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THE EFFECT OF ORGANIC, LIME, AND PHOSPHOROUS FERTILIZERS ON Pb, Cd, AND Hg CONTENT IN PLANTS

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Abstract. In 1993—94 microplot trials with organic, lime, and phosphorous fertilizers were conducted in the trial field of the Estonian Research Institute of Agriculture at Saku in order to find out the effect of fertilizers on Pb, Cd, and Hg content in plants. Of organic fertilizers manure was used, of lime fertilizers oil-shale ash and heavy metal free $CaCO_3$ were applied, and of phosphorous fertilizers superphosphate was applied. The direct and aftereffect of these fertilizers on the content of heavy metals in potato tubers and ryegrass were studied. The heavy metal content of the background variant was compared to that of fertilized trial variants. The effect of fertilizers on the uptake of heavy metals by plants was determined on the basis of differences in the heavy metal content between plants of the trial variants. The concentration of Pb decreased by 47, that of Cd by 41, and Hg by 69% in the case organic and phosphorous fertilizers were applied. On the acid soils the application of lime fertilizers resulted in 10—74% reduction of the concentration of these heavy metals in plants.

Key words: lead, cadmium, mercury, content in plants, potato, ryegrass, manure, powdered oil-shale ash, $CaCO_3$, superphosphate.

INTRODUCTION

Soil and plants always contain some amount of heavy metals including lead, cadmium, and mercury. The majority of Estonian soils contain Pb, Cd, and Hg in such amounts which neither disturb the development of plants nor pollute them. Still, there are areas in Estonia where the content of some heavy metal exceeds the average content (Kärblane & Kevvai, 1993a, b, c). Plants grown on soils polluted with heavy metals often contain large amounts of these metals.

However, there are several factors which may reduce the heavy metal content in plants grown on polluted soils (Williams & David, 1973; Кабата-Пендиас & Пендиас, 1989). To study the effect of fertilization on Pb, Cd, and Hg content in plants, trials were performed at the Estonian Research Institute of Agriculture.

MATERIAL AND METHODS

In 1993—94 three microplot trials were conducted at the Estonian Research Institute of Agriculture at Saku to study the effect of organic, lime, and phosphorous fertilizers on Pb, Cd, and Hg content in plants. Two of the trials were performed on sandy Podzol (pH_{KCl} 4.5) and one on pebble loamy Rendzina (pH_{KCl} 6.9).

The humus horizon of sandy Podzol was relatively poor in heavy metals containing in 1 kg of dry soil 3.08 mg Pb, 0.05 mg Cd, and 0.0015 mg Hg. On soils poor in heavy metals, the effect of fertilization on changes in the heavy metal content in plants is usually so small that it remains within the limits of determination exactness. Therefore, in one trial on sandy Podzol (Trial 1), additional Pb, Cd, and Hg were applied to increase their content almost to the permissible level of a corresponding heavy metal in soil. After the additional application 1 kg of soil contained 98.31 mg Pb, 4.92 mg Cd, and 2.002 mg Hg. In another trial (Trial 2) no additional heavy metals were applied.

In Trial 1 the effect of organic, lime, and phosphorous fertilizers on the Pb, Cd, and Hg content in plants was followed. Manure was used as an organic fertilizer, $CaCO_3$ as a lime, and superphosphate as a phosphorous fertilizer.

In Trial 2 the effect of different lime fertilizers, i.e. of $CaCO_3$ and powdery oil-shale ash, on Pb, Cd, and Hg content in plants was studied.

In the trial conducted on pebble loamy Rendzina (Trial 3), the effect of manure and superphosphate on Pb, Cd, and Hg content was studied. Pebble loamy Rendzina (Trial 3) contained 11.5 mg Pb, 0.17 mg Cd, and 0.015 mg Hg in 1 kg soil. Additional heavy metals were applied to the soil before establishing the trial. After the application, 1 kg of humus horizon contained 108.3 mg Pb, 5.03 mg Cd, and 1.973 mg Hg.

In manure used as a fertilizer the content of Pb was 8.6, that of Cd 0.42, and that of Hg 0.032 $mg \cdot kg^{-1}$ dry matter. In oil-shale ash the corresponding heavy metal contents were 36, 1.28, and 0.091, and in superphosphate 4.1, 0.15, and 0.08 $mg \cdot kg^{-1}$.

