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Extraction and application of bottom sediments in a closed cycle

Kamila Mazur ✉, Andrzej Eymontt, Krzysztof Wierzbicki

Institute of Technology and Life Sciences – National Research Institute, Falenty, Hrabska Av. 3, 05-090 Raszyn, Poland

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Abstract: Human activities in relation to aquatic ecosystems result in significant economic losses in the form of contamination of water sources, deteriorating its quality and therefore its availability in lakes, water bodies and even in soil. Hence the need for systematic revitalisation or reclamation of water ecosystems. Such actions, in order to be rational, require a detailed understanding of the causes, and then the use of appropriate technology. The need for the above-mentioned actions result from the weather changes that have been noticeable in recent years, as well as environmental pollutants increasing water eutrophication in reservoirs and stimulating the development of some species of cyanobacteria. These cyanobacteria can cause serious water poisoning, especially in water supply systems. Therefore, a rational, comprehensive technology for the removal of bottom sediments and their processing into organic and mineral fertiliser has been developed with properties similar to manure. It also creates opportunities to improve the structure of soils thanks to the supply of organic carbon, the loss of which was found, among others, in also in soils of Poland and EU. These new possibilities of revitalisation hitherto unknown make it possible to a large extent, compliance with environmental requirements when revitalising water reservoirs and soil.

Keywords: circular economy, cyanobacterial toxins, fishponds, organic fertiliser, prevention of water eutrophication, sediments

INTRODUCTION

Bottom sediments are sedimentary material excavated from the bottom of rivers and water bodies. The material suspended in water sediments, resulting in the formation of sedimentary matter. It is a natural part of the aquatic ecosystem containing both organic and inorganic, natural and anthropogenic substances. Excessive accumulation of bottom sediments contributes to a reduction in volume and depth, limiting the usability of water bodies. Due to the rapid rate of accumulation of excess bottom sediment, especially in small water bodies, it should be periodically removed [Maj, Koszelnik 2016].

The Water Framework Directive (Directive 2000/60/EC) obliges all Member States to take measures to protect inland surface waters, transitional waters, coastal waters and groundwater.

It aims to achieve by 2015, and where justified by 2021 or 2027, good status for water and water-dependent ecosystems. In Poland, latest Water Act Law was introduced as implementation of this Directive [Ustawa … 2021]. This could be achieved by circular economy, as well [Directive 2013] and revitalisation [Revitalisation Act 2015].

Sustainable development is required, especially in the matter of rational use of natural resources and environmental protection [Kovalenko *et al.* 2021; Rokochinskiy *et al.* 2021]. In order to protect the water against eutrophication and cyanobacteria spreading, number of practise should be introduced [Buratti *et al.* 2017; Gałczyńska, Buśko 2016; Kaczmarek *et al.* 2019].

Restoring polluted water ecosystems to a state close to the original state, called revitalisation, requires taking into account a number of factors, the interrelationships of which are shown in a synthetic way shown by Borsuk [2014].

Some of these factors result from the influence of human activity on the destruction of the aquatic ecosystem. Its reduction may occur as a result of properly conducted revitalisation. Among the factors that we have influence on, two important in the revitalisation process are distinguished: water with a suspension of solids and dissolved chemical compounds, called sentosan, and bottom sediments that are a collection of solids of mineral and organic origin, characterised by properties classified as non-

Newtonian fluids. The degree of contamination of sentosan can be influenced mainly by revitalisation processes in the catchment area that protect against pollution, and these are solids contained, among others, in in surface runoff and chemical in domestic sewage and industrial. It is much more difficult to protect against the precipitation of dust and chemical compounds from the atmosphere. The revitalisation of aquatic ecosystems, including the removal or neutralisation of bottom sediments and sentosan with the use of 16 technologies, was described by [SIUDA, CHRÓST 2015]. With regard to the removal of bottom sediments, only dredging consisting in the extraction of sediments without specifying their further economic use is given. This technology is associated with high costs, temporary degradation and disturbance of the homeostasis of the reservoir and the necessity to purify interstitial waters [JUDA, CHRÓŚCIEL 1974].

