The effect of bottom sediment supplement on changes of soil properties and on the chemical composition of plants

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Abstract: The aim of the study was to assess the effect of bottom sediments on the selected properties of light soil as well as the content of trace elements in tested plants. The bottom sediments collected from the Besko reservoir were added to the soil in an amount of 5%, 10%, 30% and 50% of air-dried sediment, in relation to dry soil mass. The pot experiment was conducted on a light soil, with weak loamy sand grain size composition and slightly acid reaction, which was enriched with a supplement of bottom sediment. The test plant was a maize, Bora c.v. An applied bottom deposit revealed in its composition a considerable content of clay fractions, alkaline reaction and low total heavy metal content. Therefore, it may be applied as an admixture to light soils to improve their productivity. The addition of sediment to light soil resulted in the improvement of acidification in soil indicators: increased soil pH and reduced value of hydrolytic acidity, as well as improved sorption properties. A non-uniform effect of bottom sediment admixture on the content of trace elements in maize was determined. The sediment added to the soil increased the content of copper, nickel, chromium and, decreased the contents of zinc and cadmium in shoots. We did not find any excess of the permissible content of metals in plants used as animals forage in the maize biomass.

Keywords: bottom sediment, agricultural utilization, soil properties, heavy metals

INTRODUCTION

Bottom sediment is a very important part of water systems. Chemical, physical and biological properties of sediments are important indicators of anthropopressure (Jasiewicz et al. 2011, Baran & Tarnawski 2013). An assessment of sediments properties is important not only for identification of water reservoir degradation, but also for determining potential applications of dredged sediment (Baran et al. 2011, Mamindy-Pajany et al. 2011). Methods and techniques of bottom sediment removal from water reservoirs, as well as their in-situ and ex-situ remediation were the subject of numerous papers (Popenda et al. 2007). If the dredged material from the bottom of reservoirs does not pose a hazard for the environment, reasonable methods of such sediment management include their use for structure and soil forming material on soilless grounds and wastelands (Kostecki 2007). Bottom sediments, particularly these having neutral or alkaline reaction and high contents of silt and clay fractions, may be used for improving physicochemical properties of light and acid soils to improve their productivity (Wiśniowska-Kielian & Niemiec 2007a, 2007b, Jasiewicz et al. 2010, Baran et al. 2010, 2011, 2012).

Currently, one of the most important environmental and agricultural problems is the progressive degradation of soils. The World Watch Institute reported that topsoil loss is globally about 1% per year, while natural remediation can take hundreds of years (Fonseca et al, 1998). According to Fonseca et al. (1998, 2003) and Baran et al. (2010), bottom sediments are good additives used to improve the chemical and physical properties of soil. Therefore, agricultural application of uncontaminated bottom sediments can be the most rational way for their reuse (Fonseca et al.1998, Jasiewicz et al. 2011, Baran & Tarnawski 2012).

The aim of the study was to assess the agricultural utilization of bottom sediment used as an additive to light soil, basing the research on the effect of the sediments on changes to light soil properties and maize yield quality, including the content of trace elements.

MATERIAL AND METHODS

Physicochemical properties of bottom sediments

The investigated material originated from the bottom of the Besko reservoir, situated on the Wisłok River in the Podkarpackie Voivodeship. The characterization of this reservoir was described in Madeyski & Tarnawski (2007). These authors found that two wide zones of the reservoir are especially prone to silting up. About 330,000 m^3 of sediments were deposited in the side arm of the river, during the 28-year reservoir operation. Field work comprised of collecting samples of bottom sediments from the main area of the reservoir. The bottom sediment was sampled within the three zones of the reservoir: inlet, middle and outlet. The sediment was studied using an Ekman sampler from the 0–15 cm layer. Detailed characteristics of bottom sediments were presented in Baran et al. (2011, 2012). The sediment was classified as a group of clay deposits with an alkaline reaction, low content of bioavailable phosphorus and potassium. Heavy metal concentrations in the analysed sediment did not exceed the permissible content for the spoil (Journal of Laws 2002, no. 55, item 498). According to IUNG assessment, the analysed material revealed natural concentrations of Cu, Pb and Cd, as well as elevated contents of Zn, Cr and Ni (Baran et al. 2011, 2012).

