Environ Sci Pollut Res (2015) 22:4706–4714
DOI 10.1007/s11356-014-3706-x

RESEARCH ARTICLE

Effect of peat on the accumulation and translocation of heavy metals by maize grown in contaminated soils

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Received: 28 December 2013 / Accepted: 7 October 2014 / Published online: 22 October 2014

Abstract Incorporation of organic materials into soil improves the soil sorption capacity, while limiting the mobility of metals in soil and their availability to plants. These effects can be taken advantage for remediation of soils polluted with heavy metals. The objective of this study is to assess the remediatory potential of peat applied to soils with concomitant pollution with Cd, Pb, and Zn. Two 1-year experiments were run in microplots in which maize was grown as the test plant. The following treatments were compared on two soils (sandy soil and loess): (1) control, (2) heavy metals (HM), (3) HM+peat in a single dose, and (4) HM+peat in a double dose. Maize was harvested in the maturity stage; the biomass of roots and aerial parts, including grain and cobs, was measured. Besides, concentration of metals in all those plant parts and the net photosynthetic rate and transpiration rate were determined. The approach of using peat in soil remediation led to satisfactory results on sandy soil only. The application of peat to sandy soil caused significant changes in the accumulation of the metals and their translocation from roots to other parts of plants, which resulted in a higher intensity of photosynthesis and an increase in the maize biomass compared to the HM treatment.

Keywords Soil contamination · Heavy metals · Peat · Bioaccumulation · Translocation · Remediation

Responsible editor: Philippe Garrigues

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Introduction

One of the strategies designed for remediation of contaminated soils is the immobilization of metals in soils, thus limiting their mobility and phytotoxicity, which should create suitable conditions for crop cultivation on these soils. Although immobilization of metals does not reduce their total content in soil, it may inhibit the accumulation of metals in plant tissues to the extent when production of good quality and quantity of crop yields is possible. Heavy metals can be immobilized in the soil solid phase through modification of soil properties, mainly its reaction and sorption capacity.

Soil liming is the most common and effective method undertaken to reduce the mobility of heavy metals. Another solution is the enrichment of soil with organic matter, particularly helpful when soils present poor sorption capacity, e.g., sandy soil. Various organic soil amending substances can be used for remediation of soil polluted with heavy metals, e.g., composts, organic carbon, tree bark, sawdust, green manure, sewage sludge, and peat. Incorporation of organic materials into soil reduces amounts of mobile forms of metals in soil (Kumpiene et al. 2007; Gondek 2009) and inhibits their uptake by plants (Wrobel and Nowak-Winiarska 2011). Metals can also be immobilized in soil by taking advantage of the so-called chemical sorption, for instance using phosphate rocks or other phosphate-containing materials (Ma et al. 1995; Cotter-Howells and Caporn 1996; Waterlot et al. 2011; Lewinska and Karczewska 2013).

Numerous laboratory tests have been conducted on sorption properties of peat, which prove that it is possible to achieve immobilization of metals (Fisher 2002; Kiikkila et al. 2002; Gupta et al. 2009; Hu et al. 2010; Lee et al. 2013) and detoxification of organic pollutants (Ghaly et al. 1999). Studies dedicated to the potential use of peat for remediation of water contaminated with heavy metals have confirmed that peat is capable of capturing metals and nutrients from aqueous environment. It has been demonstrated that peat can remove from water the following elements: Cd (Gosset et al. 1986), Cr (Sharma and Forster 1993), Cu (Gosset et al. 1986; Gardea-Torresday et al. 1996), Ni (Gosset et al. 1986; Ho et al. 1995), as well as Pb and Zn (Horacek et al. 1994; Crist et al. 1996). Scientists have shown different mechanisms involved in the sorption of metals by peat, which depend on the type of peat and its preparation and type of metal and its concentration. The most widespread is ion-exchange mechanism (Horacek et al. 1994; Ho et al. 1995; Crist et al. 1996). It has also been proven that peat adsorbs metals by complexing, surface adsorption (Gosset et al. 1986; Chen et al. 1990; Ho et al. 1995), and chemisorption (Sharma and Forster 1993). Having analyzed the research done by numerous authors, Brawn et al. (2000) have concluded that pH plays a key role in sorption of metal ions by peat from water. The optimum pH for sorption depends on a metal, but typically ranges within 3.5 to 6.5. Loading rates of metals in the environment are another factor that influences the efficiency of sorption of metal ions by peat. Experiments conducted by the researchers cited by Brawn et al. (2000) indicate the following metal ion-exchange order for peat: Pb>Cu>Cd>Zn>Ni. According to Qin et al. (2006), the competitive ability of Pb, Cu, and Cd for peat followed the order Pb>Cu>Cd. The same authors added that in multi-solute systems, quantities of absorbed Pb, Cu, and Cd decreased compared to those in single-solute systems. These abovementioned properties of peat have been verified through tests on different organic substances added to soil for removal of such pollutants as Pb, Cu, and Zn (Nwachukwu and Pulford 2008).

