Journal of Elementology ISSN 1644-2296

Rutkowska, B., Kazberuk, W. and Szulc, W. (2023)
'Recycling dredged sediments to agriculture:
effects on acidic sandy soil properties',
Journal of Elementology, 28(4), 1273-1287,
available: https://doi.org/10.5601/jelem.2023.28.4.3181

RECEIVED: 28 October 2023
ACCEPTED: 28 December 2023

ORIGINAL PAPER

Recycling dredged sediments in agriculture: effects on acidic sandy soil properties

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Abstract

Bottom sediments excavated from rivers and water bodies are commonly treated as waste and stored on waste dumps or open ocean disposal sites. However, the fine-grained bottom sediments containing substantial amounts of organic matter and macro- and microelements, characterised by neutral or alkaline reaction, can have a positive effect on the soil properties. The study objective was to assess the effect of the application of bottom sediments of various origin on physical and chemical properties of acidic sandy soil. A pot experiment with increasing amounts, such as 1%, 5%, 10%, and 20% m/m, of three different bottom sediments: (i) sediment from a large lowland river – the Vistula River, (ii) sediment from the vicinity of a dam on a small lowland river – the Łupia River and (iii) sediment from a fishpond, was conducted on Haplic Luvisol soil. The plant grown in the experiment was white mustard. After harvesting the plants, the basic soil physicochemical properties were determined. The study shows that bottom sediments can be used in agriculture for the improvement of soil quality, although their effect on the soil depends on their origin and physicochemical properties. All the analysed bottom sediments increased soil pH, and decreased the hydrolytic acidity and content of exchangeable aluminium in the soil. They also improved the sorption properties of the soil. The effect of the analysed sediments on remaining soil properties depended on their origin. Only sediment from the pond had a universally positive effect on sandy soil causing an increase in the loam and silt fraction, water holding capacity, concentration available P, K, and Mg, as well as Corg, Ntot, and Stot in the soil. The bottom sediment from the Vistula is characterised by low usefulness in terms of agricultural application for the improvement of the properties of sandy soils, and should be managed otherwise, e.g. in non-agricultural land reclamation or in construction.

Keywords: dredged sediment, sediment reuse, soil properties, nutrients

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INTRODUCTION

Bottom sediments are an integral part of the water environment. Excessive accumulation of bottom sediments in rivers and water bodies results in a decrease in their depth and retention volume, makes navigation difficult, and disturbs the functioning of water ecosystems (Renella 2021). Therefore, measures are taken systematically, involving the deepening of water bodies and removal of the accumulated bottom sediments. Such practices entail production of high amounts of excavated sediments, reaching approximately 300 million m^3 annually in Europe alone. The excavated sediments are commonly treated as waste and stored on waste dumps or open ocean disposal sites (Bose, Dhar 2022, Crocetti et al. 2022). The physical properties and chemical composition of bottom sediments are affected by all natural and anthropogenic processes occurring directly in the water environment as well as throughout the catchment area (Luvai et al. 2022). They are usually fine-grained or even extremely fine-grained materials mostly comprising fine sands, silt, and clay particles. Due to this they have the capacity for retaining organic and inorganic, natural and anthropogenic substances (Ferrans et al. 2001, Tomczyk-Wydrych, Świercz 2021). The decision on how bottom sediments are to be handled should be preceded by a detailed analysis of their physicochemical properties, and particularly the determination of the concentration of toxic substances (Ferrans et al. 2019, 2022, Koniarz et al. 2022, Luvai et al. 2022, Szara-Bąk et al. 2023). Bottom sediments are broadly used in various sectors of the economy, such as: construction, energy engineering, civil engineering, agriculture and horticulture, and reclamation of degraded land (Canet et al. 2003, Renella 2021, Bose, Dhar 2022, Gmitrowicz-Iwan et al. 2023).

Fine-grained bottom sediments containing substantial amounts of organic matter and macro- and microelements necessary for plants, characterised by neutral or alkaline reaction, have a positive effect on the soil structure. Their sorption properties can therefore be employed for the improvement of the physicochemical properties of soils, particularly acidic sandy soils, by increasing their fertility (Canet et al. 2003, Tarnawski et al. 2015, Baran et al. 2019, Koniarz et al. 2022, Gmitowicz-Iwan et al. 2023).