The innovative technology differs significantly from the previously known ones, operating on the principle of extraction of bottom sediments with the use of dredgers, in that it enables their extraction with much less hydration and then mixing with organic components that absorb a significant volume of water from sludge, which enables the production of a loose organic fertiliser with fertilisation properties similar to manure [BROGOWSKI *et al.* 2017; HAQUE *et al.* 2016].

Pursuant to the Polish Waste Act, bottom sediments containing or contaminated with hazardous substances are classified as hazardous waste with code 17 05 [Ustawa … 2012].

In turn, Art. 7 of the Waste Act allows for reclassification of hazardous waste as non-hazardous waste provided that it is demonstrated that the waste does not possess hazardous waste properties as defined in Annex 3 to the Waste Act [Ustawa … 2012].

On the other hand, bottom sediments not contaminated with hazardous substances belong to waste code 17 05 06 (dredging spoils other than those mentioned in 17 05 05), which include metals: As, Cr, Zn, Cd, Cu, Ni, Pb, Hg.

The main goal was the need to extract bottom sediments from water reservoirs rich in fertiliser components with grain diameters below 1 mm, and at the same time reducing the risk of water eutrophication and increasing the water capacity of retention reservoirs. Therefore, it is necessary to build a device that moves below the scouring speed, grains of solids preferably below the water surface, collecting the upper layer of sediment most rich in phosphorus and threatening eutrophication. Extracting this layer should not increase the organic mass in the seston, and thus reduce the transparency of the water, taking into account the long-term sedimentation processes of organic and mineral solids. Extraction dates should be adapted to the periods of the year resulting from BORSUK's [2014] research, with the lowest content of organic matter in seston and the highest water transparency. In order to confirm the above-mentioned assumptions, the model of the dredger was built. The model of the dredger consists of the following three units.

1. A shovel made of two rectangular side floats with an oblique shape on the inside and top and a combined bottom float with a width of 1000 mm and an oblique upper plane on which four pump units are mounted and in the front part a ploughshare with adjustable angle of attack. Openings have been installed in the side and bottom floats to fill the float spaces with water or sand in order to balance the total buoyancy of the floats with the weight of the dredger shovel.
2. Displacement pump units with a single-turn rotor cooperating with a two-coil rubber stator were selected for hydrotransport of bottom sediments.
3. There is also the possibility of hydrotransporting liquid bottom sediments and, after mixing with other components, spreading over the surface of the soil below the surface. At the same time, this technology does not increase the amount of solid contaminants in the sentosane, thus eliminating the negative impact of the current dredging technology. On the other hand, the sale of organic fertiliser enables the reduction of the overall costs of revitalisation. In this way, the improvement of sentosan is achieved (e.g. by reducing the penetration of chemical compounds into the water), obtaining valuable organic fertilisers, the use of which improves the quality of the soil, and thus reduces the water pollution from the aquifer and enables the so-called closed matter circulation in the water – soil environment [EYMONTT *et al.* 2017; EYMONTT, WIERZBICKI 2017; 2019a, b]. Very important role in sediments have Total Phosphorus (TP) varied from 355.46 to 764.57 $mg \cdot kg^{-1}$. Inorganic Phosphorus (IP) was the main form of TP [DĄBROWSKA, LEJCUS 2012; RZĘTAŁA 2003; WANG *et al.* 2017].

MATERIAL AND METHODS

In 2018, the Institute of Technology and Life Sciences (ITP, currently: Institute of Technology and Life Sciences – National Research Institute) conducted research on bottom sediments (not published so far) from two lakes near Pisz, namely Wądołek and Pogoń. There were measured: granularity, phosphorus concentration, nitrogen content, minerals: Mg, K, Na, C:N ratio.

