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Impact of effective microorganisms on the vermicomposting of sewage sludge

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ABSTRACT

The article presents the results of a study aimed at determining the effect of using effective microorganisms, on changing the properties and parameters of treated sewage sludge. The implementation of the research results in the form of an installation based on vermiculture sediment plots and reed sediment lagoons with an installation feeding in effective microorganisms and a device for aerating and flipping vermiculture allowed:

- a significant increase in the efficiency and speed of sludge treatment processes;
- greater reduction in the amount of sludge and the possibility of producing a high-quality fertilizer suitable for agricultural use;
- control of the amount of oxygen in the vermicompost plots and will enable the maintenance of optimal moisture content during the process;

The study showed that composting by prism and vermicomposting with dairy sludge earthworms resulted in an increase in the total content of the elements studied in mature composts and vermicomposts. This phenomenon was particularly evident for: iron, lead, zinc and chromium. The highest increase was recorded for lead, the content of which increased on average from 2.5 to 6.9 mg/kg DM, that is, by about 165%, as well as assimilable iron on average from 50% to 90%. The total content of zinc and chromium increased from 5% to 58%. A general analysis of the results of the Wilcoxon test for the fractional distribution of metals in dairy sludge processed at the research facilities allows us to conclude that, most often, the addition of effective microorganisms had the effect of reducing the percentage of metal content in fractions I and II (the most mobile), and increasing the percentage in fractions III and IV (the most stable). Experiences obtained from the application of effective microorganisms in low-cost methods of sewage sludge processing indicate great potential for intensification of these processes both in terms of their duration, as well as to reduce nuisance (e.g., odor). From the point of view of the intensification of low-input sewage sludge treatment processes, it is also extremely important to determine and evaluate the impact of effective microorganisms on the final character and physico-chemical composition of the sludge, or composts produced. Since these are often processes that require long processing times, it is necessary to continue research to confirm the effects achieved.

Keywords: Sewage sludge; Vermicomposting; Effective microorganisms; Heavy metals

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1. Introduction

The starting point in planning sewage sludge management should be, first of all, information about the real possibilities of sludge management in a given area, and only then should the technological path and logistical solutions be selected to take advantage of the chosen method. Activities should always be undertaken in this order. This increases the probability that the implemented plan will be technically (BAT – Best Available Techniques) and economically optimal, and that it will be a legally secure and effective solution. Fulfillment of these conditions should lead to the implementation of an optimal and long-lasting solution at a given site, both about the treatment and final management of sludge [1].

Currently in Poland, the energy and fertilizer potential of sludge is underestimated and underutilized in relation to current technological capabilities and the state of knowledge and science. The basic problem of sludge management is the negative perception of sludge as a huge threat to our health and life. An approach based on the use of a product method that takes into account the risk analysis of sludge application is observed more often in countries with high R&D potential, such as the US, UK, France, Denmark, Spain and others. There, the fertilizer potential of sludge is usually exploited more often than the thermal potential. The strategy in EU countries is to maintain a high level of use of the fertilizer potential of sludge in agriculture, while increasing the importance of stabilization and hygienization processes. In parallel with biological methods, thermal conversion facilities are developing, especially in regional co-incineration plants. The development of these two strategies is also determined by restrictions (or virtually total bans) on the storage of sludge containing more than 5% organic matter [1].

Previous research conducted on the agricultural use of municipal sewage sludge and dairy sludge has not attempted to use microbial inoculations containing effective microorganisms for faster decomposition of organic matter brought into the soil. The creator of the effective microorganisms technology is Professor Teruo Higa of the Ryuksyu Agricultural Academy in Okinawa, Japan. In Poland, the preparation containing effective microorganisms has been distributed for nearly 20 y under the name effective microorganisms (EM) and there are not many detailed scientific studies on it. Both domestic and foreign studies related to the production of compost, vermicompost, reclamation agents, natural fertilizers are mainly concerned with municipal sludge of a different composition and nature as dairy sludge. According to the author, it is expedient to determine the suitability of ways to process dairy sludge by low-input methods and using effective microorganisms.