One of the problems limiting the possibilities of environmental use of bottom sediments is the presence of toxic substances that they may contain, such as heavy metals, polycyclic aromatic hydrocarbons, or polychlorinated biphenyls (Mattei et al. 2016, Ferrans 2019, 2022, Koniarz et al. 2022, Sojka et al. 2023). According to many authors, however, the application of bottom sediments poses no environmental threat, either for the soil or for cultivated plants (Canet et al. 2003, Tarnawski et al. 2015, Baran et al. 2019, Kazberuk et al. 2021, Szara-Bąk et al. 2023). It therefore appears that the agricultural application of contaminated bottom sediments is the best way of their use.

The objective of the paper was to make an assessment of the effect of application of bottom sediments of various origins (sediment from a large lowland river, sediment from a small lowland river, sediment from a fishpond) on changes in physical and chemical properties of acidic sandy soil.

MATERIALS AND METHODS

A pot experiment was conducted in 2018-2019, in a greenhouse of the Experimental Station of the Institute of Agriculture of the Warsaw University of Life Sciences in Skierniewice (51°57′52.9″N 20°10′05.5″ E). Pots were filled with a volume of 10 kg of dry mass of soil. The experiment was established on soil of the Haplic Luvisol type (IUSS Working Group WRB 2015) with the grain composition of weakly loamy sand, supplemented once (in 2018) with increasing amounts corresponding to 1%, 5%, 10%, and 20% m/m of three different bottom sediments:

1) sediment from a large lowland river, the Vistula River, sampled in the territory of Warsaw (N 52°12’38.16″ E 21°5’35.879″),
2) sediment collected from the vicinity of a dam on a small lowland river, the Łupia River, sampled in Skierniewice (N 51°51′50.868″ E 20°07′32.102″),
3) sediment from a fishpond (Experimental Station of the Warsaw University of Life Sciences in Żelazna N 51°51′838″ E 20°07′176″).

Control was an object with no bottom sediments applied. The experiment involved no mineral fertilisation. The plant cultivated in the experiment was white mustard (*Sinapis alba*). During the experiment, the pots were watered with redistilled water up to 60% of full water capacity of the soil. The experiment was conducted in three repetitions, and covered 39 pots.

Before the establishment of the experiment, soil and bottom sediment samples were collected to determine their physicochemical properties. Soil and bottom sediment samples were dried at room temperature and sieved through 2 mm mesh. The grain fractions were determined in accordance with the aerometric Cassagrande method modified by (PN-ISO-11277:2005). The following fractions were determined: sand (0.05-2.0 mm), silt (0.002-0.05 mm), and loam (<0.002 mm). Moreover, soil and bottom sediment samples were subject to pH determination after extraction in 1 mol dm^{-3} KCl, soil:solution ratio 1:2.5, (ISO 10390:2005), organic carbon content (Corg), total nitrogen (Ntot), and total sulphur (Stot) with the application of a Vario Macro Cube CHNS elemental analyser (Elementar, Germany). The contents of bioavailable forms of phosphorus and potassium were determined by the Egner-Riehm DL method (PN-R-04023:1996, PN-R-04022:1996+Az1:2002), and magnesium by the Schachtschabel method (PN-R-04020:1994+Az1:2004). Properties of the soil and bottom sediments before the establishment of the experiment are presented in Table 1.

Table 1

Soil and bottom sediments properties

Specification	Unit	soil	Bottom sediment river	dam	pond
Sand (0.05–2.0 mm)	(%)	72	90	86	65
Silt (0.002–0.05 mm)		21	6	10	28
Clay (<0.002 mm)		7	4	4	7
pH	–	5.210	7.620	6.600	6.370
Corg	($g\ kg^{-1}$)	7.200	2.700	4.400	15.60
Ntot		0.700	0.300	0.400	1.400
Stot		0.021	0.009	0.032	0.083
P	($mg\ kg^{-1}$)	39.21	2.270	21.05	32.63
K		72.11	230.0	350.9	2095.4
Mg		49.41	130.2	212.8	411.6