The sediment composition was also tested for the fish ponds in Falenty. For sediment tests, samples were taken from a layer with a thickness of 10 cm. The graining was assessed using the Casagrande areometric method as modified by Prószyński [FAJER 2014]. Sodium pyrophosphate was used in place of the peptisation soda by mixing with an impeller instead of boiling. The chemical composition was determined by the AAS method after extraction of the sediment samples with concentrated perchloric acid. Organic carbon was determined by the Tiurin method. In order to assess the structure of the tested sediment samples, pictures were taken using a scanning electron microscope at the Analytical Center of the Warsaw University of Life Sciences, at a magnification of 400 to 20,000 times.

Then, in the laboratory of the Institute, preliminary pot tests (in four repetitions without statistical evaluation) were carried out on the fertilisation value of the mixture of bottom sediments obtained from fishponds with straw in several variants, with a fertiliser dose not exceeding 170 kg $N \cdot ha^{-1}$. Mixtures of the following lawn grasses were used – red fescue (*Festuca rubra*), reed fescue (*Festuca arudinacea*), perennial ryegrass (*Lolium perenne*), ryegrass / Italian ryegrass (*Lolium multiflorum*), Westerwold ryegrass / Dutch ryegrass (*Lolium westerwoldicum*). Combinations were used:

1. ZERO – soil.
2. S+BS – soil and bottom sediments from fish ponds.
3. S+BS+M – soil, bottom sediments from fish ponds and micronised straw (crushed to a particle size below 0.01 mm).
4. S+BS+M+CS – soil, bottom sediments from fish ponds, micronised straw and chaff.

RESULTS

CHARACTERISTIC OF THE BOTTOM SEDIMENTS IN CHOSEN LAKES

Higher phosphorus concentration was found in the investigated sediments, ranging from 0.161% in the upper layer of the sediment to 0.111% in its lower layer (Wądołek) and from 0.147% in the upper layer to 0.109% in the lower layer (Pogoń). Similar results reported Boers *et al.* [1998] and Siwek *et al.* [2015].

The C:N ratio was 5.93 (Wądołek) and 4.92 (Pogoń) with the N nitrogen content ranging from 3.49 to 4.18% and organic carbon from 20.7 to 20.6%.

Considering the obtained test results, the following series of shares of individual components can be determined:

– Lake Wądołek: C – 20.47; N – 2.44; P – 0.132; Mg – 1.19; K – 0.080; Na – 0.015;
– Lake Pogonie: C – 20.42; N – 3.44; P – 0.132; Mg – 0.825; K – 0.051; Na – 0.008.

However, according to the ITP research, the ratio of carbon to nitrogen in sediments collected from Lake Jamno is over 11 (C – 3.89; N – 0.35), which simplifies the technology of producing organic fertiliser in terms of the above-mentioned proportion. Studies of sediments from fish ponds were also carried out [Brogowski *et al.* 2017] show a significant and variable content of organic carbon in the 0–5 cm layer from 22.1 to 18.1 g·kg^{-1}. These values are important because with a nitrogen content of 1.61 to 7.03 g·kg^{-1}, the C:N ratio varies from 12.4 to 13.7.

CHARACTERISTIC OF THE BOTTOM SEDIMENTS IN FISHPONDS

Main characteristic of bottom sediments from fishponds was presented in Table 1. The thickness of the sediment layer (0–10 cm).

