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CONCENTRATION OF HEAVY METALS IN THE AGRICULTURAL SOILS OF THE LUBLIN REGION AND POLAND

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A b s t r a c t. The paper characterises total concentrations of Cd, Cu, Ni, Pb, Zn in the surface layers (0-20 cm) of agricultural soils in Poland (48620 soils samples) and Lublin region (3829 soil samples). The results for Lublin region are expressed in terms of the degree of metal pollution as compared to contamination in the rest of the country.

The average concentration of Cd, Cu, Ni, Pb and Zn (in mg kg^{-1} of soil) in the A horizon of agricultural soils in Poland and in Lublin region (values in parenthesis) are as follows: 0.21 (0.17); 6.5 (4.9); 6.2 (6.6); 13.6 (10.7); 32.4 (23.3).

About 79% of the agricultural soils in Poland are characterised by a natural (0^0) content of heavy metals while 17.6% contain elevated level (I^0) of these metals. In the Lublin region it is 91.9% and 6.7%, respectively. About 3% of the Polish soils (1.4% in the Lublin region) exhibit various degrees of contamination with heavy metals. This includes heavy (IV^0) and very heavy pollution (V^0) which is found in up to 0.4% of the agricultural land and up to 0.2% in the Lublin region.

K e y w o r d s: heavy metals, soil pollution, Poland, Lublin region.

INTRODUCTION

Beside air and water, soil is the basic component of the biosphere with a specific system of physical, chemical, and biological properties developed as a result of soil formation processes.

In the past decades, agricultural and non-agricultural activity without any respect paid to the elementary principles of natural environment protection caused serious soil degradation in some regions of Poland [6,12].

Agricultural activity often combined with excessive application of chemicals, use of heavy agricultural equipment, improper melioration works, application of communal waste with excessive amounts of toxic substances [7] etc., might have

negatively affected soil properties by decreasing their productivity and quality of the produced plant material.

Intensive development of industry, especially power production, chemical, and metallurgical industries, which produce great amounts of dust and gas contaminants, including heavy metals resulted in a heavy soil pollution with those components in some regions of the country [2,6,11,12].

In the recent years, there has been a common awareness of a significant pollution with toxic substances that affected Polish soils and resulted in low quality of the produced crops. Such an opinion was created by media, ecological organisations, and some scientific groups which generalised results of research on the soils from some industrialised regions onto Poland as such. Also, in the world's soil maps published by the UNEP/ISRIC [18] in 1990, the territory of Poland was shown as highly degraded. Those opinions caused specific social and economic results of limiting of the market for Polish agricultural crops.

In 1992, Regional Agrochemical Stations together with the Institute of Soil Science and Plant Cultivation (IUNG) in Puławy started research on the evaluation of the ecological state of arable land in Poland.

This paper presents a survey of the content of heavy metals (Cd, Cu, Ni, Pb, Zn) in the 0-20 cm layer of arable soils and pollution of the soils in the region of Lublin with those elements (before 1998, that area included the following provinces: Biała Podlaska, Chełm, Lublin, and Zamość) in relation to data on the whole country.

MATERIAL AND METHODS

The research programme carried out in 1992-1997 according to the instructions by the Ministry of Agriculture and Nutrition concerned evaluation of the ecological state of arable soils in Poland on the basis of chemical analysis of 48620 soil samples taken from the arable layer at the depth of 0-20 cm. The contents of heavy metals soluble in *aqua regia* (HCl and HNO_3 - 3:1) was determined in the soil samples [10].

Evaluation of the degree of soil contamination with heavy metals was made according to the common standards [8], which included the content of Cd, Cu, Ni, Pb, Zn, granulometric composition and soil reaction, as well as the content of organic substance.

This paper presents results of the analysis of 3829 average soil samples taken from the arable land of the Lublin region in 1992-1997, and 48620 average soil

samples taken from various locations all over Poland (an average sample consisted of 15-20 individual samples taken from the area of 100 m^2 = 10x10 m). One soil sample represented the area of about 419 ha in the Lublin region or about 384 ha of arable land in Poland.

RESULTS AND DISCUSSION

Cadmium

It has not been unanimously proved yet that cadmium is necessary for living organisms. Its toxic properties draw attention of ecologists and soil scientists. Research concentrates mostly on the occurrence of this element in the natural environment. In most soil mother rocks, cadmium is found only in relatively low amounts. However, due to its geo-chemical properties, it is very mobile in the soil environment, especially in light and acid soils. In these conditions, even relatively low concentrations may be toxic for humans and animals if its uptake by plants is excessive and exceeds levels admissible for agricultural crops.