After harvesting mustard plants from all pots, soil was sampled for analyses. After drying and sieving the samples through 2 mm mesh, the following was determined: pH, Corg, Ntot, Stot (the analyses enabled the determination of the C/N and C/S ratio), and the content of bioavailable forms of P, K, and Mg by means of the same methods as in the case of soil and sediment samples analysed prior to the experiment. The following was also determined in the soil: water holding capacity (WHC) using the Büchner funnel method (Veihmeyer, Hendrickson 1949) with some modifications (Koide et al. 2015, Amin 2023), hydrolytic acidity (HA) by means of the Kappen method, content of exchangeable aluminium (Al^{3+}) after extraction in 1 mol dm^{-3} KCl at a ratio of 1:10, content of base exchangeable cations Ca^{2+}, Mg^{2+}, K^+, Na^+ after extraction in 1 mol dm^{-3} ammonium acetate (NH_4OAc) at pH 7. Then, the following were calculated: sum of base cations (TEB), cation exchange capacity (CEC), and degree of saturation of the sorptive complex with base cations (BS).

For the evaluation of the effect of bottom sediments on the analysed soil properties, multi-way analysis of variance (ANOVA) was applied at a significance level $p \leq 0.05$, with the use of Statistica ver. 13.3 software (TIBCO, Software INC., Palo Alto, USA). The factors examined in the experiment were: 1) type of bottom sediment (river sediment, dam sediment, and pond sediment), and 2) bottom sediment dose (1%, 5%, 10%, and 20% w/w). The assessment of the significance of differences between mean values and determination of homogenous subsets employed the Tukey's test.

RESULTS AND DISCUSSION

The effect of bottom sediments on soil properties depends on their origin, physical and chemical properties, and dose of sediment, as well as on the properties of the soil itself (Tozzi et al. 2019, Birgham et al. 2020, Kiani et al. 2021, Ferrans et al. 2022, Koniarz et al. 2022, Szara-Bąk et al. 2023). Fertilisation with sediment from the Vistula River and the dam resulted in an increase in the content of the sand fraction in the soil in comparison to control (Figure 1).

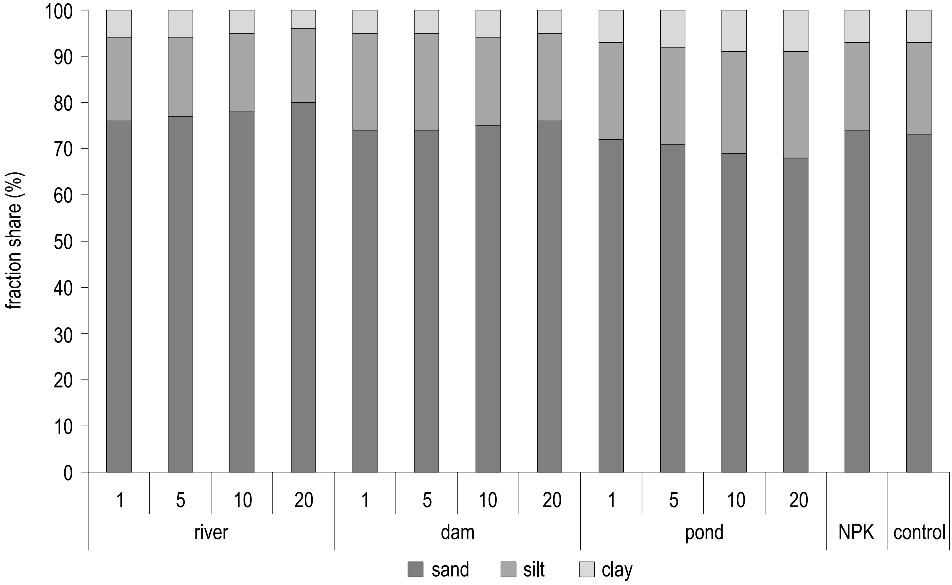

Fig. 1. Content of different fractions in the soil after bottom sediment application