The objective of this study is to determine the remediatory effects of peat applied to soil with compounds Cd, Pb, and Zn pollution based on such plant indices as the biomass yield, concentrations of metals in plant tissues, and factors showing accumulation of metals and their translocation in plants.

Materials and methods

Experimental design

Two 1-year experiments on maize were performed in a complete randomization design with four replications. The experiments were set up under the conditions of open space in concrete microplots measuring 1×1,2×1 m and filled with sandy soil or loess (Table 1) in which 10 years prior to the current study had been contaminated with Cd, Pb, and Zn by introducing the metals down to the depth of 20 cm. The doses of the metals were adjusted to the type of soil so as to obtain a moderate degree of contamination according to Kabata-Pendias et al. (1993). The content of the metals in sandy soil, after 10 years after contamination, was several folds lower than in loess. Sandy soil contained Cd 1.39, Pb 341, and Zn 484 mg kg^{-1}, while the loess one had Cd 6.86, Pb 956, and Zn 2906 mg kg^{-1}. On each of the two types of soils, the following treatments were established: (1) control (C), (2) heavy metals (HM), (3) heavy metals with a single dose of peat (HM+P1), and (4) heavy metals with a double dose of peat (HM+P2). Horticultural peat of Peat Corporation company TVO Sp. z o.o was used, with the following characteristics: bulk density 0.25 g cm^{-3}, pH 6.5, organic matter (OM) 64.2 %, cation exchange capacity (CEC) 52.1 cmol kg^{-1}, N 2.3 %, C 30.0 %, and C/N 13.0. In the autumn of 2010, peat in the doses of 20 l/plot (P1) and 40 l/plot (P2) was mixed with soil to the depth of 20 cm.

Maize (*Zea mays* L.) cv. Buran (FAO 240) was sown in May 2011 and 2012, leaving eight plants on each plot after plant thinning. Before sowing, the soil was fertilized with N 4.0, P 2.4, and K 9.6 g/plot. In addition, N 8.0 g/plot was supplied in a top-dressing treatment. During drought, the plants were watered.

Measurements of physiological parameters

During the vegetative growth of maize, the net photosynthetic rate and transpiration rate were measured with a portable Li 6400 recorder manufactured by LI-COR. The measurements with nine replicates were made on randomly selected, youngest fully formed leaves of maize in three development stages: I 6–8 leaves stage (16–18 BBCH), II 10–11 leaves (20–21 BBCH), and III cob flowering stage (63–65 BBCH). The

Table 1 Physical and chemical properties of topsoil (0–20 cm)

Soil parameters	Sandy soil	Loess
pH	5.6	5.4
SFI [%]	90	27
SFII [%]	8	63
SFIII [%]	2	10
TOC [%]	0.53	0.78
CEC [mmol(+) kg^{-1}]	6.8	32.4
Cd [mg kg^{-1}]	0.09	0.29
Pb [mg kg^{-1}]	21.7	34.0
Zn [mg kg^{-1}]	95	165

SF I, soil fraction 2.0–0.05 mm; SF II, soil fraction 0.05–0.002 mm; SF III, soil fraction <0.002 mm measurements were carried out under comparable ambient conditions: in the morning (9 a.m. to 12 noon) at the constant PAR radiation 1200 μmol m^{-2} s^{-1}, CO_2 390 ppm, and temperature 26–30 °C.

Plant samples

Maize was harvested during the maturity stage by cutting from each plot the whole aerial part of the plants, which was divided into ears and straw. Straw consisted of stems with leaves. Next, ears were divided into cobs (without grain) and grain. Roots were dug out, shaken to remove the residual soil, and rinsed with distilled water. All parts of the maize plants were weighed having previously dried them in a dryer at 60 °C. Afterwards, they were ground to fine dust and samples for chemical analyses were taken.

Chemical analyses

The concentrations of heavy metals in samples of plant previously ashed in a muffle furnace at 500 °C and dissolved with 20 % nitric acid (PN-R-04014: 1991) were determined by flame atomic absorption spectrometry (FAAS). All analyses were performed in the Central Laboratory of the Institute of Soil Science and Plant Cultivation in Pulawy certified by the Polish Centre of Accreditation (certificate no. AB 339) according to PN-EN ISO/IEC 17025.

