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RESEARCH ARTICLE

Evaluation of ecotoxicological and chemical properties of soil amended with Hudson River (New York, USA) sediment

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Abstract

The aim of this study was to assess the potential for application of Hudson River sediment as a plant growth medium by mixing with various proportions of soil. The growth medium obtained by the admixture of soil and Hudson River sediment was characterized by optimal pH, reduced salinity, and presence of macro- (K, Mg) and micronutrients (Fe, Mn). Apart from beneficial nutrients and organic matter, the riverine sediment also contained toxic metals (Zn 86 mg; Cu 17.8 mg; Ni 16.6 mg; Cr 20.7 mg; Cd 0.46 mg; Pb 20.7 mg/kg, at concentrations below the threshold effect concentration) and PCBs (total concentration 254 ng/g), which can have a negative impact on soil ecosystems. The results ecological risk assessment of six trace elements and PCBs in sediment suggested medium/moderate risk (PECq = 0.21) and the need for ecotoxicological tests prior to its use as a growth medium. However, ecotoxicity tests of the soil/sediment admixture indicated that it was non-toxic or less-toxic to crustacean *Heterocypris incongruens* (PE = − 8–38%) and bacteria *Aliivibrio fischeri* (PE = − 20–38). For *Sinapis alba* L. and *Lepidium sativum* L., the germination index (GI) indicated the dominance of inhibitory effect on plant growth; whereas for the *Sorghum saccharatum* L., the GI value showed the stimulatory effect. Based on the above physicochemical and ecotoxicological analyses, the sediment was found suitable for use as a growth medium, for non-edible plants. It is worth to underline that this sediment was collected from relatively less contaminated location of the river and therefore the results may not represent sediments from entire stretch of the Hudson River.

Keywords River bottom sediments · Growing medium · Nutrients · Pollutions · Ecotoxicity

Introduction

Management of dredged aquatic sediments is a worldwide problem. Several options for beneficial use of sediments have been suggested, which include erosion control, aquaculture, forestry, shoreline stabilization, manufacture of aggregates, construction, reference material, and energy production (Siham et al. 2008; Wang et al. 2015; Kiełbasa and Buszewski 2017). For economical, technical, and ecological reasons, most of the uncontaminated or less contaminated sediments have been advocated for use in agriculture (Macía et al. 2014; Tarnawski et al. 2017). Agricultural and environmental utilization of sediments is a promising alternative due to the beneficial properties of sediments that are rich in clay, organic matter, and nutrients (Baran et al. 2019; Siebielec et al. 2019). However, optimal conditions for agricultural and environmental use of sediments depend on appropriate admixture with different materials to reduce the risk of introducing toxic chemicals/substances present in sediment to the soil

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environment (Mamindy-Pajany et al. 2012; Thanh et al. 2015; Yang et al. 2018). Several studies reported that a mixture of soil and sediments, when used as substrates for plant cultivation, can either inhibit or stimulate plant and microbial growth (Jasiewicz et al. 2010; Siebielec et al. 2019). Therefore, a qualitative assessment of sediments is an important step prior to their introduction into the soil environment.

Most studies on amendments used in agriculture have focused on the content of inorganic and organic pollutants, nutrients, organic matter, and granulometric composition. However, physical and chemical analysis of sediment alone cannot predict their impact on living organisms. This is related to the fact that those effects on organisms can result not only from individual substances but also synergistic and/or antagonistic effects of mixture of compounds. Therefore, bioassays are recommended prior to agricultural and environmental utilization of various amendments and wastes, including sediments (Mierzwa-Hersztek et al. 2017; Antonkiewicz et al. 2018). The advantage of bioassays is that they measure integrated responses of living organisms to various contaminants as well as mixtures of compounds of both toxic and non-toxic properties present in a given matrix. To achieve high accuracy in sediment ecotoxicity tests, the model organism used in bioassay should represent various trophic levels and has to be sensitive to chemical compounds (Oleszczuk and Hollert 2011; Baran and Tarnawski 2013). Consequently, ecotoxicological studies carried out using bioassays cover the gross effect of all substances present in a given substrate and illustrate interactions between them. Such an approach allows for assessing potential risks associated with the use of sediments as well as other wastes for beneficial purposes.