The content of the sand fraction increased with an increase in the dose of bottom sediment from the Vistula River by 6-11%, and by 3-6% after the application of sediment from the dam. Simultaneously, the use of increasing doses of these sediments caused a decrease in the content of the silt and loam fraction in the soil. The application of sediment from the pond led to an increase in the content of the silt (by 5-10%) and loam fraction (14-29%) in the soil. Gmitrowicz-Iwan et al. (2023) also evidenced that bottom sediments can be used for the improvement of the grain size composition of sandy soils. The authors observed that an increase in the dose of bottom sediment applied on sandy soil was accompanied by an increase in the content of silt in the substrate and a decrease in the content of sand. Similar research was conducted by Fonseca et al. (2003). They emphasise that the application of bottom sediments is particularly recommended on light and sandy soils. The application of sediments on these soils causes an increase in the content of the silt and loam fractions, consequently increasing their fertility. Excessive doses of sediments with a high content of silt (60-70%) and loam (10-20%) and low content of sand (10-20%) may worsen the air-water relations in the soil. On soils with a considerable content of the silt fraction, bottom sediments should also be used with caution due to the possibility of worsening their physical properties (Ferrans et al. 2022).

A positive effect of the application of bottom sediments on the grain size composition of sandy soils is also manifested by some favourable changes in the remaining soil properties, including the water retention capacity of the soil (Canet et al. 2003, Gmitrowicz-Iwan et al. 2023). Depending on the properties and dose of the studied sediments, their application caused various changes in the water capacity of the soil (Figure 2).

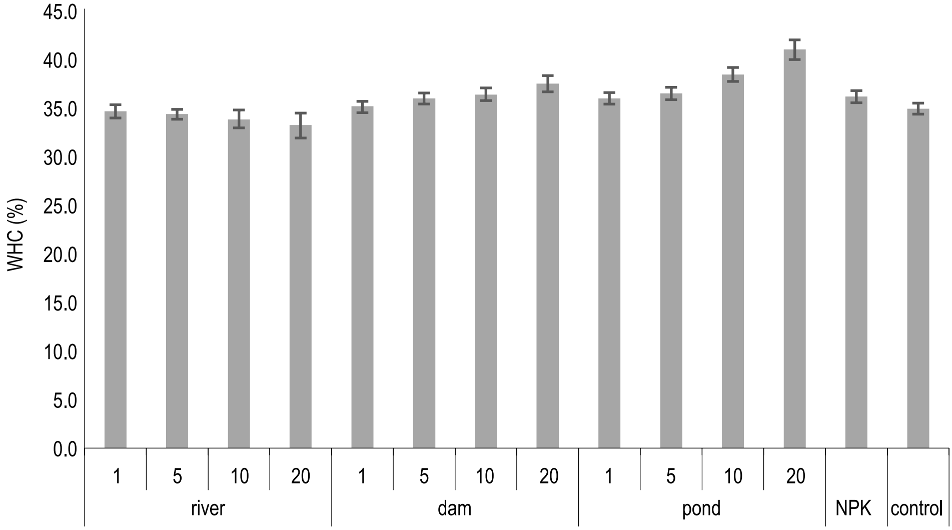

Fig. 2. Water holding capacity (WHC) of the soil after bottom sediments application; error bars – standard deviation (SD)

Sediment from the Vistula River containing the highest share of sand (90%) contributed to a decrease in the water capacity of the soil from approximately 1% to approximately 5% in comparison to the control object. The application of sediment from the dam and the pond increased the water holding capacity of the soil by 0.7 to 7.5% and 3.1-17.5%, respectively, in comparison to the control object. An increase in the dose of the analysed sediments caused an increase in the water holding capacity of the soil. A significant increase in the water retention capacity of loamy sand soil due to an increase in the doses of bottom sediments was evidenced by Canet et al. (2003).

