forest grey, alluvial sod, and alluvial meadow. Soil samples were taken in different regions of the Buryatia according to the criterion of their representativeness. The experiments were arranged at the common experimental ground in order to exclude the differences in ecological conditions (except the soil conditions) when growing the test crop. Soil samples were put into vessels 20 L in volume. The daylight area of the vessels was 0.1 m^2, the depth was 20 cm. The necessary level of pollution was modelled by introducing cadmium in the form of cadmium acetate ($Cd(CH_3COO)_2 \cdot 2H_2O$) in the amount, mg Cd / kg of soil: 0 (reference, without Cd added), 1, 2, 4, 8, 16, 32, 64. Each experiment was repeated four times.

Watercress belonging to the plant indicators of soil pollution with cadmium was used as the test crop.

Generally accepted methods of examination were used to analyse the physicochemical properties of soil [7–9]: pH of water extract was determined using the potentiometric procedure, humus content was measured using Tyurin's method in Nikitin's modification, the cation exchange capacity (CEC) was measured with Bobko–Askinazi procedure, the granulometric composition was determined using the pipette method, the amount of carbonates was measured with a calcimeter according to Rinkis method.

To measure total cadmium content in soil, the samples were subjected to complete decomposition with concentrated acids. The mobile form of cadmium was extracted with the ammonium acetate buffer solution with pH 4.8. Total content and the mobile form of the element in soil, as well as in plant samples after ashing at 450 °C followed by dissolution in diluted hydrochloric acid [10, 11] were determined using the AAS "Kvant-2A" with background correction system based on a hollow-cathode deuterium lamp.

The buffer capacity of soil with respect to heavy metals was estimated according to the scale developed by V. B. Il'in [12]. The statistical treatment of the obtained data was carried out according to B. A. Dospekhov [13] using Microsoft Excel 2000 program.

RESULTS AND DISCUSSION

The results show that the physicochemical properties of soil under investigation differ substantially from one soil type to another (Table 1). For instance, forest sand soil is characterized by the neutral reaction of the medium, loose sand granulometric composition, very low humus content and the absence of carbonates. The chestnut soil is characterized by the reaction close to neutral, sandy loam granulometric composition, very low humus content and low carbonate concentration in the upper horizon. Grey forest soil is characterized by weakly alkaline reaction, very low humus content, sandy loam granulometric composition, and insignificant carbonate content. Alluvial sod soil has alkaline reaction, light loamy granulometric composition, low humus content; alluvial meadow soil has weakly alkaline reaction, light loamy granulometric composition, medium humus content. Rather high carbonate concentration is characteristic of alluvial soil.

Soil samples exhibit different kinds of buffer capacity (stability) towards heavy metals (Fig. 1), which is to a high extent determined by the acidity of the medium, fine fraction content, and carbonate concentration. These kinds of soil may be arranged in the following sequence according to their stability against pollution with heavy metals that are mobile in the acidic medium: forest sand < chestnut < forest grey < alluvial sod < alluvial meadow.

The behaviour of cadmium in the system soil–plant is to a high extent defined by the

TABLE 1

Physicochemical properties of soil

Soil type	pH_{aq}	Content, %			CEC,	Cd content, mg/kg of soil	
		Humus	Carbonates	Physical clay	mg-eq/100 g of soil	Total	Mobile form
Forest sand	6.5	0.5	–	4	10	0.10	0.014
Chestnut	6.7	1.5	1.50	15	18	0.10	0.061
Grey forest	7.5	1.4	0.85	18	20	0.10	0.035
Alluvial:							
sod	7.8	2.3	4.10	26	24	0.12	0.072
meadow	7.3	3.9	6.19	27	26	0.20	0.127

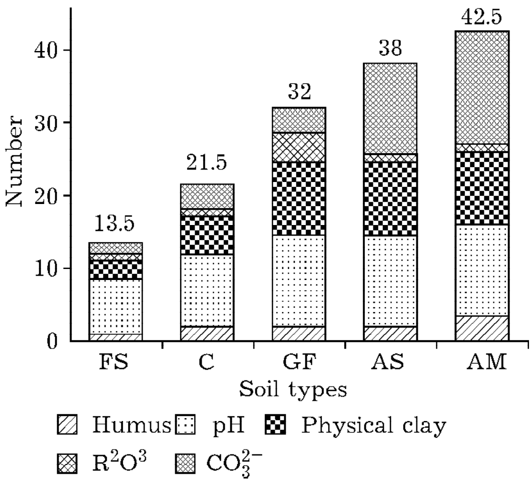

Fig. 1. Buffer capacity of soil with respect to heavy metals. Here and in Fig. 2: FS – forest sand, C – chestnut, GF – grey forest, AS – alluvial sod, AM – alluvial meadow.