The soils underwent the following determinations: soil pH; total organic carbon (TOC); cation exchange capacity (CEC); content of Cd, Pb, Zn, and soil texture (Table 1). The pH was measured potentiometrically in KCl solution (ISO10390: 2005), TOC was assessed by the Tiurin's method using potassium dichromate (PN-ISO14235: 2003), and texture was evaluated by the aerometric method (PN-R-04033: 1998). Exchangeable cations were extracted with barium chloride solution (ISO 11260), and their content was determined by flame atomic absorption spectrometry (FAAS). Total concentrations of Cd, Pb, and Zn in soil were determined by FAAS after mineralization in aqua regia.

Parameters of metal accumulation

In order to compare the uptake of tested metals from two different soils and translocation of these metals from roots to aerial parts, two parameters were calculated:

Bioaccumulation factor (BF) and translocation factor (TF), which are expressed by the following equations:

$$\mathrm{BF} = \frac{\text{the metal concentration in plant tissues } \left[\text{mg kg}^{-1}\right]}{\text{the metal concentration in soil } \left[\text{mg kg}^{-1}\right]}$$

$$\mathrm{TF} = \frac{\text{the metal concentration in plant parts } \left[\text{mg kg}^{-1}\right]}{\text{the metal concentration in roots} \left[\text{mg kg}^{-1}\right]} \times 100$$

Statistical analyses

The results for maize biomass and metal concentration data were given as means from four replications and 2 years and for photosynthesis data as means from three replications and 2 years of the experiments. For biomass, one-way and two-way ANOVAs were conducted. One-way ANOVA was used for other data. Evaluation of significance of the data between the groups of tested parameters was done through Tukey's test ($P<0.05$). Calculation of the standard errors (SE) and ANOVA were performed with the Statgraphics v 5.0 software.

Results

1. Plant growth

In general, the biomass of maize was lower on sandy soil than loess, as well as a decrease of biomass of maize grown on the HM treatment was higher on sandy soil than loess (Table 2). Relative to the control, the maize grown on sandy soil achieved the following weight parameters: grain 38 % of the control, cobs 52 %, straw 46 %, and roots 28 %. The respective percentages for the maize cultivated on loess were 64, 77, 56, and 45 %. The application of peat led to an increase in the plant biomass dependent on the type of soil, dose of peat, and part of the plant. The interaction between peat dose and a type of soil was found (Table 3). Overall, a stronger remediatory

Table 2 The decrease in maize biomass due to soil contamination with heavy metals

Plant parts; treatment	Sandy soil		Loess	
	g per plot DW	%	g per plot DW	%
Grain				
C	758.6±16.6 a	100	783.5±69.1 a	100
HM	285.4±46.6 b	38	501.2±89.1 b	64
Cobs				
C	155.5±4.2 a	100	163.5±8.2 a	100
HM	80.6±6.2 b	52	126.9±16.0 a	77
Straw				
C	598.4±31.3 a	100	739.6±15.5 a	100
HM	273.7±18.1 b	46	412.3±53.5 b	56
Roots				
C	121.0±5.1 a	100	125.1±5.1 a	100
HM	34.1±3.8 b	28	55.6±9.0 b	45

Values are expressed as mean±SE. The same letters, within the same plant parts, stand for no significant differences between treatments by Tukey's test ($P<0.05$)

Treatment: *C* control, *HM* heavy metals

Table 3 The impact of the addition of peat to the soil contaminated with heavy metals on maize biomass