Microscopic examination of a number of samples shows the lack of sand grains built up made of quartz. These are grains formed as a result of clumps of fine grains, diatom skeletons and other organisms, including very small cubes of fish (Photo 1f). Photo 1a (magnification 400) shows a grain of fine sand (0.25–0.1 mm). It was made of small mineral particles with a large number of diatom skeletons Photo 1b, c). The skeletons of various types of diatoms are clearly visible. Photo 1b (magnification 20,000) shows the elongated diatom skeleton, while Photo 1c (magnification 20,000) mesh-shaped skeletons. Photo 1d (magnification 10,000) shows a grain with a diameter of 0.05–0.02 mm, which is also made of thousands of tiny fragments of particles and also flowers with various shapes of diatom shells (Photo 1e, f, magnification 10,000) and Photo 1g (magnification 2500) showing the skeletons of tiny fish against the background of mineral particles. Photo 1h (magnification 5000) shows a fragment of a grain <0.005 mm and, similarly to grains with a larger diameter, it forms a conglomerate of fine grains bonded together (Photo 1i magnification 20,000). Therefore, the tested grains, regardless of their diameter, form porous systems.

The chemical composition of the studied bottom sediments from ponds shows a clear quantitative differentiation of the components in individual ponds and in the vertical of sediments collected from layers 0–5 and 5–10 cm (Tab. 2).

Summing up, the series of decreasing shares of individual tested components is as follows:

$$N > Mg > K > P > Na$$

The use of the contained fertilising components in the bottom sediments will be more rational if they are mined with a high concentration of the solid component of organic and mineral origin, which will not require the use of additional water-absorbing components [Brogowski, Renman 2004]. For this purpose, an experiment [Strzelczyk, Rossa 2016] was carried out, consisting in mixing 3.8 kg of bottom sediment with a dry matter content of 25% with 0.31 kg of micronised straw with a particle size greater than 100 μm in order to absorb water and obtain a density comparable to manure. The basic components of the mixture were tested using the elemental analysis method, and the results expressed in % are as follows: N – 0.66, P – 0.13, C – 12.02, S – 0.29, H – 1.103 [Strzelczyk, Rossa 2016].

RESULTS FROM POT-TESTS

The results of testing the weight of grass plants by weight are shown in Figure 1, and the percentage share of basic nutrients in fertiliser mixtures and soil (determined by colorimetric methods and ASA after mineralisation) in Table 3 and Figure 2.

Table 1. Granularity of bottom sediments from the studied ponds

The names of ponds	Grain diameter (in mm) and their share in (%)								Percentage of grains in individual diameter ranges			pH
	1–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	0.005–0.002	<0.002	1–0.1	0.1–0.02	<0.02	
Spiski Pond	7	15	52	13	9	3	tr..	1	74	22	4	6.5
No. 13 Pond	12	25	44	9	6	2	2	tr.	81	15	4	6.8
Park 2 Pond	7.9 8	22	38	12	11	5	3	tr.	69	23	8	7.1
Puchalski Pond	12.0	25	42	12	5	3	1	1	78	17	9	6.9

Explanation: tr. = traces.
Source: own study.