Scheme of pot experiment

The pot experiment was conducted on a light soil with weak, loamy, sand of grain size composition and slightly acidic reaction, which was enriched by a supplement of bottom sediment. The bottom sediments were added to the soil in the amount of 5%, 10%, 30% and 50% of air-dried sediment in relation to dry soil mass (d.m.) (Baran et al. 2011, 2012). The same NPK (nitrogen – phosphorus – potasium) fertilization, dosed respectively 1 g N, 0.4 g P and 1.1 g K per pot (6 kg of soil d.m.), was used in all treatments. The tested plant was maize, Bora c.v. The test plant was harvested after 70 days of vegetation. Concentrations of trace elements (Zn, Cd, Pb, Cr, Ni, Cu) were assessed in the plant material, using the ICP-OAS method after dry mineralization and dissolving the ash in HNO_3 (1:3). The soil samples, after the pot experiment, were analyzed for parameters such as: pH, organic matter, cation exchange capacity, total nitrogen and content of trace elements (zinc, copper, nickel, chromium, lead and cadmium). Cation exchange capacity (T) of the soil was assessed on the basis of determined hydrolytic acidity Hh, base exchange capacity S and computed V%, i.e. base cation saturation ($V = S/T \cdot 100\%$). Total element content in soil was assessed after hot mineralization in the mixture of HNO_3 and $HClO_3$ acids (2:1) (Ostrowska et al. 1991). Soluble forms of Zn, Cu, Ni, Pb, Cr, Cd were extracted from the soil, with a 1 mol $\cdot$ dm^{-3} HCl solution (Rinkis method) (Karczewska & Kabała 2008). Extraction of metal soluble forms from the soil was conducted using a static method, by means of a single shaking of the soil samples with the solution at the soil to solution ratio 1:10 and during the extraction time of one hour. The element concentrations in the solutions were assessed using ICP-AES apparatus (JY 238 ULTRACE, Jobin Yvon). Plant and soil materials were analysed in four replications. The result was considered reliable if a relative standard deviation (RSD) did not exceed 5%. The obtained results were verified statistically using the one-way ANOVA at significance level $\alpha = 0.05$, by means of the Statistica 10 programme.

RESULTS

Properties of the soil after the pot experiment

Selected physicochemical properties of the soil were presented in Table 1. After a period of pot experiments, the soil pH, depending on the experimental treatment, was between 5.94 (control treatment) and 7.34 (treatment with a 50% bottom sediment supplement) (Tab. 1). Therefore, sediment supplement to the soil caused a significant increase in light soil pH value from 17% (5% sediment supplement) to 24% (50% addition of the sediment) in relation to the control treatment. Other investigation carried out by the authors proved that the application of bottom sediments with alkaline or neutral pH may have a de-acidifying effect on the soil. This application limits the toxic effect of heavy metals on plants, and therefore, may be a trap for heavy metals (Baran et al. 2010). The sediment supplement to the soil caused a significant decrease of the hydrolytic acidity Hh value and significant increase of base exchange capacity *S* and value of cation exchange capacity (*T*) in relation to the control treatment (Tab. 1). The value of hydrolytic acidity in the studied sediment ranged from 9 (treatment with a 50% bottom sediment supplement) to 17 (control treatment) mmol (+) · kg^{-1} d.m. In the soil, after the pot experiment, the value of base exchange capacity ranged from 16.29 (control treatment) to 639.6 (treatment with a 50% bottom sediment supplement) mmol (+) · kg^{-1} d.m (Tab. 1). Moreover, in the treatments with bottom sediment supplement, dominance of base cations (V = 92–98%) were registered in the sorption complex. An organic carbon content in the studied soil ranged 1.36–2.19% (Tab. 1). Only the 30% and 50% addition of the sediment to the soil caused a significant increase in the content of organic carbon in relation to the control treatment.