Studies by other authors also show that the effect of bottom sediments on water retention capacity can be variable. Ferrans et al. (2022), assessing a mixture of compost from green waste and bottom sediments from the

Malmfjärden Bay, Sweden, as substrate for the cultivation of lettuce (*Lactuca sativa*), determined that an increase in the amount of sediment in the mixture causes an increase in water holding capacity, which was related to an increase in the content of fine particles in the substrate. At a 70% share of bottom sediment, the water holding capacity was higher by 60% in comparison to compost alone. Tozzi et al. (2019), investigating the usefulness of port bottom sediments as substrate for the cultivation of vegetables, evidenced that an addition of bottom sediment characterised by sandy loam (56% sand, 25% silt, 19% clay) to peat-based medium texture (1:1 v/v) resulted in a considerable decrease in the water holding capacity of the substrate. The amount of easily available water was lower by more than 30% in comparison to the control object (peat-based medium).

The analysed bottom sediments were characterised by a higher share of potassium and magnesium than the soil on which the experiment was conducted (Table 1). Therefore, in the conditions of their application, a significant increase in the content of bioavailable forms of those elements in the soil was observed in comparison to the control object (Figure 3).

Depending on the type and dose of the bottom sediment, the content of bioavailable potassium in the soil after the application of sediment from the river and dam reached from 30 to 60%, and it was 40-80% higher than in the control object following the application of sediment from the pond. The content of bioavailable magnesium in the soil after the application of sediment from the river increased in comparison to the control object by 12-44%, and in the case of sediment from the dam – by 37-76%. In objects fertilised with sediment from the pond, the content of bioavailable magnesium in the soil was 1.7-2.8-fold higher than in control.

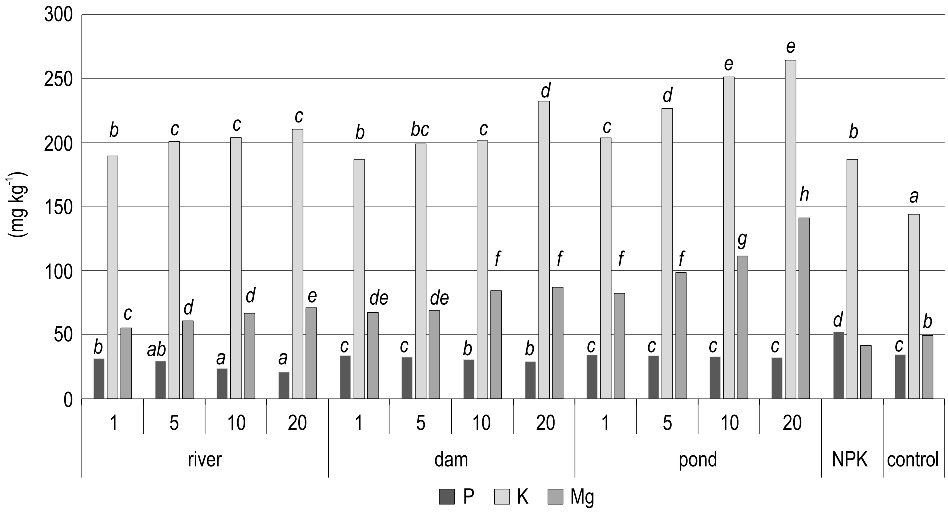

Fig. 3. Content of available forms of phosphorus, potassium and magnesium in soil after the application of bottom sediments; *a*, *b*, *c*... – values marked with the same letters are not significantly different

The content of phosphorus in sediment from the Vistula and from the dam was lower, and in sediment from the pond it was comparable to the content in the soil. Therefore, the application of sediment from the pond and lower doses (1% and 5%) of sediment from the dam did not contribute to changes in the content of bioavailable phosphorus in the soil. The application of sediment from the Vistula and from the dam in doses of 10% and 20% caused a significant decrease in the content of bioavailable phosphorus in the soil in comparison to control (Figure 3).