Peat dose, factor II	Soil type, factor I				Mean for peat dose
	Sandy soil		Loess		
	g per plot DW	%	g per plot DW	%	
Grain					
HM	285.4±46.6 B b	100	501.2±89.1 A b	100	393.4±55.5 b
HM + P1	583.1±55.4 A a	204	616.5±83.2 A ba	123	599.8±48.4 a
HM + P2	700.7±32.2 A a	246	829.6±88.3 A a	166	765.0±48.3 a
Mean for soils	523.1±43.7 B		649.0±55.7 A		
Tukey LSD (*P*<0.05): factor I, 113.2; factor II, 166.5; factor II/I, 235.5; factor I/II, 196.0					
Cobs					
HM	80.60±6.2 B b	100	126.9±16.0 A b	100	103.8±10.2 c
HM + P1	124.8±9.0 A a	155	134.3±7.8 A ba	103	129.6±5.9 b
HM + P2	149.6±8.7 A a	186	161.7±7.8 A a	124	155.7±5.8 a
Mean for soils	118.3±7.4 B		141.0±6.9 A		
Tukey LSD (*P*<0.05): factor I, 16.03; factor II, 23.58; factor II/I, 33.35; factor I/II, 27.76					
Straw					
HM	273.7±18.1 B b	100	412.3±53.5 A ba	100	343.0±32.6 b
HM + P1	436.5±37.5 A a	159	382.2±20.4 A b	93	409.4±21.7 b
HM + P2	522.1±40.2 A a	191	521.1±27.4 A a	126	521.6±23.5 a
Mean for soils	410.8±28.3 A		438.5±23.7 A		
Tukey LSD (*P*<0.05): factor I, 57.32; factor II, 84.344; factor II/I, 119.28; factor I/II, 99.28					
Roots					
HM	34.1±3.8 B c	100	55.6±9.0 A a	100	44.9±5.5 c
HM + P1	79.0±8.3 A b	232	51.2±4.7 B a	92	65.1±5.8 b
HM + P2	113.3±11.6 A a	332	72.3±4.6 B a	130	92.6±5.0 a
Mean for soils	75.4±8.2 A		59.7±4.0 B		
Tukey LSD (*P*<0.05): factor I, 12.32; factor II, 18.13; factor II/I, 25.64; factor I/II, 21.34					

Treatment: *HM* heavy metals without peat, *HM + P1* heavy metals+single dose of peat, *HM+ P2* heavy metals+double dose of peat. Values are expressed as mean±S.E. The same capital letters within the same line and with the same small letters within columns stand for no significant differences between treatments by Tukey's test (*P*<0.05)

effect of both peat doses (P1 and P2) occurred on sandy soil than on loess. The root weight doubled more in response to the P1 peat dose and tripled under the influence of the P2 dose compared to the HM treatment. These increments were statistically significant. At the same time, a significant increase in the grain weight appeared 2- and 2.5-fold more than from the HM treatment. Significant although smaller increases were also observed in the weight of straw and cobs. Besides, the application of P2 caused a weight increase of roots and aerial parts of plants to the level achieved in the control treatment. Statistically significant effects of peat added to loess appeared in respect of grain and cobs. The weight of these parts was 1.6-fold and 1.2-fold higher following the application of P2. Some statistically insignificant tendency towards a weight increase of straw also appeared, while the weight of roots did not change after the application of peat.

2. Changes in the physiological parameters of plants

The photosynthetic efficiency of maize was evaluated according to the measured leaf gas exchange parameters: net photosynthesis rate and transpiration rate (Table 4). Under the control condition, the photosynthetic efficiency of maize was similar on both soils, which was confirmed by the similar values of such parameters as the net photosynthesis rate ($P_{N)}$ and transpiration rate (E). In maize grown in the HM treatment, the quantity of CO_2 absorbed by leaves ($P_{N)}$ was about 45 % lower than in the control, which meant a significant decrease in the case of sandy soil. On both soils, the transpiration rate of maize leaves tended to decrease (by about 40–50 %), although this effect was not statistically proven. The enrichment of sandy soil with peat improved photosynthesis parameters, even though it did not raise them up to the levels detected in the control variant. Compared to the HM, a significant

Table 4 Net photosynthesis rate and transpiration rate of maize leaves, average from three development stages and 2 years

Treatment	Sandy soil	Loess
Net photosynthesis (μmol CO_2 m^2 s^{-1})		
C	30.0±3.29 b	31.2±2.19 a
HM	16.5±2.51 a	18.3±2.08 a
HM + P1	25.1±2.69 ab	24.7±2.51 a
HM + P2	26.0±2.06 ab	27.7±1.89 a
Transpiration (mmol H_2O m^2 s^{-1})		
C	3.1±0.42 a	3.0±0.39 a
HM	1.7±0.22 a	1.9±0.22 a
HM + P1	2.6±0.40 a	2.7±0.29 a
HM + P2	2.7±0.36 a	2.9±0.30 a

Treatment: *C* control, *HM* heavy metals, *HM + P1* heavy metals+single dose of peat, *HM + P2* heavy metals+double dose of peat. Values are expressed as mean±SE. The same letters within the same plant parts stand for no significant differences between treatments by Tukey's test ($P<0.05$)

increase in the net photosynthesis rate was noticed (by about 50 %), with no statistical differences between the peat doses. On the other hand, no effect of the peat doses such as a higher net photosynthesis rate was evidenced on loess. Besides, no significant changes in the transpiration rate were triggered by peat added to either of the soils.