The effect of bottom sediment admixture on the content of the analyzed trace elements is shown in Table 2. Total content of zinc in the soil after the completion of the experiment was not significantly diversified. On the other hand, under the influence of 1 mol HCl · dm^{-3}, a significant decrease of the availability of this metal was observed by an average 7% in relation to the control treatment (Tab. 2). Total content of copper, nickel chromium lead and cadmium in the soil after the finished experiment was significantly diversified, depending on the bottom sediment addition to the soil. Doses of bottom sediment added to the soil significantly increased the total content and soluble forms of copper, nickel and chromium. The highest content of the above metals was found in the soil with 50% supplement of bottom sediment (Tab. 2). The sediment supplement to the soil caused a significant decrease of total content of lead and cadmium in relation to the treatment without sediment (Tab. 2). The highest total content of these metals was assessed on the control treatment, whereas the lowest on the treatment with 30% (Pb) and 50% (Cd) of sediment addition. Application of bottom sediment to the soil apparently decreased the content of cadmium and lead soluble forms (Tab. 2). Sediment supplement to the soil caused a significant decrease of the content of cadmium soluble form from 27% (5% deposit supplement) to 86% (30% and 50% addition of the sediment) in relation to the control treatment. A decreased content of lead soluble forms was observed only in the treatments with 30% and 50% supplement of sediment.

Table 1
Characteristics of selected soil properties after the experiment

Treatment	pH	C-org.	Hh[1]	*S*[2]	*T*[3]	*V*[4]
	[KCl]	[%]	[mmol (+) · kg^{-1}]			[%]
Control	5.94^{a*}	1.36^{a}	17.00^{a}	16.29^{a}	33.29^{a}	49
5% sediment	6.93^{b}	1.38^{a}	8.25^{b}	91.96^{a}	100.20^{a}	92
10% sediment	7.16^{b}	1.48^{ab}	6.75^{b}	113.5^{a}	120.30^{a}	94
30% sediment	7.24^{bc}	1.66^{b}	9.25^{b}	315.30^{b}	324.60^{b}	96
50% sediment	7.34^{c}	2.19^{c}	9.00^{b}	639.60^{c}	648.60^{c}	98

[1]hydrolytic acidity, [2]base exchange capacity, [3]cation exchange capacity, [4] degree of base cation saturation in the sorption complex, [*]homogenous groups according to Tukey test, α ≤ 0.01.

Table 2
Content of trace elements in the soil after the experiment [mg · kg⁻¹ d.m]

Treatment	Cr	Zn	Pb	Cu	Cd	Ni
Extraction with 1 mol HCl · dm^{-3}						
Control	0.62^{a*}	20.47^{b}	18.77	2.30^{a}	0.37^{d}	0.48^{a}
5% sediment	0.55^{a}	18.60^{a}	19.30	2.86^{b}	0.27^{c}	0.97^{ab}
10% sediment	0.71^{ab}	19.60^{ab}	19.70	3.16^{b}	0.13^{b}	1.38^{b}
30% sediment	0.86^{bc}	18.70^{a}	17.33	5.13^{c}	0.05^{a}	3.41^{c}
50% sediment	1.13^{c}	18.77^{a}	16.20	7.13^{d}	0.05^{a}	6.32^{d}
Total contents						
Control	5.90^{a}	59.00	25.27^{c}	3.68^{a}	0.48^{b}	3.83^{a}
5% sediment	7.05^{ab}	57.50	23.95^{bc}	4.43^{a}	0.48^{b}	5.08^{a}
10% sediment	7.70^{ab}	57.00	22.75^{b}	4.90^{a}	0.47^{b}	6.40^{a}
30% sediment	10.17^{b}	55.50	19.73^{a}	7.43^{b}	0.39^{a}	12.22^{b}
50% sediment	12.17^{b}	60.17	20.32^{a}	10.50^{c}	0.39^{a}	18.48^{c}

* homogenous groups according to Tukey test, $\alpha \leq 0.01$.

In addition to providing general knowledge about the total trace element contents in the soil, it is also useful to know the contents of their soluble forms. This is because of their potential mobilization from the solid phase, as well as the ability to supply plants with these elements. Extraction of the bioavailable forms of metals from the soil after the experiment was extracted using 1 mol HCl · dm^{-3}. Application of this test is routine and a commonly used method at agricultural chemistry stations and at IUNG for the assessment of contents of the available forms of microelements in soil. The proportion of the soluble forms of trace elements extracted with 1 mol HCl · dm^{-3} ranged between 7–11% Cr, 31–35% Zn, 74–88% Pb, 63–68% Cu, 13–77 Cd, 13–34% Ni in relation to the correspondent total contents in soil (Fig. 1).