Bottom sediments can be a source of macro- and microelements easily available to plants. Therefore, their application in agriculture can have a positive effect on soil fertility (Renella 2021). According to studies by various authors, however, the content of these elements in sediments depends on their origin. Gmitrowicz-Iwan et al. (2023), analysing the effect of the application of bottom sediment from a dam reservoir, evidenced a significant increase in the content of bioavailable forms of P, K, and Mg in the soil. Koniarz et al. (2022), also investigating the possibilities of agricultural use of bottom sediments from another dam reservoir, observed a decrease in the content of bioavailable phosphorus and potassium in the soil with an increase in the dose of bottom sediment. According to Urbaniak et al. (2020), the application of bottom sediment from a river resulted in discrepancies similar to those in our research. They determined a double decrease in the content of phosphorus and a significant increase in the content of potassium in the soil. Kiani et al. (2021, 2023) documented that sediments removed from eutrophic lakes are rich in phosphorus compounds, and their application leads to an even three-fold increase in the content of the element in the soil in comparison to control. The same authors also observed a double decrease in the content of potassium, and a double increase in the content of magnesium in the soil.

The effect of the analysed sediments on the content of carbon, nitrogen, and sulphur in the soil depended both on the type of sediment and its dose (Table 2).

The application of sediment from the pond had the most positive effect on the content of these elements in the soil, while sediment from the Vistula produced the most negative outcome. The application of sediment from the Vistula, the poorest in terms of content of the analysed element, resulted in a decrease in the content of Corg by an average of 9%, Ntot by an average of 30%, and Stot by an average of 50% in the soil in comparison to the control object. Similar dependencies were observed in changes in the content of Corg and Ntot in the soil following the application of sediment from the dam.

The content of Corg decreased by an average of 2.5%, and Ntot by 14%. The content of sulphur did not change in comparison to the control object. An increase in the dose of these sediments caused a decrease in the content of nitrogen in the soil, and the content of sulphur remained unchanged.

Table 2

Effect of bottom sediments on organic carbon (Corg), total nitrogen (Ntot), total sulphur (Stot), C/N and C/S ratio in soil

Bottom sediment	Dose (%)	Corg	Ntot	Stot	C/N	C/S
		(g kg^{-1})			-	-
River	1	0.690*b*	0.060*c*	0.010*a*	11.50*a*	69.00*e*
	5	0.670*b*	0.050*b*	0.010*a*	13.40*a*	67.00*e*
	10	0.650*ab*	0.050*b*	0.010*a*	13.00*a*	65.00*e*
	20	0.610*a*	0.030*a*	0.010*a*	20.33*a*	61.00*d*
	mean	**0.665*A***	**0.048*A***	**0.010*A***	**14.56*C***	**65.50*C***
Dam	1	0.720*b*	0.070*c*	0.010*a*	10.29*a*	72.00*e*
	5	0.710*b*	0.060*c*	0.020*b*	11.83*a*	35.50*b*
	10	0.700*b*	0.060*c*	0.020*b*	11.67*b*	35.00*c*
	20	0.680*b*	0.050*b*	0.030*c*	13.60*a*	22.67*b*
	mean	**0.703*A***	**0.060*B***	**0.020*B***	**11.85*B***	**41.29*B***
Pond	1	0.850*c*	0.090*d*	0.020*b*	9.440*b*	42.50*c*
	5	1.070*d*	0.110*ef*	0.060*d*	9.730*b*	17.83*a*
	10	1.470*e*	0.140*f*	0.120*e*	10.50*c*	12.25*a*
	20	2.160*f*	0.190*g*	0.200*f*	11.37*a*	10.80*a*
	mean	**1.388*C***	**0.133*D***	**0.100*D***	**10.26*A***	**20.85*A***
NPK	–	**0.750*B***	**0.080*C***	**0.040*C***	**9.38*A***	**18.75*A***
Control	–	**0.720*B***	**0.070*B***	**0.020*B***	**10.29*A***	**36.00*B***

a, *b*, *c*... – lowercase letters indicate values when comparing doses of individual bottom sediments, *A*, *B*, *C*... – uppercase letters indicate the values when comparing the averages for individual types of bottom sediments, values marked with the same letters are not significantly different

Similar dependencies were evidenced by Koniarz et al. (2022). According to the authors, an increase in the dose of bottom sediment from the central part of a dam reservoir resulted in a decrease in the content of TOC (total organic carbon) from 3 to 63% in comparison to control, and the content of nitrogen decreased by 5-68%. Unlike the results obtained in our research, however, the content of sulphur in the soil after the application of bottom sediment significantly increased with its dose (Koniarz et al. 2022). Urbaniak et al. (2020) also observed a decrease in the TOC content in the soil caused by the application of sediment from the Hudson River.