The natural content of cadmium in world's soils varies according to the geological rock origin, age of the soil, intensity of weathering processes, etc. Literature data [1,5,9] indicate that the average contents of cadmium in the world's soils ranges from 0.2 to 1.05 mg/kg of soil. Most often it is about 0.5 mg/kg, while in Poland it is between 0.20 and 0.31 mg/kg. Excessive cadmium accumulation above its natural level depends on the type of geological background, phosphorus fertilization level, use of sewage sediments or other kinds of wastes, etc. The most serious source of soil pollution with cadmium are emissions of dust from the non-ferrous metal steel plants and dust from metallurgical plants or waste dumps carried for long distances by wind.

The content of cadmium in the Polish soils (Table 1) is between 0.01-49.73 mg/kg. The average content is 0.21 mg/kg. In the Lublin region it is between 0.01-5.70 mg/kg, while the average content is 0.17 mg/kg. The estimated range allows us to estimate the actual threat of cadmium pollution in the soils of the investigated regions. We can draw a conclusion that the content of cadmium in the Polish soils is not much different from its content in the soils of the world. The highest contents of cadmium can be found in the soils of the southern zone of the country. It results from the petrographic composition of soil mother rocks, accumulation of cadmium during geological processes, and its emission from industrial plants. The highest contents of cadmium (49.7 mg per kg of soil) was found in the former Katowice

Table 1. Concentration and degree of pollution with Cd, Cu, Ni, Pb, Zn in the surface layer (0-20 cm) of agricultural soils in Poland and Lublin region

Element	Area	mg/kg of soil			% of agricultural soils with a given degree of pollution							
		ranges		geometrical mean	0^o	I^o	II^o	III^o	IV^o	V^o	0^o+I^o	II^o-V^o
		determined	expected									
Cd	Poland	0.01-49.73	0.10-0.46	0.21	88.9	9.5	1.0	0.3	0.2	0.1	98.4	1.6
	Lublin region	0.01-5.70	0.06-0.34	0.17	95.4	4.3	0.2	0.1	0.0	0.0	99.7	0.3
Cu	Poland	0.20-725.0	3.1-13.6	6.5	96.5	3.0	0.3	0.1	0.1	0.0	99.5	0.5
	Lublin region	0.7-566.7	1.9-12.8	4.9	98.0	1.1	0.5	0.2	0.1	0.1	99.1	0.9
Ni	Poland	0.1-328.3	2.6-14.7	6.2	95.4	4.2	0.3	0.1	0.0	0.0	99.6	0.4
	Lublin region	0.1-64.0	2.5-19.3	6.6	98.4	1.5	0.1	0.0	0.0	0.0	99.9	0.1
Pb	Poland	0.1-5000.0	7.4-25.0	13.6	96.9	2.4	0.4	0.3	0.0	0.0	99.3	0.7
	Lublin region	1.3-345.0	5.9-18.2	10.7	99.6	0.3	0.1	0.0	0.0	0.0	99.9	0.1
Zn	Poland	0.5-5745.0	16.1-65.2	32.4	87.9	10.6	1.3	0.2	0.0	0.0	98.5	1.5
	Lublin region	2.4-158.0	11.7-48.9	23.3	98.9	0.9	0.2	0.0	0.0	0.0	99.8	0.2
w.s.	Poland	-	-	-	79.3	17.6	2.2	0.5	0.3	0.1	96.9	3.1
	Lublin region	-	-	-	91.8	6.7	1.0	0.3	0.1	0.1	98.5	1.5

w.s. - synthetic index of soil pollution (all metals).

province. However, the polluted area is not big, which means that it is only of a local character.

The degree of soil pollution with cadmium in individual districts and provinces is very differentiated. Data presented in Table 1 indicate that part of the arable land in Poland with the natural content of cadmium (0^{o}) is almost 89%. Areas where Cd content is a little higher (I^{o}) constitute about 10%. The soils with low cadmium pollution (II^{o}) are 1.0%, while those with medium (III^{o}), strong (IV^{o}), and very strong (V^{o}) pollution constitute 0.6% of the total area of the Polish soils. Therefore, it can be concluded that pollution of the arable soils in Poland with cadmium does not pose a threat for agriculture in terms of the quality of the produced plant crops, except in the highly industrialised regions. The purity of soils of the Lublin region is even better than in the rest of the country. The total area of soils with the natural (0^{o}) or slightly increased (I^{o}) content of cadmium which is suitable for any plant breeding, except the crops used for baby food products, is 99.7% (Table 1).