The Hudson River in New York State (USA) is one of the most contaminated waterbodies. The river received wastewater discharges from capacitor manufacturing operations at General Electric plants in Hudson Falls and Ford Edward, NY. As a consequence, the Hudson River ecosystem has been contaminated by organic compounds, especially polychlorinated biphenyls (PCBs). One of the most contaminated compartments of the Hudson River ecosystem was sediments, wherein PCBs and other organic compounds have been deposited and accumulated for decades, posing a long-term threat to benthic organisms, fish, aquatic birds, and humans (Foley 1992; Cho et al. 2004; O'Keefe et al. 2006; Field et al. 2016; Madden and Skinner 2016; Pinkney et al. 2017). The dredging of the Hudson River sediment enabled removal of approximately 2.10 million m^3 of sediments and 141,000 kg of PCBs (US EPA 2015). However, this amount constituted only 24% of the total mass of PCBs deposited historically. An ecotoxicological assessment of the Hudson River sediments for potential utilization as a soil additive is important to evaluate further remediation options available. Although several studies have reported on the quality and agricultural/environmental use of sediments from dams and ponds (Fonseca et al. 2003; Mouendo et al. 2014; Tarnawski et al. 2015), little is known on agricultural/environmental utilization of riverine sediments (Parkpian et al. 2002; Darmody et al. 2004; Ebbs et al. 2006; Marlin and Darmody 2018).

The aim of this study was to assess potential ecotoxicological effects of Hudson River sediment collected from relatively less contaminated location near Waterford, New York, and use of the sediment/soil admixture as a growth medium for plants, in this case cucumber (*Cucumis sativus* L. cv "Wisconsin SMR 58") – a potential phytoremediation plant for PCB-contaminated matrices.

Material and methods

Materials

The Hudson River sediment samples were collected using a grab sampler from three sampling points near Waterford (WTFN6) gauge station located above the Mohawk River tributary and above Champlain Canal Lock 1. The samples were collected within a 30-m-long transect. The samples were then transported to the laboratory where they were homogenized to obtain a representative sediment sample. These sediments were used as a soil additive to prepare plant growth medium.

Vegetable potting soil and seeds of cucumber (*Cucumis sativus* L. cv "Wisconsin SMR 58") were obtained from FoxFarm Soil & Fertilizer Company (Arcata, California, USA), and from Seeds 'n Such, Graniteville, South Carolina, USA, respectively.

Pot experiment

The vegetable potting soil was mixed with fresh sediment derived from the Hudson River near Waterford at various proportions. The treatment doses were calculated based on the dry weight of soil and sediment. The sediments were used in the following proportions in relation to soil: 0% (only soil, control), 10%, 25%, 50%, 75%, and 100% (only sediments). Each treatment was prepared in six replicates in polypropylene pot (capacity: 400 cm^3). Three replicates of each treatment (0%, 10%, 25%, 50%, 75%, and 100%) were incubated in a growth chamber without plants (no plants – NP variants), whereas three replicates were planted with cucumber (*Cucumis sativus* L. cv. "Wisconsin SMR 58") (with plants – WP variants) in order to assess the influence of cucumber cultivation on the soil-sediment mixtures parameters.

The both unplanted and planted soil/sediment substrates were incubated for 4 weeks (28 days) in a growth chamber (Thermo Scientific Plant Growth Chamber 3768, Marietta, Ohio, USA) at 25 °C ± 0.5 °C with a 16-h light/8-h dark cycle.

After incubation, the soil/sediment mixtures were referred to as "growth medium."

After incubation, subsamples from both unplanted and planted variants were collected and used for analyses of physicochemical parameters and ecotoxicity tests; PCBs were analyzed only in soil and sediments used for the preparation of the growth medium, as it is described below.

Physicochemical parameters of the sediments, soil, and growth medium

Physicochemical parameters of the sediments, soil, and growth medium were determined: pH by potentiometric method (pH – meter CP - 401, ELMETRON, Poland), electrical conductivity by conductometric method (conductivity/oxygen meter CCO - 401, ELMETRON, Poland) total organic carbon (TOC), total nitrogen, and sulfur using a CNS analyzer (Vario EL Cube, Elementar Analysensysteme, Langenselbold Germany). Macroelements (P, K, Na, Mg, Ca) and trace elements (Fe, Mn, Cu, Zn, Ni, Cr, Cd) were analyzed after digestion in a mixture of $HClO_4$ (70%) and HNO_3 (65%) acids, (3:2 *v*/v) (Suprapur, MERCK, KGaA Darmstadt, Germany) and then by inductively coupled plasma optical emission spectrophotometer (Perkin Elmer ICP-OES Optima 7300 DV, Centennial, Colorado, USA) (Antonkiewicz et al. 2018). The quality of the analysis was verified based on the results of element determinations obtained on the certified reference material CRM023–050. The recoveries for metals ranged from 89 to 102%. Samples were analyzed in three replicates for which the relative standard deviations (%RSDs) were less than 10%.