As a result of the application of sediment from the pond that contained twice as much Corg and Ntot as the soil, and four times more Stot, while the content of organic carbon, total nitrogen, and total sulphur in the soil significantly increased in comparison to the control object. A significant increase in the content of C, N, and S in the soil was also observed with an increase in the dose of the sediment. These dependencies are confirmed by many authors (Brigham et al. 2021, Kiani et al. 2021, Ferrans et al. 2022, Tarnawski et al. 2022, Gmitrowicz-Iwan et al. 2023, Kiani et al. 2023, Szara-Bąk et al. 2023).

Irrespective of the type and dose of the applied bottom sediment, a narrow value of the carbon to nitrogen ratio below 20:1 and carbon to sulphur below 200:1 points to the prevalence of processes of organic matter mineralisation in the soil, which increases the bioavailability of nutrients, particularly N and S, for plants (Brust 2019).

The analysed bottom sediments were characterised by reaction varying from slightly acidic (sediment from the pond), through neutral (sediment from the dam), to alkaline (sediment from the Vistula). Therefore, their application in the soil with acidic reaction (pH = 5.21) had a positive effect on the soil acidification indices, manifested in a significant increase in pH values and a decrease in the content of exchangeable aluminium in the soil in comparison to the control object (Table 3). Baran et al. (2019) also showed that irrespective of the dose of the bottom sediment, the pH value of the soil

Table 3

Soil pH and sorption properties of the soil after bottom sediments application

Bottom sediment	Dose (%)	pH	Al^{3+}	HA	TEB	CEC	BS
		–	(cmol(+) kg^{-1})				(%)
River	1	5.390*a*	0.485*c*	2.591*b*	2.114*a*	4.706*b*	44.89*a*
	5	5.420*a*	0.451*c*	2.463*a*	2.161*a*	4.623*b*	46.75*a*
	10	5.640*a*	0.385*a*	2.390*a*	2.173*a*	4.565*a*	47.59*a*
	20	6.050*b*	0.402*b*	2.235*a*	2.210*a*	4.447*a*	49.77*a*
	mean	**5.625*B***	**0.431*A***	**2.420*A***	**2.165*B***	**4.587*A***	**47.25*B***
Dam	1	5.320*a*	0.452*c*	2.603*b*	2.142*a*	4.744*a*	45.15*a*
	5	5.410*a*	0.433*b*	2.751*b*	2.244*a*	4.990*b*	44.89*a*
	10	5.760*a*	0.370*a*	2.236*a*	2.263*a*	4.491*a*	50.33*a*
	20	6.120*b*	0.391*b*	2.352*a*	2.321*a*	4.675*a*	49.68*a*
	mean	**5.653*B***	**0.411*A***	**2.486*A***	**2.243*B***	**4.725*A***	**47.51*B***
Pond	1	5.36*a*	0.490*c*	2.561*b*	2.335*a*	4.893*b*	47.65*a*
	5	5.41*a*	0.415*b*	2.416*a*	2.341*a*	4.754*a*	49.26*a*
	10	5.67*a*	0.352*a*	2.612*b*	2.451*b*	5.061*b*	48.42*a*
	20	6.02*b*	0.331*a*	2.380*a*	2.740*c*	5.120*b*	53.52*b*
	mean	**5.615*B***	**0.397*A***	**2.492*A***	**2.467*C***	**4.957*A***	**49.71*B***
Control	–	5.190*A*	0.522*B*	2.651*A*	1.823*A*	4.472*A*	40.72*A*

Al^{3+} – exchangeable aluminium, HA – hydrolytic acidity, TEB – total exchangeable bases, CEC – cation exchange capacity, BS – base saturation,
a, *b*, *c* – lowercase letters indicate values when comparing doses of individual bottom sediments, *A*, *B*, *C* – uppercase letters indicate the values when comparing the averages for individual types of bottom sediments; values marked with the same letters are not significantly different

significantly increases in comparison to the non-fertilised object. Szara-Bąk et al. (2023), investigating the effect of mixtures of bottom sediment with waste material, evidenced that an addition of mixtures based on bottom sediments had a deacidifying effect on the soil, irrespective of the type or dose of the mixture. Research by other authors also points to the deacidifying effect of bottom sediments and their mixtures with other wastes (Tarnawski et al. 2015, Tozzi et al. 2019, Martínez-Nicolas et al. 2020, Urbaniak et al. 2020, Brighman et al. 2021, Ferrans et al. 2022).