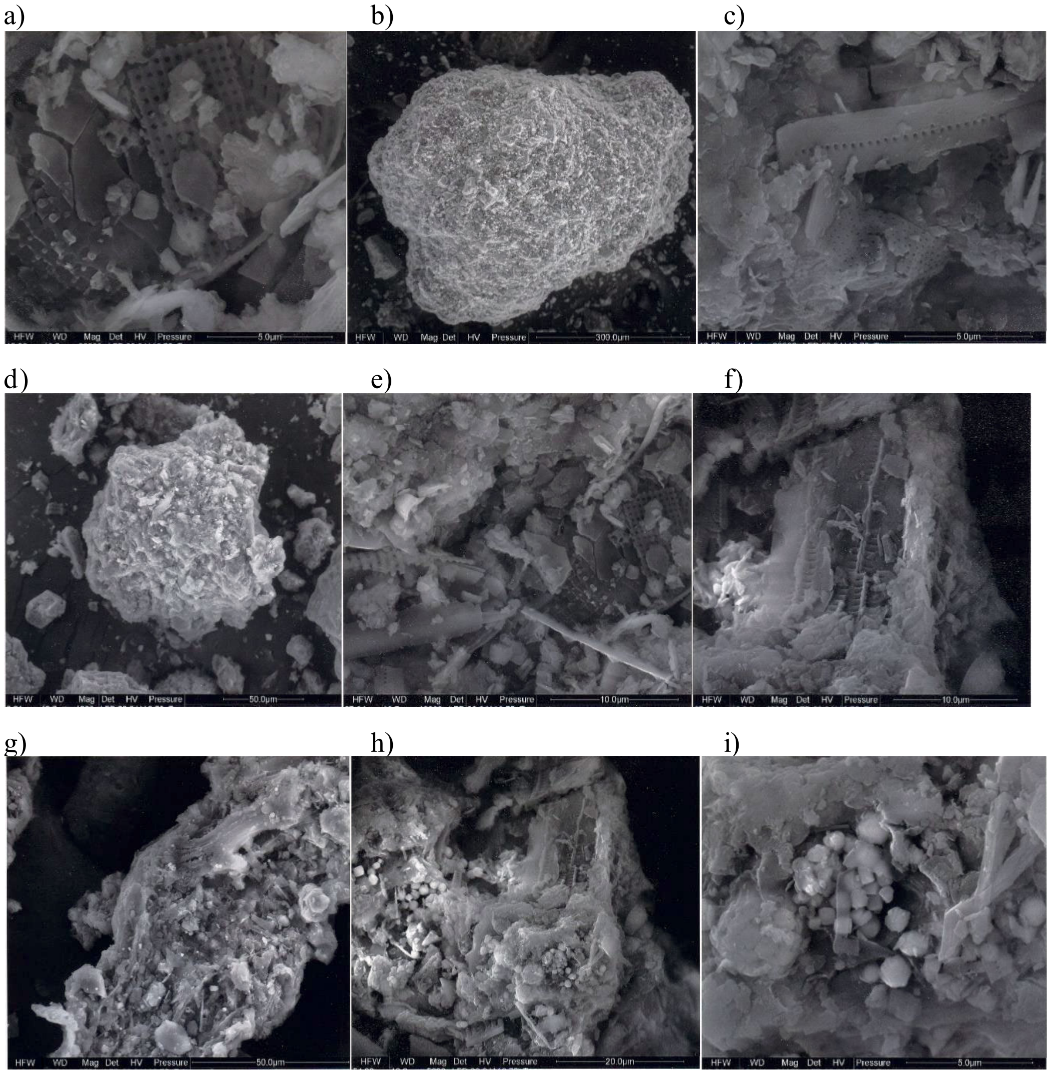

Photo 1. Microscopic examination of bottom sediments collected from ponds in Falenty: a) fine sand grain 0.25–0.1 mm, area 400x; b) sand grain inside with visible diatom, area 20,000x; c) fine sand interior with visible diatom, area 20,000x; d) grain with a diameter of 0.05–0.02 mm, area 1000x; e) grain interior with a diameter of 0.05–0.02 mm, visible granular structure with diatom skeletons, area 10,000x; f) grain inside with a diameter of 0.05–0.02 mm, skeletons of small fish are visible, area 10,000x; g) grain with a diameter of <0.005 mm, area 2500x; h) a fragment of grain <0.005 mm, skeletons of small fish and a porous structure are visible, area 5000x; i) grain fragment <0.005 mm, porous structure, unidentified organisms are visible, area 20,000x; source: own study

Table 2. The content of some components in bottom sediments of the Falenty – Raszyn ponds