The total PCB contents in soil and sediment were analyzed in freeze-dried and homogenized samples. Two grams of each sample were spiked with ^{13}C-labeled internal standard mixture (PCB-LCS-H; Wellington Laboratories Inc., Guelph, Ontario, Canada) and extracted with hexane using Accelerated Solvent Extractor (ASE 200; Dionex, Sunnyvale, California, USA) at 1500 psi, and 100 °C. The samples were purified by passage through a multilayer silica column packed with neutral and acidic silica gel and elution with hexane. The extracts were further concentrated to 500 µL under a gentle stream of nitrogen. The identification and quantification of PCB congeners were performed by Agilent Technologies 7890B GC coupled with 5977B MSD connected to a Zebron 5MS (15 m, 0.25 mm i.d., 0.10 µm film thickness; Phenomenex; Torrance, California, USA) capillary column. The GC was operated in the split-less injection mode, and selected ion monitoring (SIM) mode was used. A 12-point calibration curve with concentrations that ranged from 0.05 to 200 ng/mL was used to determine the concentration.

Ecotoxicity tests

The ecotoxicity of growth medium was assessed using the following battery of bioassays: Phytotoxkit, Ostracodtoxkit, and Microtox (see Supplementary materials Table 1). The utility of these bioassays as a convenient and accurate method in the assessment of ecotoxicity of sediments, soils, composts, biochar, and municipal sewage sludge has been reported (Baran and Tarnawski 2013; Antonkiewicz et al. 2018; Kopeć et al. 2013; Mierzwa-Hersztek et al. 2017; Mierzejewska et al. 2018). Bioassays were conducted in accordance with the standard protocol suggested by the manufacturer of the test kits (Phytotoxkit 2004; Ostracodtoxkit 2001; Microbics Corporation 1992) and described in detail in our previous studies (Baran and Tarnawski 2013; Kopeć et al. 2013).

Data analysis

The concentrations of trace elements and PCBs in the river sediment were assessed using sediment quality guideline (SQGs) values and Bojakowska's geochemical quality classes (Macdonald et al. 2000; Bojakowska 2001; Tarnawski and Baran 2018). For determining potential effects of pollutants in a complex mixture, a mean PEC quotient was used (Perrodin et al. 2006). The PECq was calculated using the following equation (Perrodin et al. 2006):

$$PEC_q = \frac{\sum \frac{C}{PEC}}{n}$$

where C, measured concentration of trace element/PCB in sediments; PEC, probable effect concentration (Macdonald et al. 2000); and n, the number of chemical compounds.

The ecotoxicity results are expressed as a percent toxic effect (PE%). The system of toxicity classification developed by Persoone et al. (2003) was used to estimate toxicity: PE < 20% no toxic sample; 20% ≤ PE < 50% low toxic sample; 50% ≤ PE <100% toxic sample, PE − 100% very high toxic sample. The germination index (GI), calculated as GI = (GsLs)/(GcLc) 100%, was used to assess the phytotoxicity of soil/sediment substrates. Gs and Ls are the seed germination and root elongation (mm) for sediment substrate, and Gc and Lc are the corresponding control (soil) (Baran and Tarnawski 2013; Szara et al. 2017).

Statistical analysis

Pearson's correlation matrix was used to explore relationships between ecotoxicological and physicochemical parameters of soil/sediment admixture. The differences between the means were analyzed by ANOVA and Tukey's test at a significance level of 0.05. Statistical analyses were preformed using STATISTICA 12.0 software.