It has been commonly accepted that copper, lead, chromium and nickel are the least mobile elements in soil, while zinc and cadmium are counted among the most mobile (Badora 2002, Dziadek & Wacławek 2005). Mobility of the elements analyzed in the treatment with supplement of bottom sediment was as follows: Pb > Cu > Zn > Cd > Ni > Cr. Moreover, it was also found that bottom sediment supplement to light soil decreased the mobility of cadmium, chromium and zinc and increased the mobility of lead, copper and nickel in relation to these elements' mobility in the soil without the sediment supplement (Fig. 1).

Content of trace elements in maize biomass

The concentrations of trace elements in maize shoots and roots were presented in Table 3. Sediment supplements to light soil caused an increase in copper, nickel, chromium and lead in maize shoot biomass in relation to the control treatment. Only the content of copper and nickel in maize shoot was statistically significant. The highest content of both metals in the shoots was registered in the treatment with a 50% supplement of bottom sediment (Tab. 3).

The highest content of chromium and lead was found in the treatment with 30% supplement of sediment. Zinc and cadmium content was not markedly dependent on the applied amount of bottom sediment (Tab. 3). Regardless of the bottom sediment dose, a decline in zinc and cadmium content, ranging from 23% to 30% in comparison with the control, was noted in the maize shoots. Contents of chromium, zinc, lead and cadmium in roots were lower in the treatments with sediment supplement in comparison with the control (Tab. 3).