Copper

Copper is an important component, necessary for the normal course of metabolic processes (regulator of generative processes in plants such as: photosynthesis, respiration, transformations of nitrogen compounds). Copper is mostly accumulated in plant roots, and in the conditions of high environmental pollution, we can observe an increased level of copper in cereal grains.

Copper content in soil is highly differentiated. Copper occurs in various forms in the soils. It usually forms bonds that are not too mobile bindings, in the form of carbonate precipitation and bonds with clayey minerals and organic matter [9]. Copper mobility increases highly with an increasing degree of soil acidification and decreases in neutral or alkaline soil reaction. Intensive fertilization with phosphorus and organic fertilizers decreases copper mobility in the soil, which means that its toxicity to plants also decreases.

Copper metallurgy, some plant pesticides, irrational use of micro-fertilizers, and fertilization with organic waste are fundamental causes of the soil pollution with copper.

Content of copper in the non-polluted soils of the world ranges from 1 to 140 mg/kg, while in Poland it is from 6 mg/kg in the lightest podzolic soils, to 53 mg/kg in some chernozem soil formations [9].

An average content of copper in the Polish soils is 6.5 mg/kg with a wide range of variation found (0.2-725.0 mg/kg) and evaluated (3.1-13.6 mg/kg) - Table

1. In the soils of the Lublin region, the respective values are: 4.9; 0.7-566.7; and 1.9-12.8 mg/kg. The highest copper content was found in the soils of the southern and south-western part of Poland [14,15]. It is definitely related to copper mining and metallurgy in that region and to the natural copper accumulation in the soils derived from the mother rocks rich in copper.

On the national scale, about 96.5% of the arable area have a natural (0^{o}), and 3% - increased (I^{o}) content of copper. Soils polluted with copper to various degrees (II^{o}-IV^{o}) are only 0.5% of the arable land in Poland. 98.0% of the arable land in the Lublin region have a natural (0^{o}), or increased content of copper (1.1%) (Table 1).

Data concerning the content and pollution of the Polish soils with copper indicate that it is not a factor that would limit agricultural production anywhere except in some specific regions where the natural accumulation of copper in the soil mother rock is high and in the regions with copper metallurgy. This allows to produce high quality crops for fodder and human consumption in Poland.

Nickel

Nickel is geo-chemically related to iron and cobalt. Those elements regulate distribution and behaviour of nickel in the environment. The soils rich in iron and clayey minerals usually contain much nickel [9]. Nickel mobility in the soil is limited by the compact granulometric composition and high content of iron hydroxides and clayey minerals.

The physiological role of nickel has not been fully recognised yet. It is, however, known that some plant species do not normally develop without its presence. Nickel is easily taken up and transported by plants. High concentration of nickel in the soil causes plant chlorosis.

The content of nickel in soils of the world varies in wide limits: in the light soils, it is between 8 and 33 mg/kg, while in the heavy soils, it is from 10 to 92 mg/kg. The level of 100 mg of Ni/kg of soil is considered an admissible concentration [8].

An average concentration of nickel in the Polish soils is 6.2 mg/kg and it ranges from the determined range of 0.1-328.3 mg/kg and the estimated range of 2.6-14.7 mg/kg (Table 1). In the soils of the Lublin region the respective levels are: 6.6; 0.1-64.0; and 2.5-19.3 mg/kg. The upper limits of the estimated range for the Polish soils (14.7 mg/kg) and the Lublin region (19.3 mg/kg) do not exceed the admissible value of nickel soil concentration (Poland - 6.2; Lublin region - 6.6 mg/kg of soil) and do not exceed 10 mg/kg, which is the value considered the critical concentration

for the very light soils. The soils of the provinces of Bielsko-Biała, Krosno, and Nowy Sącz have high Ni contents [16]. It is related to the geological origin of soil mother rocks (Flysh and weathering formations) of vast areas there.

Data presented in Table 1 indicate that 95.4% of the arable area in Poland have the natural content of nickel (0^o), while 4.2% have an increased content (I^o). The soils polluted with nickel (II^o-V^o) and used for agriculture are only 0.4% of the area in Poland, and 0.1% in the Lublin region. The above information indicates that soil pollution with nickel in Poland, and especially in the Lublin region, does not present any problem in terms of agriculture and environment. Neither is it an important factor limiting soil usefulness for plant cultivation.