Koniarz et al. (2022), who analysed the effect of bottom sediment from Chechło Reservoir, evidenced acidic reaction of the analysed sediment (pH = 5.38-5.52), with no significant effect on an increase in soil pH. Kiani et al. (2021) showed that the application of bottom sediment from a shallow eutrophicated lake decreased soil pH. In the conducted study, the content of exchangeable aluminium in the soil decreased from 17% after the application of sediment from the river to 23% in following the application of sediment from the pond in comparison to the control object. The content of Al^{3+} in the soil decreased with an increase in the dose of the analysed bottom sediments (Table 3). The positive effect of the application of bottom sediments on a decrease in the content of exchangeable aluminium in the soil was demonstrated in earlier research conducted by Kazberuk and Rutkowska (2019). They showed that after the application of bottom sediment from a fishpond on soil with pH < 4.5, the content of Al^{3+} in the soil decreased even eight times in comparison to the control object. Bottom sediments are characterised by high content of organic carbon, and organic matter is commonly known to have the ability to limit the activity of exchangeable aluminium in the soil through its transformation to forms with lower mobility, e.g. organically bound Al and other non-crystalline fractions (Vieira et al. 2008, Li et al. 2022).

The analysed sediments also had a positive effect on the sorption properties of the soil by causing a significant increase in the value of total exchangeable bases in comparison to control, reaching from 19% after the application of sediment from the pond to 36% following the application of sediment from the river, and by improving base saturation (from 16 to 22%). Depending on the type of sediment, the hydrolytic acidity value decreased from 6 to 9%, and the CEC value increased by 2.5-11% in comparison to control. According to Koniarz et al. (2022), the effect of bottom sediments on the sorption capacity of the soil depends on their grain size composition, content of organic matter, and acidity. This is confirmed in the our research, where sediment from the pond, characterised by the highest content of silt fraction and organic carbon among the analysed sediments, had the best effect on the sorption capacity of the soil at comparable pH values.

CONCLUSIONS

The study shows that bottom sediments can be used in agriculture for the improvement of soil quality, although their effect on the soil depends on their origin and physicochemical properties.

All the analysed bottom sediments showed a positive effect on the soil acidification indices by increasing its pH, and decreasing the hydrolytic acidity value and content of exchangeable aluminium in the soil. They also improved the sorption properties of the soil. In view of these results, it appears justified to use such sediments, particularly on acidified soils with a small capacity of the sorption complex.

The effect of the analysed sediments on remaining soil properties depended on their origin. Only sediment from the pond had a universally positive effect on sandy soil with low content of organic matter and nutrients, causing an increase in the loam and silt fraction, and an increase in the water holding capacity of the soil, its abundance in bioavailable forms of P, K, and Mg, as well as an increase in the content of Corg, Ntot, and Stot in the soil.

The application of sediment from the river and dam led to worsening the grain size composition through an increase in the sand fraction in the soil, as well as a decrease in the water holding capacity of the soil and content of bioavailable P, Corg, Ntot, and Stot in the soil.

The results show that bottom sediment from the Vistula River is characterised by low agricultural usefulness for the improvement of properties of sandy soils, and should be managed in another way, e.g. in non-agricultural land reclamation or in construction. Sediment from the dam, owing to its physical and chemical properties, could become an agriculturally useful soil substrate.

Author contributions

B.R., W.S. – conceptualization, B.R., W.S. – formal analysis, B.R., W.S., W.K. – methodology, W.K. – investigation, B.R. – visualization, B.R., W.S., W.K. – writing-original draft preparation, B.R. – writing-review and editing. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declare no conflict of interest. The authors ensure that they have neither professional nor financial connections related to the manuscript sent to the Editorial Board

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