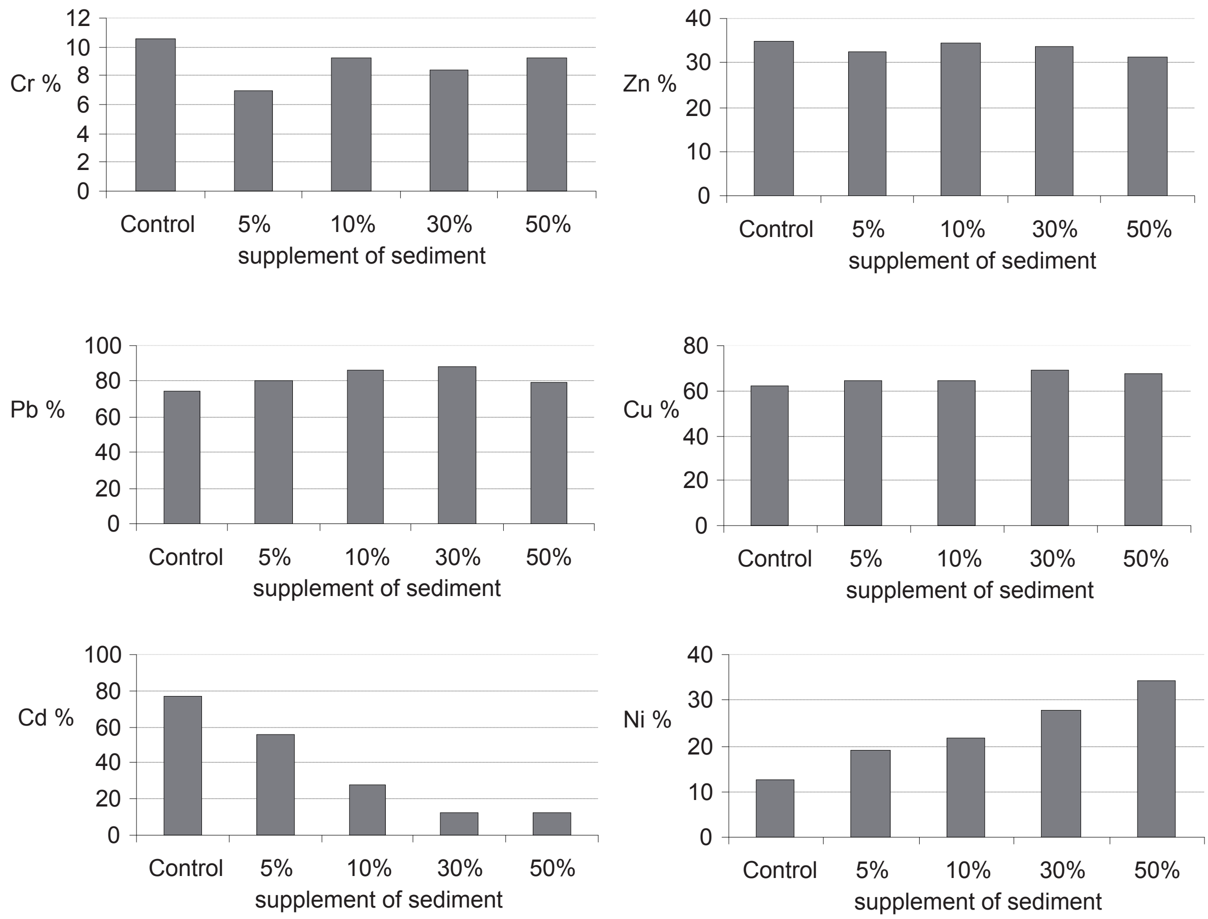

Fig. 1. *Percent share of available forms of trace elements relative to the corresponding total content in the soil*

Table 3
Content of trace elements in maize [mg · kg⁻¹ d.m]

Treatment	Cr	Zn	Pb	Cu	Cd	Ni
Shoots						
Control	0.50	35.67	0.41	1.51^{a*}	0.32	0.27^{a}
5% sediment	0.59	25.57	0.43	1.90^{ab}	0.20	0.31^{ab}
10% sediment	0.69	29.57	0.42	2.15^{ab}	0.20	0.34^{ab}
30% sediment	0.79	26.87	0.49	2.50^{b}	0.26	0.42^{ab}
50% sediment	0.77	26.27	0.48	3.31^{c}	0.21	0.46^{ab}
Roots						
Control	6.67	65.05^{c}	7.93^{c}	4.62^{a}	2.79^{b}	4.63^{a}
5% sediment	5.96	44.00^{b}	5.73^{b}	5.24^{ab}	2.42^{b}	4.85^{a}
10% sediment	5.37	37.73^{ab}	4.78^{ab}	5.84^{ab}	1.41^{a}	5.03^{ab}
30% sediment	5.54	33.80^{a}	3.09^{a}	12.43^{c}	1.06^{a}	8.19^{c}
50% sediment	6.21	36.67^{ab}	4.02^{ab}	8.93^{b}	1.40^{a}	7.67^{bc}

* homogenous groups according to Tukey test, $\alpha \le 0.01$.

However the dependence was statistically significant for Zn, Pb and Cd. Sediment addition significantly increased the content of copper and nickel in roots. The highest content of both metals was found in the treatment with a 30% supplement of bottom sediment. Assessment of the analysed elements distribution in respective parts of the maize demonstrated the higher contents of all elements (from the double increase of Zn to 17-fold of Ni) in the root biomass in comparison with the shoot one (Tab. 3). The permissible content of trace elements in feeds are: Zn < 100 mg · kg^{-1}, Cu, Cr, Ni, Pb < 10 mg · kg^{-1} and Cd < 5 mg · kg^{-1} d.m. (Kabata-Pendias et al. 1995, Journal of Laws 2007, no. 20, item 119). The assessment of trace elements content in above ground biomass indicated that the maize would be used for production of animal feeds.