3. Concentration of metals in plant tissues

Concentrations of all three metals increased in tissues of maize grown on the HM treatment. The increase was the highest in roots, followed by straw and cobs. Reversely, maize grain contained unchanged concentrations of the analyzed metals compared to the control treatment (Table 5). The application of peat to sandy soil, irrespective of the dose, depressed the levels of Cd in roots and cobs, although the decrease was not proven statistically. On loess, both peat doses significantly decreased the concentration of Cd in roots, and the P2 dose (P2) also diminished the concentration of this metal in cobs. A statistically unproven effect of peat added to sandy soil on the lowering of Pb concentrations was also noted, but only in roots. Generally, there was no effect of peat on the reduction of Pb in maize tissue on the loess. However, peat added to sandy soil significantly decreased the concentration of Zn in roots and cobs, with the P2 dose being more effective than P1. At the same time, an increase in Zn concentrations in straw occurred. On loess

Table 5 Concentrations of Cd, Pb, and Zn in different maize parts

Plant parts; treatment	Concentration of heavy metals (mg kg^{-1})					
	Cd		Pb		Zn	
	Sandy soil	Loess	Sandy soil	Loess	Sandy soil	Loess
Grain						
C	0.05±0.001 a	0.05±0.004 a	0.28±0.05 a	0.34±0.02 a	38.4±2.1 a	29.7±1.5 a
HM	0.05±0.002 a	0.06±0.019 a	0.34±0.02 a	0.34±0.02 a	46.1±4.7 a	41.5±4.8 a
HM + P1	0.05±0.001 a	0.05±0.001 a	0.34±0.02 a	0.34±0.02 a	42.2±2.5 a	37.4±3.1 a
HM + P2	0.05±0.001 a	0.04±0.007 a	0.34±0.02 a	0.34±0.02 a	40.5±3.4 a	41.3±3.8 a
Cobs						
C	0.04±0.004 a	0.05±0.004 a	0.68±0.03 a	0.30±0.06 a	147±8.6 a	102±0.1a
HM	0.11±0.020 b	0.34±0.080 b	2.34±0.85 a	0.54±0.05 a	253±8.6 c	181±5 b
HM + P1	0.07±0.005 ab	0.16±0.017 ab	0.88±0.24 a	0.47±0.16 a	192±3.2 b	175±6 b
HM + P2	0.07±0.003 ab	0.12±0.023 a	0.71±0.21 a	0.71±0.22 a	198±0.3 b	190±12 b
Straw						
C	0.16±0.003 a	0.09±0.001 a	3.17±0.11 a	1.92±0.68 a	436±13.5 a	181±7 a
HM	0.43±0.058 b	1.52±0.421 b	10.9±0.80 b	8.15±0.07 b	556±17.6 b	504±78 b
HM + P1	0.46±0.043 b	0.99±0.268 ab	12.4±0.34 b	8.86±1.86 b	712±19.8 c	534±70 b
HM + P2	0.52±0.089 b	0.84±0.242 ab	11.4±0.14 b	6.52±0.28 b	703±9.8 c	642±17 b
Roots						
C	0.62±0.006 a	0.39±0.040 a	15.6±0.49 a	12.4±2.5 a	518±30.3 a	273±15 a
HM	4.01±0.753 b	10.2±0.057 c	203±64 b	140±1.2 b	1700±121.2 c	1958±20 b
HM + P1	2.31±0.346 ab	5.80±1.319 b	89.1±14.4 ab	104±19.7 b	1083±72.1 b	1698±180 b
HM + P2	2.25±0.525 ab	4.55±0.225 b	117±34.3 ab	95.4±17.0 b	969±92.1 b	1645±39 b

Treatment: *C* control, *HM* heavy metals, *HM+ P1* heavy metals+single dose of peat, *HM+ P2* heavy metals+double dose of peat. Values are expressed as mean±SE. The same letters within the same plant parts stand for no significant differences between treatments by Tukey's test ($P<0.05$)

plants, it did not respond to the application of peat by decreasing the concentration of Zn in their tissues.

4. Accumulation of metals in plants

   Maize absorbed and accumulated metals in tissues much more readily when growing on sandy soil than on loess. All the BF values for sandy soil were even several folds higher than for the loess one (Table 6). On both soils, metals in the HM treatment were accumulated in the following order: Zn>Cd>Pb, and they were all gathered mainly by roots in which the BFs were several folds higher than in straw and several dozens higher than in cobs and grain.