The technology of effective microorganisms is based on inoculation with microorganisms found only in the natural environment properly selected and meeting strict criteria for non-harmfulness to humans, animals and plants. The "beneficial" effect of effective microorganisms has been shown to change the surrounding microflora towards regeneration. This contributes to maintaining the N:P:K and C:N ratio in the surrounding environment at an optimal level. The product's effect of eliminating decay processes in the soil by accelerating the transformation of organic matter is also proven [2,3].

Dairy wastewater is characterized by significantly higher values of pollutant indicators compared to municipal wastewater [4,5].

Sludge from the treatment of dairy wastewater can therefore be managed in nature, in agriculture for fertilization and reclamation. Numerous studies presented in the literature related to the issue of sludge management show that sludge from dairy wastewater treatment plants is characterized by a low content of heavy metals compared to municipal sludge in Poland and around the world [6.7].

Based on a number of studies conducted on the properties of sewage sludge, it has been concluded that the forms of heavy metals contained in sewage sludge affect the availability and assimilability of these elements after application to soils. Thus, examining only the total amount of heavy metals in sewage sludge, despite the fact that this is a commonly used parameter of its contamination, does not really determine the degree of uptake of the metals by plants, nor the potential mobility of the metals in the environment. Thus, the total form does not determine the potential risk of heavy metals impacting the environment [8,9].

The scientific objective of the project and the topic of the research conducted was to determine the effect of using effective microorganisms in the vermicomposting process, on changing the properties and parameters of treated dairy and municipal sewage sludge.

2. Material and methods

2.1. Characteristics of the research subject

Research installations for low-cost sewage sludge treatment, such as common reed beds, energy-crop willow beds and vermicompost beds designed and created by the author constituted the subject of the research.

Excess sewage sludge from biological dairy wastewater treatment which was aerobically stabilized in separate chambers sampled from the wastewater treatment plant SM Mlekovita in Wysokie Mazowieckie was the research substrate. The substrate, depending on research installation, was initially thickened or dewatered.

The vermicompost beds were supplied with the same dairy sewage sludge but with approximately 80% single-time hydration in the amount of 1.5 m^3 of hydrated sludge per one bed of 4 m^2 area. Before supplying the bed with sewage sludge, it was embanked with a so-called stock nursery containing red Californian earth worms from a wastewater treatment plant in Zambrów. One section of the research installation containing vermiculture was supplied with the EM formula once per month during the vegetation period, with 3 L per section.

The reed beds were planted with 5 one-year-old reed seedlings from the wastewater treatment plant in Zambrów per m^2, while the beds with energy-crop willow – with 4 one-year-old seedlings of *Salix viminalis* from a private tree nursery per m^2. Supplying the installation with dairy sewage sludge began in May 2010 with 0.5 kg of dry mass per m^2 of a section, gradually increasing the amount to 2.0 kg·dm/m^2 of a section. The frequency was increased from one per 3–4 weeks to one per 1–2 weeks (the supplied sewage sludge was initially thickened with approximately 95% hydration). In two sections of the research installation, that is one containing willow and one – reed, 1 L of the EM formula was applied per section once a month during the vegetation period.

Effective microorganisms (EM) were also applied in all methods for comparison. EM-BIO formula produced by Greenland – EM Technology was applied. The formula created by this company has authenticity and originality certificates confirmed by dr Teruo Higa, the inventor of Effective Microorganisms™ (EM), professor emeritus at University of the Ryukyus, Director of International Institute for EM Research Technology at Meio University.

The basic element in low-cost treatment processes was sewage sludge from the dairy wastewater treatment plant SM Mlekovita in Wysokie Mazowieckie. The same dairy sewage sludge was used in all research installations for comparative purposes.

2.2. Vermicomposting research methods

The applied dairy sewage sludge vermicomposting process was conducted for two vegetation periods.