Results and discussion

Physicochemical properties of sediments, soil, and growth medium

The physicochemical properties of soil and river sediments are shown in Table 1. The soil was slightly acidic with a pH of 5.6. The organic carbon and nitrogen contents were high, whereas potassium, phosphorus, calcium, and magnesium contents were moderate (Table 1). The sediment was alkaline (pH 7.38), with low organic carbon, nitrogen and sulfur contents and relatively high iron, magnesium, and potassium contents (Table 1). Alkaline sediment was suitable for admixture with acidic soils, to achieve optimal pH for plant growth. Moreover, pH has an important influence on the mobility of trace elements: the higher the pH, the lower the mobility of toxic metals from soils (Tarnawski et al. 2017).

Select physicochemical properties of growth medium after 4 weeks of incubation with plants (cucumber) and without plants are presented in Tables 2–5. The pH, depending on the treatment, was between 5.85 (dose of 50% sediment) to 7.22 (100% of sediment). Amendment of sediment to soil at 75% and 100% dose resulted in a significant increase in pH, which varied from 2 to 14% (NP), and from 6 to 21% (WP) relative to the controls. These results indicate buffering properties of sediment. The application of sediments appears to have a de-acidifying effect on the soil. Moreover, alkaline or neutral reaction limits the toxic effect of harmful substances on plants (Tarnawski et al. 2017). The growth medium was rich in minerals, as evidenced by high electrolytic conductivity (EC) values ranging from 0.31 to 2.2 mS (NP) and from 0.25 to 1.34 mS (WP) (Visconti and de Paz 2015). Moreover, the results showed that higher doses of sediment (50%, 75%, and 100%) significantly decreased EC (Table 2). Lower EC values observed in WP treatments in comparison to NP treatments suggest uptake of minerals by cucumber. Total organic carbon content in the growth medium ranged between 1.74 and 35.1% (Table 2). There was no significant difference in TOC, S, and N between NP and WP treatments (Table 2). However, all doses of the river sediment decreased TOC content (from 1.06- to 20-fold) relative to the control. Treatments with sediments decreased N (11 to 85%) and S (0 to 66%) content as compared to the control samples. The ratio of C:N has a direct impact on residue decomposition and nitrogen cycling, with greater decomposition occurs at lower ratios (Chen et al. 2014; Shi et al. 2017; Baran et al. 2019). In our growth medium, the C/N ratio fluctuated from 10 to 34. The addition of the highest doses (75% and 100%) of the sediment significantly reduced the C/N ratio. This means that the soil-sediment mixtures easily release N to the plants during the microbiological decomposition of organic matter. In the our previous studies was found that the C/N ratio fluctuated from 9 to 18 after application of the Rzeszow sediments bottom sediments to soil (Baran et al. 2019). In most soils, the C/N ratio lies in the range of 8:1 to 10:1, whereas a ratio > 30 is considered too high and can result in nitrogen deficiencies (Chen et al. 2014; Talgre et al. 2017).

Sediment supplementation of soil increased K, Mg, and decreased in Ca, Na, and P relative to the control, unamended soil (see Supplementary materials Tables 4 and 5). The amendment of the sediment to the soil increased macronutrients content in the growth medium, respectively, by 12–69% (K) and 11–43% (Mg) relative to the treatment without the sediment. The observed reduction in Ca, Na, and P content ranged from 1.1- to 3.0-fold (Ca); 1.0- to 1.8-fold (P), and 0.8- to 3.8-fold (Na) as compared to the control. Moreover, in the treatments with sediment, Fe, Mn, Cr, and Ni contents were significantly increased compared to the control, ranging from 12 to 78% for Fe; from 11 to 80% for Mn; from 30 to 82% for Cr; and from 9 to 84% for Ni. On the other hand, Zn, Cd, and Cu did not differ significantly. Regardless of the experiment variants (NP vs WP), a significantly higher content of the above elements was found in treatments with 100% sediment (see Supplementary materials Table 5). In the studies of Baran et al. (2019), sediment amended to the soil in doses of 30% and 50% caused a significant increase content of P, K, and Mg in growth medium relation to the control. Moreover, it was also observed that bottom sediments added to the soil significantly increased the content of Mn, Zn, Cu, and Ni and decreased the content of Cd and Pb (Baran et al. 2019). Similar results were found in our other studies focused on the agricultural application of sediments from dam reservoirs (Baran et al. 2016; Tarnawski et al. 2015). The utilization of sediments, as soil amendments/conditioners, has been suggested in several earlier studies (Canet et al. 2003; Karanam et al. 2008; Thanh et al. 2015; Tarnawski et al. 2017; Siebielec et al. 2019). The sediments, especially those with neutral or alkaline pH, a high content of silt/clay fractions or organic matter, and