Lead

The content of lead in the soils depends mainly on the mineralogical and granulometric composition and the origin of mother rocks. The minerals composed of lead show low solubility. This makes lead less mobile in the environment than zinc or cadmium. High concentration of lead in the soil, as well as acidic soil reaction, favour easy transportation of lead into the trophic chain. Low humus content and weak sorptive soil abilities increase lead mobility in the environment. Lead fixation in the cell-membranes, especially in roots increases plant tolerance of high lead concentration levels in the soil.

Lead is redundant for humans and animals. In the polluted environment, there is an accumulation lead in liver, kidneys, marrow, and brain, which causes diseases of those organs.

The content of lead in the soils derived from sand is usually lower than 16 mg/kg; whereas in the soils derived from more solid formations, it is between 13 and 60 mg/kg. The natural content of lead in the Polish soils usually does not exceed 20 mg/kg [4,5,9,13], while in soils of the world, it is 25-40 mg/kg [1,9].

An average lead content in the arable soils of Poland, is 13.6 mg/kg, with the variation range from 0.1 to 5000.0, and estimated fluctuation range from 7.4 to 25.0 mg/kg (Table 1). The soils of the Lublin region show lower average lead content (10.7 mg/kg) and clearly lower values of the found and estimated range when compared to the data for the whole country (Table 1).

An analysis of the soils in Poland in terms of lead pollution, proved that 96.9% of the total area of the arable land had a natural (0^o) content of lead, while 2.4% had an increased content (I^o) - Table 1. Soils weakly (II^o) and medium (III^o) polluted with lead constitute the total of 0.7 % of the area. The soils of the arable land in the Lublin region most often showed a natural (0^o) - 99.6% and increased (I^o) -

0.3% content of lead. The soils polluted with lead (II^{o}-V^{o}) were found on the 0.1% of the area used for agricultural purposes.

Zinc

Unlike cadmium and lead, zinc is necessary in the processes regulating metabolic paths of living organisms. Zinc appears in the soils in easily soluble compounds, which means that it is relatively intensively uptaken by plants. Increasing zinc mobility in the soil environment may also depend on the content and properties of organic substances, especially fulvic acids and some fractions of humic acids with which zinc forms relatively easily soluble complex bonds. Plants cultivated on the zinc polluted soils or in the conditions of strong air contamination with zinc, show high zinc accumulation in their biomass. excessive accumulation of zinc in the consumption goods causes damage to the bio-chemical control system and tumours. Generally, there are no symptoms of the toxic effect of zinc, except in the regions that are highly polluted. In many regions, people may suffer from the shortage of zinc deficiency which is manifested by skin diseases, disturbances in procreation, allergies, sclerotic changes, etc.

An average content of zinc in the soils of the world ranges from 50 to 60 mg/kg at the range of fluctuations from 27 to 235 mg/kg [9]. The natural content of zinc in the soil is hard to define, especially in the regions of metal ores since there are no threshold pollution levels determined for the zinc inputs with dust deposition or strict relations between zinc concentration and grain-size distribution. For example, in the soils derived from sand, the content of zinc does not usually exceed 30 mg/kg, in clays it reaches 60 mg/kg, and in solid alluvial formation it reaches as high as 90 mg/kg [5,9]. The natural content of zinc in the Polish soils, established on the basis of many-years of research carried out by the IUNG, should not exceed 40 mg/kg [7].

Average concentrations of zinc in the Polish soils (32.4 mg/kg) and the Lublin region (23.3 mg/kg) are close. The ranges found (Poland - from 0.5 to 5754.0 mg/kg; Lublin region - from 2.4 to 158.0 mg/kg) are totally different from the estimated ranges, which are, respectively: 16.1-65.2 and 11.7-48.9 mg/kg (Table 1). This indicates that both low and very high zinc content in the soils of Poland and the Lublin region, occur only occasionally. Nevertheless, the upper limit of the estimated range in the soils of both Poland and Lublin region exceed zinc concentration considered as natural. An average zinc concentration, higher than the upper limit of the estimated range (65.1 mg/kg) appears mainly in the soils of the southern part of Poland. It is related to the kind of mother rocks (pre-quaternary and

Flysh formations), rich in zinc, as well as to the emission of this element to the environment, mostly by non-ferrous metal industry.