The research frequency was adjusted to the characteristics of the technological process and the features of the controlled parameters. The established methods assumed 5 test series of vermicompost mixture samples from each section:

- Samples collected from dairy sewage sludge applied in the vermicomposting process – the start of vermicomposting (the beginning of earth worms' biological activity season (spring – May) in the first year – Phase 0);
- Samples collected after 5 months of vermicomposting process – the end of earth worms' biological activity season (autumn – October) in the first year – Phase I;
- Samples collected after 12 months (year 1) of vermicomposting – the beginning of earth worms' biological activity season (spring – May) in the second year – Phase II;
- Samples collected after 17 months of vermicomposting process – the end of earth worms' biological activity season (autumn – October) in the second year – Phase III (end of proper vermicomposting);
- Samples collected after 24 months – representative for the end of vermicompost maturing phase (mature vermicompost – spring – May) – Phase IV.

The vermicomposting period in the sections was 2 y (2 vermiculture vegetation seasons). After that period each of the sections was deconstructed and their content was deposited on an open-air prism in order to finish the maturing process (6 months).

2.3. Analytical methods

Kjeldahl nitrogen (N), the sum of organic and ammonia nitrogen, was determined in the analyzed sludge. The sludge sample was dried and homogenized. It was then alkalized using a 35% solution of NaOH and mineralized in the presence of the catalyst $CuSO_4 + K_2SO_4$ using ammonium distillation. The determination of ammonia nitrogen was carried out using the distillation method.

For determining the phosphorus concentration, the sample was dried, homogenized and then mineralized using a mixture of the concentrated acids $HClO_4$ and HNO_3. In the obtained solution, PO_4^- ions were determined calorimetrically in the reaction with ammonia molybdate in the presence of glycerine with dissolved $SnCl_2$.

Sewage sludge samples were treated in a HACH mineralizer with the use of sulphuric acid and hydrogen peroxide in a mixture of nitric and hydrochloric acid in a ratio of 1:3. For further analysis mineralizers were filtered through MN 616 G paper filter.

Determination of cadmium, nickel and total chromium content was done in samples of mineralizers with the use of an atomic absorption spectrometer Perkin-Elmer 4100 ZL with transversely heated graphite cuvette and Zeeman Effect background correction.

The determination of mercury content was done in samples of mineralizers by means of the cold steam technique with the use of an atomic absorption spectrometer Perkin-Elmer 4100 ZL equipped with add – on device FIAS-200.

The determinations of zinc, lead and copper contents were done in samples of mineralizers with the use of an atomic absorption spectrometer Varian SpectrAA 20 Plus by means of flame atomization.

Determination of fractions: Cu, Zn, Pb, Cd, Cr, Ni.

In the study of six heavy metals: lead, cadmium, chromium, copper, nickel and zinc, in addition to the total content, IV fraction determinations were made using a modified BCR method:

- an exchangeable, acid-soluble fraction F1, bound to carbonates;
- F2 reducible fraction, bound to Fe/Mn oxides;
- oxidizable fraction F3, associated with organic matter and sulfides;
- residual fraction F4, the residue from the previous three steps was mineralized in a mixture of concentrated HNO_3 and 30% H_2O_2. The mineralizate was subjected to analysis.

Determinations of the test samples were performed in triplicate.

2.4. Statistical analysis

Statistical assessment methods applied to the obtained results of own research (Wilcoxon test) point to a significant influence of the EM formula on different "behavior" of many analyzed characteristics of the treated sludge.

3. Results and discussion

Changes in basic characteristics and content of macroelements, observed as a result of the research, were the consequence of microbiological and biochemical transformations occurring during stabilization and dewatering in the beds with energy-crop willow and reeds, as well as in the vermicomposting process.

Fig. 1 present changes over time in the analyzed physical characteristics and macroelements content in sewage sludge in particular phases of vermicomposting.