Table 1 Physicochemical properties of river sediments used in this study ($n = 3$)

Material	pH	TOC	N	S	Ca	Mg	K	P	Mn	Fe
		g/kg d.m.								
Sediments	7.38	16.9	1.40	0.60	5.30	5.00	2.35	0.65	0.57	15.67
Soil	5.60	364	8.40	2.70	11.04	2.54	1.28	0.87	0.12	4.67

Table 2 Physicochemical properties of growth medium (soil/sediment mixture) after 4 weeks of incubation with cucumber (*Cucumis sativus* L. cv "Wisconsin SMR 58") (WP variant) and without plants (NP variant) ($n = 6$)

Sediment doses		pH_{KCl}	Salinity mS	TOC %	S	N	TOC/N
No plant (NP)	0%	5.75a*	1.93c	34.5e	0.47c	1.01f	34b
	10%	5.99ab	2.32d	31.0de	0.42c	0.90e	34b
	25%	5.88a	2.30d	27.1d	0.41c	0.80d	34b
	50%	6.06c	1.21b	18.0c	0.19b	0.54c	33b
	75%	6.33 cd	1.15b	10.9b	0.16b	0.37b	29b
	100%	7.13d	0.31a	1.74a	0.07a	0.15a	12a
With plant (WP)	0%	5.95a	1.32d	35.1e	0.44b	1.15e	30c
	10%	5.93a	1.34d	33.0e	0.44b	1.02e	32c
	25%	5.85 a	1.29d	27.5d	0.39b	0.89d	31bc
	50%	6.03a	0.95c	20.5c	0.17a	0.65c	32bc
	75%	6.30ab	0.72b	10.6b	0.11a	0.45b	23b
	100%	7.22b	0.25a	1.74a	0.06a	0.18a	10a

* homogenous groups according to Tukey test. $\alpha \leq 0.05$

low contents of pollutants, have been reported as useful amendments to soil (Sheehan et al. 2010). In the current study, we demonstrated that the admixture of sediment from the Hudson River near Waterford improved physical and chemical properties of soil as well as nutrient availability to plants. Moreover, the amendment of sediments may reduce the toxic effects of trace elements on plants as it was demonstrated in studies of Jasiewicz et al. (2010), Middleton and Jiang (2013), and Baran et al. (2019). It is worth to note that sediments that meet the pertinent regulatory guidelines in terms of inorganic and organic substances can be utilized for the production of vegetables for human consumption (Ebbs et al. 2006). However, as demonstrated Mattei et al. (2017), it is the over-normative concentration of inorganic and organic pollutants that is the main limiting factor for the use of sediments in land application.

Ecological risks of sediments

The sediments were classified as non-toxic if the concentrations of pollutants were below the threshold effect concentrations (TEC), whereas they were classified as toxic if the pollutants concentrations were above the probable effect concentration (PEC). The concentrations of trace elements in the river sediments were below TEC values, whereas the concentration of PCBs was between TEC and PEC (Table 3). Macdonald et al. (2000) showed that sediments with pollutant content between TEC and PEC were neither toxic nor non-toxic. According to Bojakowska's geochemical quality, the sediment analyzed was classified as class I (non-contaminated sediment). The results of ecological risk assessment of six trace elements and PCBs in river sediment are shown in Table 3. The sediments were characterized by low toxicity, and negligible risk when the mean PECq was < 0.1. If the mean PECq was > 0.5, the sediments were considered toxic, with high ecological risk. The PECq between 0.1 and 0.5 indicated medium risk, and ecotoxicity tests should be carried out on the sediment (Perrodin et al. 2006). Moreover, sediments with PECq values below 0.1 can be used without any bioassays. The sediment had a PECq of 0.21, suggesting medium/moderate risk and the need for ecotoxicological tests prior to its use as a growth medium. Similarly, higher PEC quotients were reported for trace elements and PAHs in sediments from Rybnik Reservoir (1.2–2.1) and Rzeszów Reservoir

Table 3 Concentrations of trace elements and total PCBs in river sediments used in this study ($n = 3$)