The names of ponds	The thickness of the sediment layer (cm)	Mg	K	Na	P	N	Sum	C	C:N	Fe	Mn	Zn	Cu	Pb
		g·kg^{-1}							n.u.	mg·kg^{-1}				
Spiski Pond	0–5	0.80	0.75	0.06	0,22	1.61	3.44	22.1	13.7	445	50.2	14.4	4.9	16.2
	5–10	0.62	0.62	0.05	0.37	1.08	2.74	26.0	24.0	386	45.4	11.8	4.9	13.2
No. 13 Pond	0–5	1.02	0.88	0.07	1.77	2.08	5,82	32.7	15.7	1443	291.9	21.1	8.1	9.4
	5–10	0.70	0.75	0.06	1.75	1.78	5.04	36.5	20.5	1125	229.7	16.7	7.0	8.0
Park 2 Pond	0–5	1.07	0.96	0.08	0.50	3.45	6.06	56.7	16.4	809	170.0	36.7	8.5	7.7
	5–10	1.21	1.82	0.10	0.22	1.20	4.55	18.3	15.2	1080	97.3	30.6	7.2	13.4
Puchalski Pond	0–5	2.24	1.93	0.14	1.63	6.32	12.26	87.1	13.8	1911	313.5	50.9	13.0	15.8
	5–10	2.93	2.25	0.17	2.07	7.03	14.45	92.3	13.1	2507	341.0	60.5	14.1	11.6

Source: Brogowski *et al.* [2017].

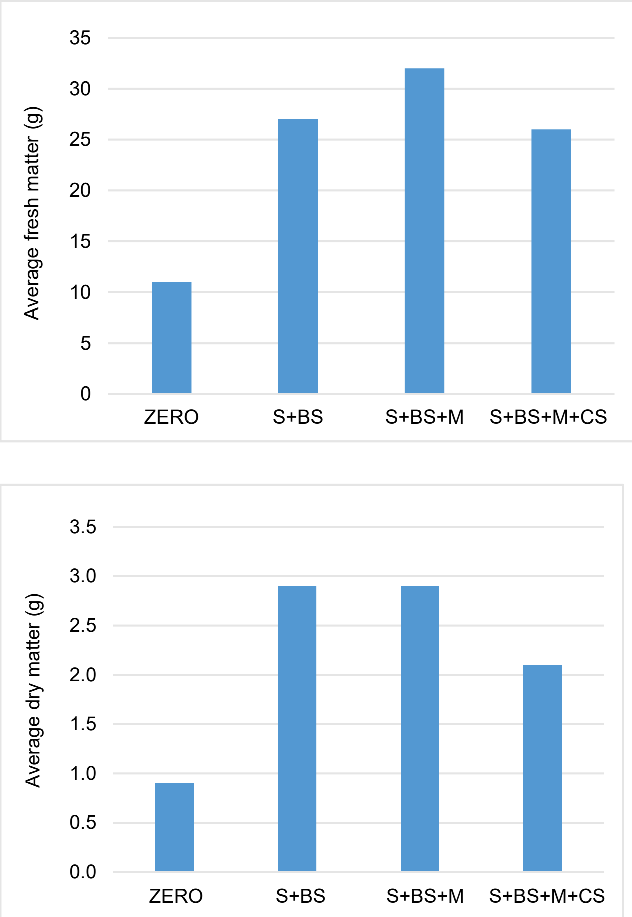

Fig. 1. Average mass of grasses collected from four vases for subsequent combinations; ZERO = soil, S+BS = soil and bottom sediments from fish ponds; S+BS+M = soil, bottom sediments from fish ponds and micronised straw; S+BS+M+CS = soil, bottom sediments; source: STRZELCZYK and ROSSA [2016]