In reference to sewage sludge characteristics and its examined content of macroelements, the greatest EM's

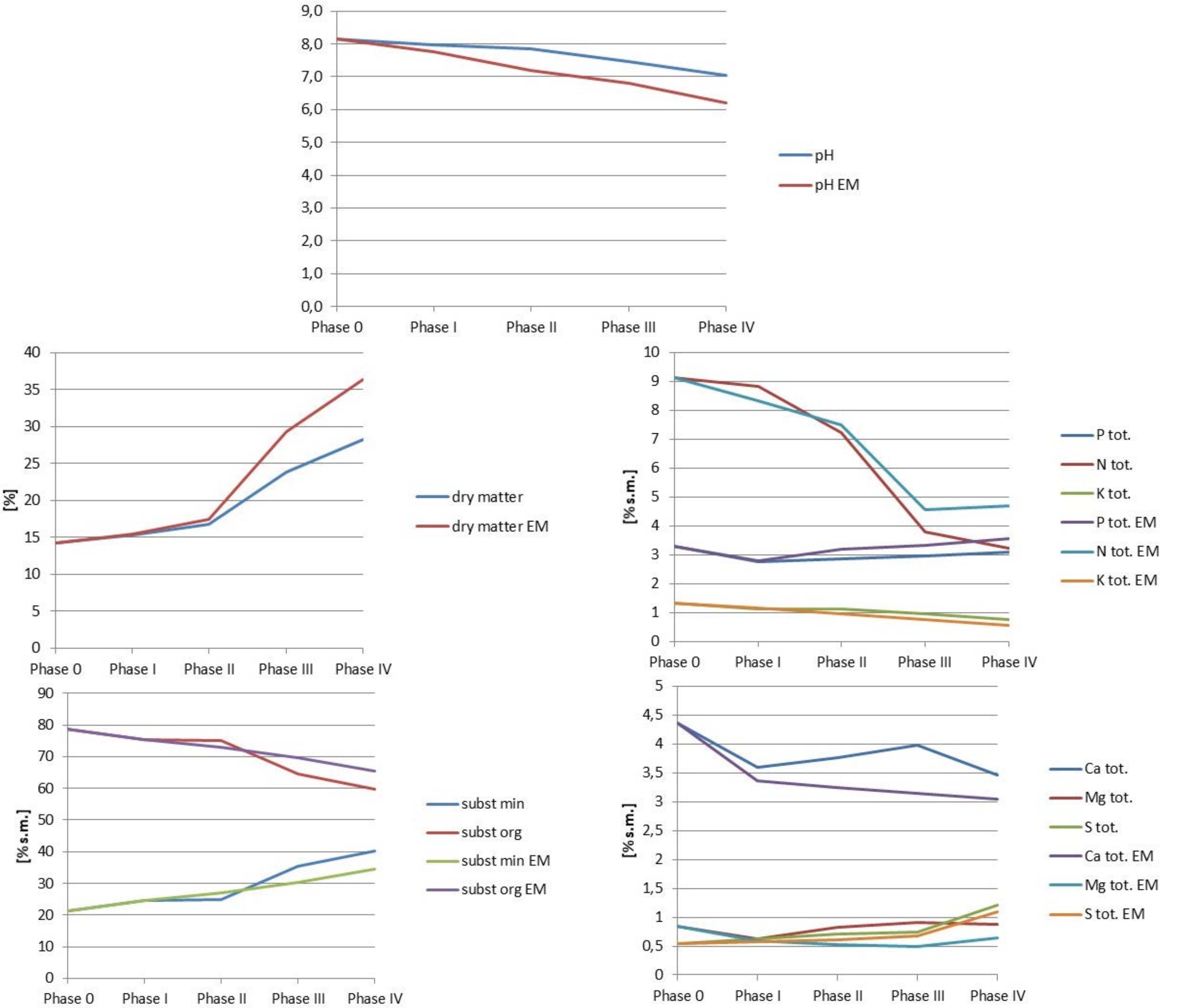

Fig. 1. Changes in selected characteristics and macroelements content and percentage changes in macroelements' share in dairy sewage sludge treated in the research installation with vermicompost.