The application rate of manure was either 30 (1 dose) or 60 (2 doses) $t \cdot ha^{-1}$. Lime fertilizers were applied either in single or double doses depending on the hydrolytical acidity of soil ($H_{8.2}$). A single superphosphate dose corresponded to 20 kg $P \cdot ha^{-1}$, a double dose was twice as much.

RESULTS

In all trials the heavy metal content in the plants of the background variant was compared to that of fertilized variants, and on the basis of differences the effect of a corresponding fertilizer on the heavy metal content in plants was determined.

Table 1 shows the effect of phosphorous, lime, and organic fertilizers on the heavy metal content in plants (Trial 1).

The given data indicate that plants grown on soils rich in Pb, Cd, and Hg had a high content of these heavy metals. It became also evident that ryegrass contained considerably more Pb and Hg than potato tubers. At the same time superphosphate, $CaCO_3$, as well as manure reduced the content of all the three heavy metals in plants.

The effect of different lime fertilizers on the heavy metal content in plants grown on soils with acid reaction is characterized by Table 2.

As the soil in this trial was considerably poorer in Pb, Cd, and Hg than that of Trial 1, the content of these heavy metals both in potato and ryegrass was also lower. However, also in this trial the liming of acid soils reduced the content of the above-mentioned heavy metals in plants.

On pebble loamy Rendzina the effect of superphosphate and manure on the content of heavy metals in plants was followed. The results are given in Table 3.

As additional Pb, Cd, and Hg were applied also to pebble loamy Rendzina, the content of these heavy metals in plants was high. The application of both phosphorous and organic fertilizers reduced the Pb, Cd, and Hg content in plants.

Table 1

Pb, Cd, and Hg content in potato tubers and ryegrass (mg · kg⁻¹ dry matter) grown on trial plots treated with phosphorous, lime, and organic fertilizers

Fertilizer and dose	Year and crop					
	1993, potato			1994, ryegrass		
	Pb	Cd	Hg	Pb	Cd	Hg
Background (B)	2.11	0.63	0.0343	13.80	0.53	0.0716
B+P (1)	1.67	0.51	0.0201	12.60	0.44	0.0566
B+$CaCO_3$ (1)	1.56	0.57	0.0160	4.50	0.16	0.0583
B+$CaCO_3$ (2)	1.50	0.50	0.0132	3.20	0.14	0.0500
B+manure (1)	1.52	0.42	0.0115	10.30	0.43	0.0378
B+manure (2)	1.11	0.37	0.0108	9.20	0.38	0.0300
LSD 5%	0.22	0.06	0.0031	0.46	0.06	0.0067

Table 2

Pb, Cd, and Hg content in potato tubers and ryegrass (mg · kg⁻¹ dry matter) grown on trial plots treated with $CaCO_3$ and oil-shale ash

Lime fertilizer and dose	Year and crop					
	1993, potato			1994, ryegrass		
	Pb	Cd	Hg	Pb	Cd	Hg
Background (B)	0.44	0.07	0.0260	2.20	0.17	0.0600
B+oil-shale ash (1)	0.38	0.05	0.0200	1.80	0.15	0.0500
B+oil-shale ash (2)	0.34	0.04	0.0180	1.90	0.16	0.0467
B+$CaCO_3$ (1)	0.36	0.04	0.0170	1.70	0.13	0.0367
LSD 5%	0.04	0.01	0.0025	0.15	0.02	0.0059

Table 3

Pb, Cd, and Hg content in ryegrass and potato tubers (mg · kg⁻¹ dry matter) grown on trial plots treated with superphosphate and manure

Fertilizer and dose	Year and crop					
	1993, ryegrass			1994, potato		
	Pb	Cd	Hg	Pb	Cd	Hg
Background (B)	1.70	0.66	0.0720	2.80	0.42	0.0658
B+P (1)	1.50	0.60	0.0500	2.30	0.40	0.0545
B+P (2)	1.30	0.52	0.0520	2.40	0.36	0.0367
B+manure (1)	1.50	0.62	0.0400	2.50	0.32	0.0283
B+manure (2)	1.40	0.59	0.0370	2.30	0.35	0.0234
LSD 5%	0.15	0.05	0.0028	0.27	0.03	0.0051

DISCUSSION

Several heavy metals form complex compounds with the soil's organic matter reducing thus their own mobility in soil and the uptake by plants. Of the heavy metals under observation Hg was the most firmly bound by the organic matter. In case of manure fertilization the content of Hg decreased by 44—69%. The higher the application rate of manure, the lower was the Hg content in plants.