The incorporation of peat to soil led to a decrease in the values of the BF, which reflected the reduced uptake of the metals by plants on P1 and P2 treatments. An addition of peat to metal-contaminated sandy soil caused a similar range of reduction of BFs for all the three metals in maize roots, where they fell by about 50–60 % against the HM treatment. The reduced accumulation of the metals from sandy soil was also manifested by smaller BFs of Pb (70 %), Cd (50 %), and Zn (40 %) for cobs. In turn, grain and straw were characterized by smaller modifications of the BFs, which changed in the case of Cd and Zn but remained unchanged for Pb. In general, the effect of P2 on reducing the accumulation of metals on sandy soil was not stronger than that of P1.

On loess, the accumulation of Cd in maize roots decreased by about 60 % while the quantities of accumulated Pb and Zn were 27 and 20 % lower following the application of the P2 dose. The P2 dose was more effective than P1 decreasing the Cd accumulation in roots. In response to the P2 dose, the BF of Cd for cobs declined by 70 %, for straw by 54 %, and for grain by 41 %. In contrast, the BF of Pb remained unchanged, except for a small decrease in straw (by about 20 %). Moreover, the application of P2 induced an increase of the BF of Zn for straw, but modifications of the BF of Zn for cobs and grain were negligible.

The distribution of metals between parts of maize growing on the HM depended on the metal and type of soil, as evidenced by the TF values (Fig. 1). On both soils, the highest transfer of metals from roots to aerial parts was detected for Zn, although the TFs were higher on sandy soil. The second metal most readily transferred from roots to aerial parts was Cd, with the higher TF values determined on loess. Grain was an exception in that. It was better protected from excess Cd on loess than on sandy soil. Transport of Pb from roots to aerial parts of maize was the smallest and on a similar level for both soils.

The enrichment of soil with peat raised the TF values for straw in respect of Zn and, to a comparable extent, Cd and Pb. Very small changes in the TFs were determined for grain and cobs. Larger changes in the distribution of metals appear in

Table 6 Bioaccumulation factors of metals on Cd-, Pb-, and Zn-polluted soils

Plant parts; treatment	Cd				Pb				Zn			
	Sandy soil		Loess		Sandy soil		Loess		Sandy soil		Loess	
	BF	%	BF	%	BF	%	BF	%	BF	%	BF	%
Grain												
HM	0.039	100	0.009	100	0.001	100	0.000	100	0.099	100	0.014	100
HM + P1	0.030	78	0.007	76	0.001	100	0.000	100	0.069	70	0.013	90
HM + P2	0.030	76	0.005	59	0.001	100	0.000	100	0.066	67	0.014	100
Cobs												
HM	0.079	100	0.050	100	0.007	100	0.001	100	0.527	100	0.063	100
HM + P1	0.041	51	0.021	42	0.002	33	0.001	100	0.313	59	0.059	94
HM + P2	0.038	48	0.015	30	0.002	28	0.001	100	0.318	60	0.062	99
Straw												
HM	0.322	100	0.224	100	0.032	100	0.009	100	1.177	100	0.176	100
HM + P1	0.270	84	0.130	58	0.032	100	0.009	100	1.163	99	0.180	103
HM + P2	0.298	93	0.104	46	0.032	100	0.007	81	1.135	96	0.211	120
Roots												
HM	2.824	100	1.488	100	0.573	100	0.147	100	3.514	100	0.676	100
HM + P1	1.309	46	0.744	50	0.228	40	0.108	73	1.751	50	0.576	85
HM + P2	1.238	44	0.568	38	0.321	56	0.107	73	1.537	44	0.541	80

Treatment: *HM* heavy metals, *HM+ P1* heavy metals+single dose of peat, *HM+ P2* heavy metals+double dose of peat