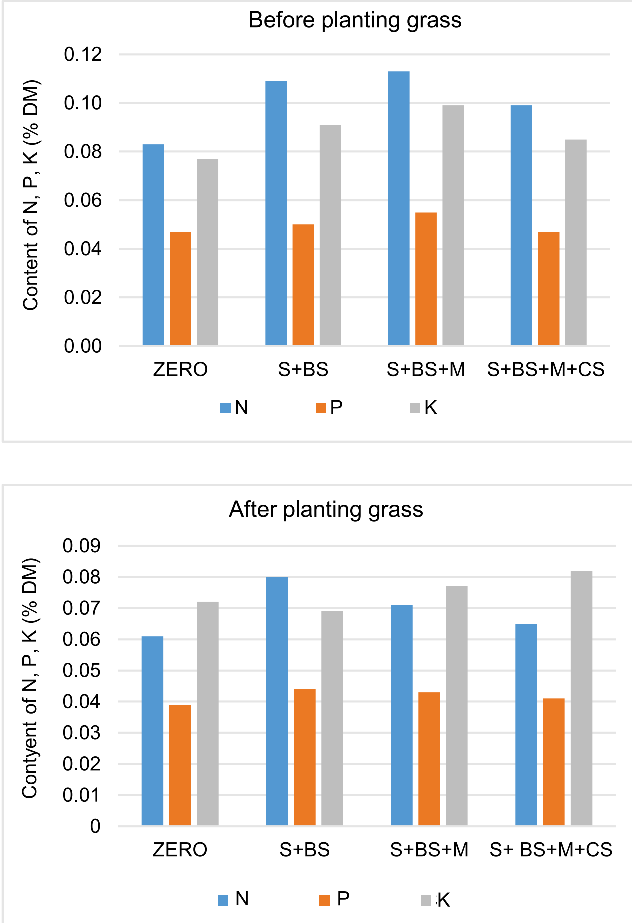

Fig. 2. Content (% DM) of nutrients in fertilising mixtures before and after a fertilisation experiment; source: STRZELCZYK and ROSSA [2016]

Table 3. Content (% DM) of nutrients in fertilising mixtures before and after a fertilisation experiment

Type of fertilising mixture	Before planting grass			After cutting grass		
	N	P	K	N	P	K
Soil (S)	0.093	0.047	0.077	0.061	0.039	0.072
Soil + bottom sediment (S+BS)	0.109	0.050	0.091	0.080	0.044	0.069
Soil (S) + bottom sediment (BS) + micronisate (M)	0.113	0.055	0.099	0.071	0.043	0.077
Soil (S) + bottom sediment (BS)+ micronisate (M) + cutted straw (CS)	0.099	0.047	0.085	0.065	0.041	0.082

Source: STRZELCZYK and ROSSA [2016].

DISCUSSION

Despite the fact that bottom sediments contain relatively less carbon and nitrogen compounds compared to other organic semi-liquid substances, such as e.g. liquid manure, adding them as a fertiliser causes a significant increase in the weight of the harvested plants.

The addition of micronised straw increases the yield even more, as opposed to the addition of chopped straw. In vases with a mixture of bottom sediments with micronised straw, the greatest reduction in the content of nutrients occurred, which seems to confirm the positive role of micronisate in their release.

The use of a comprehensive technology that enables the rational extraction of bottom sediments, and then their processing after adding appropriate components, allows to obtain a multi-component organic fertiliser at an acceptable market price which compared to the manure imported from The Netherlands (average EUR217 for 1 Mg) [CZUBIŃSKI 2017]. Mining efficiency of sediments with proposed equipment is 50 m^3 per 1 h with calculated selling price of ready organic fertiliser EUR150 for 1 Mg (according to our own calculation) what creates good possibility of production and thus contributes to the growth of agricultural production and the implementation of the EU strategy and Directives, Polish law Regulations.

CONCLUSIONS

The analysis and evaluation of hitherto unrecognised sources of raw materials to produce organic fertilisers with high efficiency for plant production growth and at the same time satisfying the preferred directions of economic innovation by the European

Union were analysed and evaluated. These raw materials are pond bottom sediments, organic rock called "opoka" and micronised straw. Properly prepared fertiliser from these raw materials according to the technology developed at the Institute (ITP) is characterised by properties equal to manure and its market price is lower than manure imported from The Netherlands. In addition, the developed technology enables rational use of bottom sediments and reduces environmental negative impact.

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