Zn	Cu	Ni	Cr	Cd	Pb	PCBs	PECq
mg/kg d.m.						µg/kg d.m.	0.21
86.0	17.8	16.6	20.7	0.46	20.7	254	
*123**	*31.6*	*22.7*	*43.3*	*0.99*	*35.8*	*59.8*	
*459***	*149*	*48.9*	*111*	*4.98*	*128*	*676*	

*TEC (threshold effect concentration), **PEC (probable effect concentration)

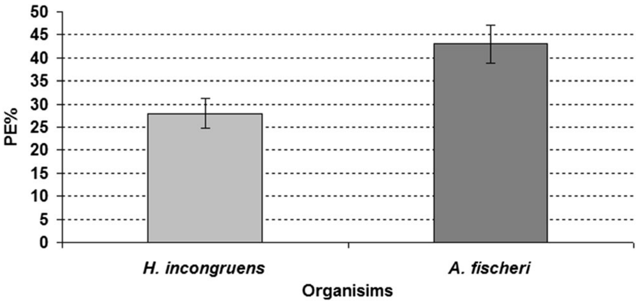

Fig. 1 Results of various ecotoxicity tests using kits in river sediments ($n = 6$)

Table 4 Ecotoxicity of growth medium (soil/sediment mixture) after 4 weeks of incubation with cucumber (*Cucumis sativus* L. cv "Wisconsin SMR 58") (WP variant) and without plants (NP variant) ($n = 6$)

Sediment doses		*H. incongruens*	*A. fischeri*	*L. sativum*	*S. alba*	*S. saccharatum*
		Response of organisms (PE%)				
No plant (NP)	0%	20b[*]	−2a	-6a	1	−10a
	10%	20b	−12a	8a	16	−29a
	25%	13ab	−20a	8a	27	−21a
	50%	6ab	−17a	6a	13	−30a
	75%	8ab	23d	10a	18	8a
	100%	-8a	10c	−22a	2	9a
With plant (WP)	0%	38c	38c	−27a	−11a	−21a
	10%	34c	35c	−28a	−1ab	−11a
	25%	21b	18b	−20a	7ab	3a
	50%	21b	8a	11a	33c	−5a
	75%	4 a	6a	1a	24bc	−10a
	100%	8 a	10a	−11a	5ab	−19a

[*] homogenous groups according to Tukey test. $\alpha \le 0.05$

(0.38–0.69) in Poland (Baran and Tarnawski 2015; Tarnawski and Baran 2018). PECq values correlated positively with the toxicity of sediments from bioassays (Baran and Tarnawski 2015).

A low toxic potential of the river sediment was found in two bioassays (Fig. 1). A higher ecotoxicity was observed in the Microtox test than in the Ostracodtoxkit test. Growth inhibition of *Heterocypris incongruens* was 28%, whereas luminescence inhibition of *Aliivibrio fischeri* was 43%. Persoone et al. (2003) showed that the toxicity PE < 20% was indicative of a lack of significant negative effect on organisms, whereas the PE in the range of 20% ≤ PE < 50% suggests less-toxic response of test organisms. Samples with PE in the range of 50% ≤ PE < 100% are considered toxic. On the basis of bioassays, the sediment analyzed in this study was classified as less-toxic. However, Dercova et al. (2008, 2009) found that PCB-contaminated sediments are a source of toxic effects on two bioindicator organisms – *Lemna minor* L. and *A. fischeri*. As shown in Table 2, the ecotoxicity of the river sediment used in this study was mainly related to the PCBs content. PCBs are remarkably stable compounds with a strong affinity for lipids and organic matter. Organic carbon is known to regulate the behavior of PCBs in the environment (Chen et al. 2012; Urbaniak 2013; Chen and Wang 2018). The interaction of organic contaminates with organic carbon plays an important role in the bioavailability and protection of organisms against toxicity caused by the excess of these contaminants. Chen and Wang (2018) found that organic carbon promoted the reduction of extractable PCBs and toxicity in sediment because PCBs bound on organic carbon were relatively immobile. Our results suggest that bioassays are required to further evaluate the utility of sediments as a substrate for plant growth.