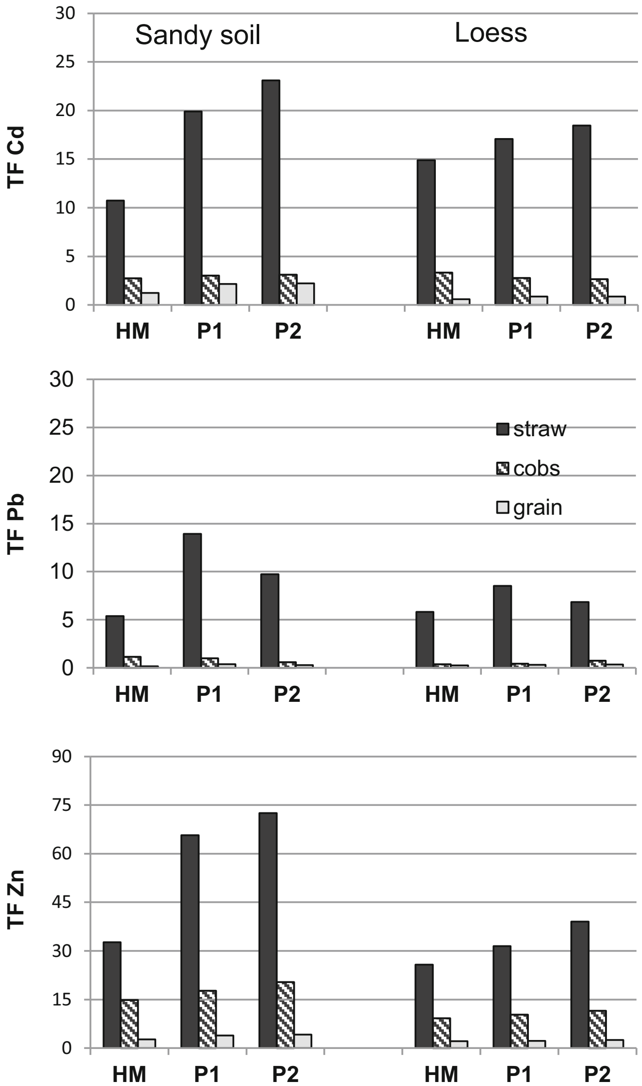

Fig. 1 Translocation factors of metal (TF) in maize growing on Cd, Pb, and Zn polluted soils. Treatment: *HM* heavy metals, *P1−HM+* single dose of peat, *P2−HM+* double dose of peat

maize grown on sandy soil than on loess. Our comparison of the effects produced by both doses of peat demonstrated a tendency for more intensive transport of Zn and Cd from roots to aerial parts of maize on the P2 than P1 treatments.

Discussion

The experiments provided us with some knowledge about the response of maize to moderate concomitant soil contamination with Cd, Pb, and Zn and changes in the accumulation and distribution of metals which are induced by the soil enrichment with peat as soil remediation substance. It should be noted that the obtained results are not universal, and they are only concerned on the variety of maize and soil type which were tested in the experiment.

Maize responded to excess metals, first of all, by reducing the biomass of roots, which led to a depressed biomass of aerial parts, including grain. Jarausch-Wehrheim et al. (1999) also demonstrated the shoot yield reduction up to 25 % against the control in maize cultivated on soil with an excessive content of Zn, although the weight of grain did not change. In our experiments, where the soil was simultaneously polluted with three metals, the reduction of maize biomass was higher (40–60 %) and depended on the type of soil. A higher loss of biomass was noted on sandy soil than on loess. This corresponds to the fact that maize took up and accumulated metals much more easily from sandy soil than loess. These findings are supported by several fold higher values of the BF for sandy soil than for loess. The impact of soil texture as well as other physicochemical properties on the plant availability of heavy metal is confirmed by the research of Qian et al. (1996) and Waterlot et al. (2013).

Regardless of the type of soil, maize most easily took up and accumulated Zn, followed by Cd, and—to the least extent—Pb. Some authors report a reverse tendency appearing under concomitant soil pollution with Cd and Zn. The removal rate of heavy metals from soils to plants was higher for Cd than for Zn according to Song et al. (1996), Li et al. (2002), and Yang et al. (2011). However, the research of Waterlot et al. (2013) proves that on soils contaminated by several metals from anthropogenic sources, the metal bioaccumulation factor order for Cd and Zn depended on the plant species and physicochemical properties of soil, while Pb was always the least accumulated metal.

The metals taken up by maize from the HM treatment were accumulated at maturity stage mainly in roots, next in straw, and finally in cobs and grain, where they appeared in quantities dozens of times lower than in the roots and straw. Sękara et al. (2005) have also concluded that maize grown on soil weakly contaminated with Cd and Pb accumulated less of these metals in the stem, shank, and grain in comparison to roots and leaves. In addition, the authors have observed that the Pb level in the shoot was four times lower than in the roots.

Based on microplot experiment, Korzeniowska et al. (2011) demonstrated a higher accumulation of metals in roots than in the aerial parts of maize.

The translocation factors calculated for straw, cobs, and grain prove that the transport of metals from roots to aerial parts in plants on both soils was most efficient for Zn, with the metal being accumulated in cobs and grain in higher concentrations than the other metals. Jarausch-Wehrheim et al. (1999) discovered that upper leaves and the stem rather than grain were the site where Zn accumulated at the end of the vegetative season of maize grown on soil enriched with Zn from sewage sludge. Maize grain accumulated Zn only when the metal content in soil was low. It can be hypothesized that there is some mechanism which protects grain from excessive accumulation of metals. According to Lasat et al. (1996), there are different specific systems of Zn translocation and storage depending on the concentration of Zn in substrate.