DISCUSSION

The sediment from the Besko reservoir improved soil properties. The sediments revealed high contents of clay fractions, alkaline pH and low contents of trace elements. The studies showed that sediment supplement increased the value of pH and cation exchange capacity, content of C-organic and decreased both total and bioavailable content of toxic metals for plants, i.e. lead and cadmium. After a period of research, the light soil pH value was 5.94 on the control treatment, 6.93 after the treatment with a 5% sediment supplement and above 7% after the treatment with a 10–50% of sediment admixture. Similar results were obtained in studies on the agricultural use of bottom sediments collected from the Zesławice reservoir (Małopolska province) (Baran et al. 2009, 2010). The studies showed a positive effect of the sediment in improving indicators of soil acidification, buffering properties and content of organic matter in soil (Baran et al. 2009). Moreover, the authors found that the bottom sediment supplement to light soil significantly decreased the content of zinc, lead and manganese as available forms extracted with 1 mol HCl · dm^{-3} and bioavailable forms of cadmium, manganese and iron extracted with 0.01 mol $CaCl_2$ · dm^{-3} (Baran et al. 2010). In this study, we found that bottom sediment added to the soil significantly increased the total content and soluble forms of copper, nickel and chromium and decreased the content of cadmium, lead (both forms) and zinc (soluble forms). Many studies have shown that trace elements may pass into less soluble forms at higher pH values, which leads to their uptake by plants and decreases their toxicity for plants (Du Laing et al. 2009). The total and soluble forms of zinc, lead and cadmium were correlated negatively with pH (total content $r = -0.65$ for Zn, −0.43 for Pb, −0.93 for Cd, soluble forms $r = -0.30$ for Zn, −0.81 for Pb, −0.60 for Cd, $p < 0.05$). However pH was correlated positively with the content of nickel, chromium and copper. Most studies reported that soil pH is a key factor in determining Zn and Cd mobility (Shaheen & Rinklebe 2014). Our results showed that the decreasing content of Zn, Cd and also Pb in the treatment with sediment admixture was caused by increasing the value of the pH. Another important factor affecting the content and mobility of trace elements in soil includes organic matter (Shaheen & Rinklebe 2014). Content of chromium, copper and nickel in soil enriched with bottom sediment was significantly correlated positively with organic matter (total content $r = 0.92$ for Cr, 0.93 for Cu, 0.95 for Ni, soluble forms $r = 0.80$ for Cr, 0.93 for Cu, 0.95 for Ni, $p < 0.05$). This may be due to the high affinity of Cu and Cr for organic matter (Shaheen & Rinklebe 2014). In studies undertaken by Kaczmarski & Jasiewicz (2013), it was demonstrated that addition of bottom sediment from the Rzeszów reservoir to the light soil caused a change reaction of the soil. Therefore, the content of soluble forms of copper and zinc in soil increased as consequence of rising sediment doses introduced to the substratum.

The chemical composition of plant growth in soil enriched with bottom sediments was the subject of numerous studies (Wiśniowska & Niemiec 2007a, 2007b, Jasiewicz et al. 2010, 2011, Baran et al. 2012, Kaczmarski & Jasiewicz 2013). Generally, the experiments demonstrated a positive effect of bottom sediment supplement to soil on the yield of test plants (Wiśniowska & Niemiec 2007a, 2007b, Jasiewicz et al. 2010, Baran et al. 2012). Moreover, the studies revealed that the permissible content of heavy metals was not exceeded in the assessment of plants, in view of their forage usability (Jasiewicz et al. 2010). In this study, we also indicated that maize can be used for production of animal feeds. Bottom sediment from Besko added to soil had a positive effect on maize biomass, but only when applied in small dosages, i.e. 5% (Baran et al. 2012). Higher doses of bottom sediment caused a decrease of crop yield, as a result of unfavourable air conditions in the formed substratum (Baran et al. 2012). A positive effect of the soil enriched with bottom sediments from the reservoir Monte Novo (Portugal) was also noted by Fonseca et al. (1998), during their investigation of their influence on growth of pepper plants.

To sum up, if the heavy metal content in the sediments are below toxic thresholds, and the content of nutrients is low, the use of sediments for agricultural purposes would not constitute risks. However bottom sediments cannot replace fertilizer. The studies of Jasiewicz et al. (2009) showed that when using bottom sediment for plant cultivation, one should apply supplementary mineral fertilization, because of the low content of phosphorus and potassium in the sediment. As soil amendment and building material, the sediments have potential economic value.

CONCLUSIONS

1. The applied bottom deposit contained a considerable amount of clay fractions, alkaline reaction and low total heavy metal content. Therefore, it may be applied as an admixture to light soils to improve their productivity.
2. The addition of reservoir sediment to light soil resulted in the improvement of soil acidification indicators: increased pH of the soil, reduction of the hydrolytic acidity value, as well as improved sorption properties of the soil.
3. Bottom sediment supplement to the light soil decreased the contents of the available forms of zinc, lead and cadmium and increased chromium, nickel and cooper in the soil.
4. A non-uniform effect of the bottom sediment admixture on trace elements content in maize was determined. The sediment added to the soil increased the content of copper, nickel, and chromium, whereas it decreased the content of zinc and cadmium in shoots.
5. An excess of the permissible content of metals in plants used as animals forage was not observed in the maize biomass.

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