Ecotoxicity of growth medium

The effect of soil/sediment admixture on the responses of organisms was multidirectional and varied depending on the test species, doses of sediment, and incubation conditions (Table 4). The inhibition of plant root growth was between −28 and 33%, growth inhibition of *H. incongruens* was between − 8 and 38%, and *A. fischeri* luminescence inhibition ranged from −20 to 38% (Table 4). Among the plant species, *Sinapis alba* L. appears to be most sensitive in comparison to *Lepidium sativum* L. and *Sorghum saccharatum* L. Depending on the incubation conditions, the highest toxic responses were observed for *H. incongruens* (PE: 4–38%) and *A. fischeri* (PE: 8–38%) in the WP (with plant) treatments. Similarly, stimulation of root growth was observed for *L. sativum* and *S. saccharatum,* in medium gown with plants. In NP (no plant) treatments, higher sensitivity was found for *S. alba* (PE: 1–27%) and *H. incongruens* (PE: −8–20%) followed by bacteria (PE: −20–23%), *L. sativum* (PE: −22–10%), and *S. saccharatum* (PE: −29%–9%). Regardless of the incubation conditions (with or without plant), sediment amendment with soil decreased toxicity for *H. incongruens* by 1.2- (10% of sediment) to 9.5-fold (100% of sediment) in comparison to the control treatment (0% of sediment). A reduction in toxicity of the growth medium was also observed for *A. fischeri* (from 0.8- to 4.6-fold) but only in those WP treatments (Table 4). However, higher doses of sediment (50%, 75%, and 100%) significantly increased the toxicity for *A. fischeri* (NP variants) and *S. alba* (WP variants) compared to the control group. *S saccharatum* showed a higher inhibition of root growth with 75% and 100% admixture of sediment; however, these differences were not statistically significant.

In general, the growth medium, composed of vegetable potting soil and the river sediment, was classified as non-

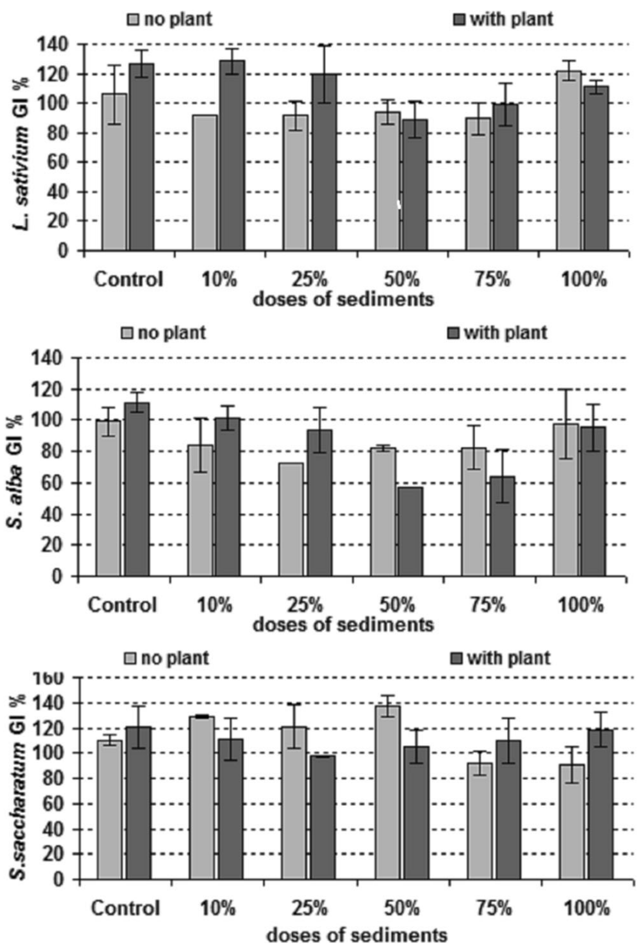

Fig. 2 Germination index of plants at various doses of bottom sediments ($n = 6$)

toxic or less-toxic to test organisms (Table 4). Oleszczuk (2008) indicated that solid waste exhibiting low toxicity toward *H. incongruens* can be used in the reclamation of degraded areas for non-agricultural purposes. The Ostracodtoxkit test is often used in the toxicity assessment of solid medium (soils, sewage sludge, composts, bottom sediments, and biochars). An advantage of this test is the direct contact of the medium with the test organism, to determine total toxicity. It is worth noting that *H. incongruens* showed the most toxic response in comparison to other organisms.