The translocation of Cd from roots to higher parts of maize plants was 2- to 3-fold smaller than that of Zn. Moreover, cobs and grain were more effectively protected from Cd on loess than on sandy soil. Lead was the metal that was least translocated in maize. Besides, Pb translocation was similar on both soils. Sękara et al. (2005) found smaller accumulation of Cd and Pb in the stem, shank, and grain of maize than in the roots and leaves and a smaller leaves/roots ratio for Pb than for Cd. Brennan and Shelley (1999) suggest that the primary mechanism in maize controlling the uptake and translocation of Pb from soil is the precipitation of Pb as a Pb-phosphate in roots.

Our experiments revealed much more profound disturbances in the biomass production by maize growing on sandy soil than loess, an outcome associated with a much stronger inhibition of the net photosynthesis rate on sandy soil than on loess, which in turn was most probably caused by the higher accumulation of metals. It is common knowledge that excess of heavy metals adversely affects the physiological processes in plants. For example, the presence of heavy metals is conducive to decrease the content of chlorophyll in plants and depress the activity of photosystems I and II (Chugh and Sawhney 1999; Plekhanov and Chemeris 2003; Burzynski and Klobus 2004; Qufei and Fashui 2009; Ci et al. 2010). Disorders in the photosynthetic activity of maize under Cd contamination stress were also demonstrated by Zhang et al. (2012). The phytotoxic effects of Pb on seedling growth and photosynthesis rate in two maize genotypes were found by Ahmad et al. (2011).

The application of peat to soil contaminated with heavy metals caused changes in the uptake and accumulation of the metals as well as their translocation in plants, which resulted in a higher biomass growth of maize compared to the HM treatment. Also, in a study of Al Chami et al. (2013), enrichment of Zn-polluted soil with organic matter as a compost and manure decreased the bioaccumulation factor and therefore improved the growth of plants and their tolerance to Zn. Sewage sludge mixtures with peat compared to sewage sludge alone caused an increase in the biomass yield of maize (Gondek 2009). The application of peat has also been found to alleviate the toxic influence of metals of energy willow, especially on sandy soil (Stanislawska-Glubiak et al. 2012). The current experiments also demonstrated that peat had a stronger remediatory impact on sandy soil than on loess.

The weight of both roots and aerial parts of maize grown on sandy soil amended with peat was higher, with the double dose of peat causing a significant rise in biomass compared to the control level. This increase was achieved through an improvement of the net photosynthesis rate, although it did not reach the control level. On loess, it was only the mass of grain that improved owing to the soil enrichment with peat, while the other plant parts were unaffected by the treatment. At the same time, no increase of the net photosynthesis rate was proven.

The varied and soil-dependent response of maize to peat remediation can be attributed to the fact that peat differentiated the uptake of metals by maize differently on the two types of soil. On sandy soil, the accumulation of all the three metals in roots went down by about 50–60 % and in cobs by 40–70 %, with the decreasing BFs of the metals in the order Pb > Cd > Zn. At the same time, the metal accumulation in grain and cobs did not undergo any larger changes. In contrast, peat added to loess substantially depressed the Cd accumulation only. This was evident in roots and cobs and, to a lesser extent, in the grain and straw.

In response to peat added to soil, the distribution of the metals between particular parts of maize was also modified. On both soils, maize in the maturity stage was found to present higher TFs for all the metals in straw, which may have acted as a storage site for excessive quantities of the metals. However, modifications in the distribution of individual metals in maize plants were much bigger on sandy soil than on loess.

Conclusions

The soil remediation effect produced by peat added to soil with the concomitant Cd, Pb, and Zn pollution depended on the type of soil and was satisfactory for the sandy soil only. The amendment of sandy soil with peat significantly decreased the uptake of the tested metals by maize. It also led to some modifications in their distribution between roots and aerial parts of plants and raised the photosynthetic rate. All this translated into a substantial increase in the plant biomass on the peat treatments compared to the soil without peat.

Moreover, the study has shown that maize can be cultivated on loess with medium Cd, Pb, and Zn contamination without peat remediation. The maize growing on the contaminated loess accumulated much less heavy metals, and its biomass productivity was higher than in the case of sandy soil.

Acknowledgments The work has been prepared as a part of 2.6 Long-term Program (funded by the Polish Ministry of Agriculture and Rural Development) in the Institute of Soil Science and Plant Cultivation—State Research Institute.

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