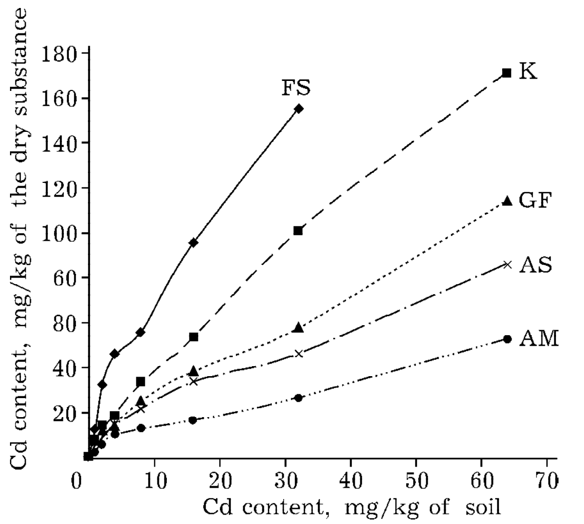

Fig. 2. Accumulation of cadmium in the green mass of watercress depending on the doses of the element when growing the plants on different types of soil. For designations, see Fig. 1.

stability of soil towards the metal (Fig. 2). The highest translocation of cadmium into plants was detected at the soil with the lowest buffer capacity: forest sand, while the lowest translocation was observed for alluvial meadow soil. It is necessary to stress that the differences in cadmium accumulation in the green mass of watercress on forest sand and alluvial meadow soil increased linearly with an increase in cadmium dose (from 1.3 times in the reference to 6.0 times for the dose of 32 mg/kg). We failed to carry out the comparative analysis for the maximal cadmium dose (64 mg/kg) because the plants grown on forest sand were dead.

The levels of cadmium intake into the green mass of watercress on the investigated types of soil have the linear functional dependence and may be reliably described with the equations of forward regression (Table 2). The correlation between cadmium concentration in soil and in plants is very high; the r value is 0.98–0.99, depending on soil types and the vegetative parts of plants.

TABLE 2

Correlation between increasing doses of cadmium and its accumulation in watercress

Soil type	Vegetative part	Correlation coefficient	Regression equation*
Forest sand	Green mass	0.983	$y = 4.5169x + 16.582$
	Root mass	0.992	$y = 4.5778x + 13.286$
Chestnut	Green mass	0.996	$y = 2.014x + 6.6394$
	Root mass	0.996	$y = 1.27x + 5.5596$
Grey forest	Green mass	0.995	$y = 1.6733x + 7.4089$
	Root mass	0.997	$y = 1.1253x + 4.5355$
Alluvial sod	Green mass	0.987	$y = 1.2941x + 6.5882$
	Root mass	0.993	$y = 0.9144x + 3.4968$
Alluvial meadow	Green mass	0.987	$y = 0.7427x + 4.9275$
	Root mass	0.990	$y = 0.7021x + 5.3581$

*y is cadmium concentration in plants, mg/kg of dry substance; x is cadmium dose, mg/kg of soil.

TABLE 3

Excess over PRC for vegetable crops in cadmium in the green mass of watercress grown on different types of soil, times

Dose of Cd, mg/kg of soil	Soil types				
	Forest sand	Chestnut	Grey forest	Alluvial	
				sod	meadow
0	13	6	7	2	9
1	98	48	51	23	24
2	227	80	82	35	64
4	285	101	96	92	66
8	313	175	152	127	87
16	507	309	246	209	115
32	890	390	357	260	165
64	–	683	590	472	321

Note. Dash means dead plants.

The results of the experiment provide evidence that watercress concentrates cadmium rather well. Thus, cadmium concentration in the edible parts of watercress (green mass) even in the reference experiments exceeded the permissible residual concentration (PRC) which is equal to 0.03 mg/kg of the raw material [14] (Table 3). In the experiments with alluvial sod soil, cadmium concentration exceeded PRC by a factor of 2, with chestnut soil 6 times, with grey forest soil 7 times, with alluvial meadow soil 9 times and with forest sand 13 times, In this situation, cadmium concentration in soil was never observed to exceed MPC.

In spite of high concentrations of cadmium in this crop, one can hardly speak of an essential danger for population because the fraction of watercress in human food is insignificant.

Nevertheless, an increase in cadmium concentration in soil leads to a noticeable excess of the element concentration over the PRC level in watercress even in the case of the minimal dose of cadmium (1 mg/kg) from 23–24 times (alluvial sod and meadow soil) to 98 times (forest sand). In this connection, it is necessary to stress that even in the case of insignificant cadmium pollution of soil it is unreasonable to grow this crop for food supply.

SUMMARY

1. The major types of soil in Western Transbaikalia have different buffer capacities (stability) towards heavy metals. The most important factors determining the buffer capacity of soil are pH of the medium, content of fine fraction and concentration of carbonates.

2. The types of soil are arranged in the following sequence according to the buffer capacity towards cadmium: forest sand < chestnut < grey forest < alluvial sod < alluvial meadow.

3. Cadmium translocation into plants is closely connected with the buffer capacity of soil. The highest level of cadmium admission in watercress was detected for forest sand, the lowest one for alluvial meadow soil. Chestnut, grey forest and alluvial sod types of soil occupy intermediate positions.

4. Metal content in the green mass of watercress exceeds PRC even in reference versions. With an increase in Cd concentration to 64 mg/kg of soil, cadmium content exceeds PRC 321 to 890 times, depending on soil type.

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