According to Scheffer and Schachtschabel (1982), soil organic matter always binds Pb more firmly than Cd. Therefore, the applied organic fertilizer should in principle reduce the Pb content in plants more notably than the Cd content. However, in our trials there was no such distinct difference in the effect of manure on the reduction of Pb and Cd contents in plants. In case of manure fertilization the Pb content decreased by 11—47% and that of Cd by 8—41% (Tables 1 and 3). In one trial the Pb content decreased more, in another one the Cd content showed the biggest reduction.

In case manure was applied the Pb, Cd, and Hg content in plants decreased more on acid soil than on calcareous soil. It can be explained by the fact that in acid soil manure not only enriches the soil with orgnic matter, but regulates the soil reaction as well. Together with the decrease in soil acidity the mobility of several heavy metals in soil also decreases (Касатиков, 1992).

Table 1 shows that in the year of the direct effect of manure, the content of Pb and Cd in plants decreased more than in the year of its after-effect. No such regularity was observed for Hg.

The soil reaction in the place where the plants grow has an essential effect on the uptake of heavy metals. In acid soil heavy metals are usually more easily soluble and plants take them up in larger quantities (Oberländer, 1981; Kowalewsky & Veter, 1983). Thus, the liming of acid soils reduces the pollution of plants with heavy metals.

When the sandy Podzol was neutralized with $CaCO_3$, potato tubers showed the biggest decrease in the Hg content (53—62%), the Pb content decreased by 26—29%, and that of Cd by 10—21%. In case of ryegrass the situation was the opposite: the Cd content decreased the most notably (70—74%) and the Hg content least of all (19—30%); while the decrease in the Pb content (67—77%) was almost as big as that of Cd (Table 1). Depending on the $CaCO_3$ dose, pH_{KCl} increased from 4.5 either to 5.7 or 6.4.

The trial results (Tables 1 and 2) also indicated that the bigger the content of a heavy metal in soil, the more it fell in plants after liming. For example, when Pb-poor soil was limed with $CaCO_3$, the Pb content in potato tubers diminished by 18%, in case of Pb-rich soil the decrease was 26%.

In recent decades oil-shale ash has been one of the main lime fertilizers in Estonia. However, it contains several heavy metals. One tonne of powdery oil-shale ash contains 17—60 g Pb, 1—2 g Cd, and up to 0.1 g Hg. Thus, oil-shale ash used as fertilizer affects the heavy metal content in plants in two ways. As the content of Pb, Cd, and Hg in oil-shale ash is slightly higher than in soil, liming enriches the soil with these heavy metals. On the other hand, oil-shale ash neutralizes the acid reaction in soil and therefore reduces the uptake of heavy metals by plants. As the latter effect is greater, the liming of acid soil with oil-shale ash reduces the Pb, Cd, and Hg content in plants. In the trials with lime fertilizers either heavy metal free $CaCO_3$ or oil-shale ash was used. It became evident that both fertilizers reduced the Pb, Cd, and Hg content in plants (Table 2). However, if they were applied at rates equal in their neutralizing ability, $CaCO_3$ reduced the heavy metal content in plants more than oil-shale ash did.

Several chemical elements that are applied to soil with fertilizers can affect the uptake of heavy metals from soil by plants (Kowalewsky & Veter, 1983; Касатиков, 1992). One of these elements is phosphorus. When plants are sufficiently supplied with phosphorus, the penetration of several heavy metals, especially that of Hg, into plant roots, as well as the movement from roots to above-ground parts, is hindered (Кабата-Пендиас & Пендиас, 1989; Ельников & Кочатов, 1992). Thus the content of heavy metals in plants is reduced.

In our trials superphosphate was used as a phosphorous fertilizer. It contains Pb, Cd, and Hg. Thus, superphosphate affects the heavy metal content in plants in two ways. However, as the ability of phosphorus to reduce the uptake of Pb, Cd, and Hg by plants is greater than the pollution caused by superphosphate fertilization, then altogether the Pb, Cd, and Hg content in plants decreased. The greatest reduction occurred in the Hg content of plants.

CONCLUSION

The application of organic and phosphorous fertilizers reduces the Pb, Cd, and Hg content in plants. On acid soils the content of these heavy metals in plants decreases also in case of liming.

Thus, in order to reduce the content of heavy metals in agricultural crops grown in an area polluted with Pb, Cd, or Hg, large quantities of organic and phosphorous fertilizers should be used. On acid soils lime fertilizers should be applied.

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