Data in Table 1 indicate that about 88% of the arable land in Poland do not show any zinc pollution (0^{o}), and 10.6% have an increased zinc content (I^{o}). 1.3% of the soils are weakly polluted with zinc (II^{o}), while only 0.2% are medium polluted (III^{o}). The state of soil pollution in the Lublin with zinc is much better than the total for the Polish soils. 98.9% of the area of agricultural soils contain a natural amount of zinc (0^{o}), while 0.9% have an increased zinc content (I^{o}). Only 0.2% of the arable land of the Lublin region show weak (II^{o}) pollution with zinc. The zinc content in the soils of Poland and Lublin region, is not a factor limiting production of high quality crops used for human consumption and fodder.

Evaluation of the toxic influence of an increased zinc content in the soil remains an open issue together with some other problems such as zinc deficiency in the diet (in some regions of Poland), or limitation of the cadmium uptake by plants [3]. Some authors expressed an opinion that in the regions polluted with cadmium, zinc is the element that limits cadmium transition into the trophic chain, especially when the ratio of Zn:Cd is higher than 100:1.

Soil pollution with combined heavy metals

Data presented in Table 1 (w.s. index) indicate that the arable area in Poland not polluted with heavy metals (0^{o}) is 79.3%, whereas in the Lublin region it is close to 92%. The above soils can be used for field and garden cultivation. About 18% of the arable land in Poland contains increased quantities (I^{o}) of heavy metals. In the Lublin region, those soils constitute only 6.7% of the area used agriculturally. The soils with slightly increased content of heavy metals (I^{o}) should be excluded from plant cultivation (especially fruit and vegetable) for direct human consumption or production of nutritional concentrates for children. These soils, despite some limitation in their use, are of extraordinary value for agriculture. The soils weakly polluted by heavy metals (II^{o}) that are hazardous for plant production constitute 2.2% of the arable area in the country. In the Lublin region, the area of such soils that are used by agriculture is much lower, i.e. only 1.0%. The above soils should not be used for production of garden plants for direct consumption. One can, however, cultivate cereal, root, and fodder crops on such soils. Soils, which are medium polluted with heavy metals (III^{o}) can be dangerous to the quality of the produced plant crops. Such soils are 0.5% of the total arable area in Poland and 0.3% of the arable area in the Lublin region. It is allowed to cultivate cereal, root, and fodder crops on such soils. It is recommended, though, to periodically put

the content of heavy metals in plant crops used for consumption and fodder, under control. Soils strongly (IV^o) and very strongly (V^o) polluted with heavy metals take about 0.4% of the area of arable land in Poland (0.2% in the Lublin region). Such soils should be excluded from agricultural production. They can be used for the production of industrial plants, sowing material, and seedlings of fruit trees, shrubs, etc. Bigger areas of soils polluted with different amounts of heavy metals can be found mainly in the southern (industrialised) part of Poland [14].

CONCLUSIONS

The present research allowed to draw the following conclusions:

1. The actual and estimated (after excluding 5% of extreme values) ranges of heavy metal soil levels (Cd, Cu, Ni, Pb, Zn) in the arable soils of the Lublin region are much lower than the values for the whole country.

2. The average values of the analysed heavy metal content in the arable soils of Poland (values for the Lublin region are given in parentheses) are: Cd - 0.21 (0.17); Cu - 6.5 (4.9); Ni - 6.2 (6.6); Pb - 13.6 (10.7); Zn - 32.4 (23.3) mg/kg. Concentrations of the analysed heavy metals in the arable soils of the Lublin region are a little lower, except for nickel, than in the soils of Poland.

3. About 92% of the arable area of the Lublin region (Poland - 79.3%) have a natural (0^o) and 6.7% (Poland - 17.6%) increased (I^o) content of heavy metals. The area of arable land of Poland polluted with various amounts of heavy metals (II^o-V^o) is about 3.0% (in the Lublin region it is only 1.5%). High purity of the arable soils of Poland, especially in the Lublin region, allows to produce plant crops with high quality parameters for human consumption and fodder.

4. Opinions on the high pollution of the Polish soils, including the soils of the Lublin region, with heavy metals are not confirmed by the results of the present research. Small areas of arable land polluted by heavy metals, occur in the southern and south-western parts of Poland (provinces of: Katowice, Bielsko-Biała, Kraków, Częstochowa, and Wałbrzych), which are highly industrialised regions.

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