The germination index (GI) was used to assess the phytotoxicity of soil/sediment substrates (Fig. 2). Germination index values < 90% means growth inhibition, GI values > 110% means growth stimulation, and GI between 90 and 110% means no effect (Baran and Tarnawski 2013; Szara et al. 2017). Regardless of the incubation conditions, the lowest values of GI were observed for *S. alba* and the highest for *S. saccharatum*. The GI values were in the range from 56% to 111% for *S. alba*, from 89% to 129% for *L sativum*, and from 91% to 137% for *S. saccharatum* (Fig. 1). The lowest GI values were observed with 50% and 75% bottom sediment (WP treatments). For *S. alba* and *L. sativum*, the GI indicated the dominance of inhibitory effect on plant growth, whereas for the monocotyledonous plant *S. saccharatum*, the GI value showed the stimulatory effect on plant germination. These results are different from those of Mamindy-Pajany et al. (2011); Baran and Tarnawski (2013), and Szara et al. (2017) who reported that *S. saccharatum* was the most sensitive species in identifying phytotoxicity of sediment samples over *L. sativum* and *S. alba.* In the studies of Urbaniak et al. (2016) and Oleszczuk and Hollert (2011), *L. sativum* was the most sensitive and suitable test plant for the assessment of phytotoxicity of soil and sediments.

Correlation analysis

Correlation between physicochemical parameters of the growth medium and ecotoxicity analysis was examined (Table 5). The highest number of significant correlations was found between the growth inhibition of *H. incongruens* and

Table 5 Relationships between physicochemical composition of growth medium (soil/sediment mixture) and response of organisms from bioassays

Parameter	*H. incongruens*	*A. fischeri*	*L. sativum*	*S. alba*	*S. saccharatum*
V.fischeri	0.468*				
L. sativum	− 0.341	− 0.687*			
S. alba	− 0.281	− 0.486	0.823*		
S. saccharatum	− 0.291	0.456	− 0.213	0.035	
pH	− 0.571	0.209	− 0.364	− 0.303	0.355
Salinity	0.832*	0.374	− 0.387	− 0.220	− 0.114
TOC	0.801*	− 0.011	− 0.107	− 0.215	− 0.425
Zn	− 0.753*	− 0.252	0.097	0.268	0.402
Cu	0.649*	0.388	− 0.376	− 0.235	0.161
Ni	− 0.845*	− 0.074	0.130	0.173	0.389
Cr	− 0.885*	− 0.194	0.277	0.220	0.372
Cd	0.431*	− 0.183	− 0.120	− 0.300	− 0.155

*significant at $p \leq 0.05$

salinity, TOC content, and trace elements. Generally, positive correlation indicates a relation between the physicochemical composition and ecotoxicity to organisms; negative values indicate that the sample parameters did not affect the toxicity. A positive correlation was found for TOC, Cu, and Cd, whereas a negative one was found for Zn, Cr, and Ni content and response of *H. incongruence*. Moreover, a significant positive correlation was observed between *A. fischeri* and *H. incongruens* and *L. sativum and S. alba*, suggesting a similar sensitivity to substances in the growth medium. The results of significant correlations for *H. incongruens* confirm its high sensitivity. Therefore, *H. incongruens* is a useful bioassay for assessing the quality of wastes/materials used in agriculture.

Conclusions

The sediment derived from the Hudson River near Waterford improved the pH and reduced the salinity of the growth medium. This sediment contained nutrients, including macro- (K, Mg) and microelements (Fe, Mn). Apart from beneficial nutrients and organic matter, the sediment contained toxic metals and organic pollutants (PCBs), which can have a negative impact on the soil/land environment. Therefore, the environmental use of sediment with different chemical properties is the reason why the assessment of its ecotoxicity is important. We observed a reduced ecotoxicity of the growth medium compared to the ecotoxicity of the sediment. The average decline in PE% for *H. incongruens* and *A. fischeri* reached 55% and 86% in relation to the sediment. We assumed that the reduced ecotoxicity was related to a high organic carbon content of the growth medium.

Based on both the physicochemical and ecotoxicological analysis, the sediment coming from a relatively cleaner location within the Hudson River can be considered as a suitable growth medium. However, as this sediment was taken from a small section of the river that contained low PCB concentrations, it cannot reflect the pollution status of the entire Hudson River sediments. It should be noted that PCBs present in these sediments can pose potential ecological risk when used on lands; thus further, detailed research in this field are needed.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict(s) of interest.

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