influence was observed in the vermicomposting process. Changes results in the content of the analyzed macroelements in sewage sludge, in particular phases of it being processed by earth worms, in reference to EM inoculation, show very similar values, but several differences were also observed. For mature vermicompost in which production EM was used, higher contents of phosphorous and nitrogen was observed, while the contents of potassium, calcium, magnesium and sulfur was lower than in mature vermicompost in which production EM was not used. Adding EM to the vermicomposting process also influenced the increase of phosphorous content in sewage sludge and higher content of dry mass which points to better mineralization. Organic substance content in mature vermicompost with EM was over 5% higher than in vermicompost without EM. An even bigger difference was observed in dry mass: mature vermicompost with EM had over 8% more dry mass than vermicompost without EM. The use of EM for sludge vermicomposting led to significant but often different changes in the macronutrient content of the sludge.

Analyzing the results, it can be concluded that the process of sludge processing by earthworms had an impact on the content of individual trace elements. For some of the trace elements in the mature vermicomposts, a higher content was found compared to the initial content (start). These elements included lead, iron, zinc, chromium and mercury. The content of: copper, cadmium, nickel and manganese in the mature vermicomposts (stage IV) was lower compared to the initial content.

Observing the effect of the time of sludge processing by earthworms (stages) on the total content of all metals tested, it can be concluded that the greatest changes occurred in stage IV (vermicompost maturation).

The process of vermicomposting dairy sludge with earthworms conditioned the fractional distribution of metals in the studied sludge in different ways. In general, the composting process contributed to a decrease in the percentage of lead, chromium, nickel, copper and zinc in fraction I and cadmium, chromium and copper in fraction II, that is, it reduced the solubility of metals. In general, mature vermicomposts had higher percentages of copper and nickel in fraction III and lead and cadmium in fraction IV. The use of EM for vermicomposting of sludge may have increased biosorption and bioaccumulation of heavy metal forms.

Interdependencies for characteristics examined in the experiments – statistical analysis.

The consequence of biochemical processes in various methods applied for treating sewage sludge from dairy wastewater treatment was changes in sewage sludge physico-chemical characteristics. In order to examine the interdependencies for the examined sewage sludge characteristics, various description and statistical analysis methods were applied: Wilcoxon signed-rank test and Spearman rank correlation.

Wilcoxon signed-rank test.

In order to examine whether a statistically significant change occurred, Wilcoxon signed-rank test was applied for particular matched pairs. The same characteristics of sewage sludge with and without EM in all of the treatment processes were chosen as matched pairs and subjected to the test. Table 1 presents the results of Wilcoxon test statistical calculations for chosen characteristics and macroelements content in dairy sewage sludge processed in the research installations.

The assumed zero hypothesis stated that "parameters compared in pairs (sewage sludge with and without EM) for the most part of the treatment process do not differ, that is there are no significant differences between the matched pairs". Reaching probability with Benjamini–Hochberg correction bigger than $p > 0,05$ (*p*-test value with multiple testing corrections) was the basis for rejecting the zero hypothesis. An alternative test hypothesis was assumed that "significant differences occur between the matched pairs". The zero hypothesis is rejected in favor of the alternative hypothesis when $p < 0,05$. For statistically significant tests post-hoc was determined. The numeral values of the test statistics show which measurements (either for sewage sludge with or without EM) are significantly bigger or smaller.

Explanation of abbreviations used in Table 1 containing Wilcoxon test results:

- *p*-test value with Benjamini–Hochberg correction (for multiple testing);
- Stat. – testing statistics;
- Int. – interpretation;
- n.s. – not significant;
- –EM – significantly smaller measurement for sewage sludge with EM;
- +EM – significantly bigger measurement for sewage sludge with EM;

General analysis of Wilcoxon signed-rank test points to various behaviors of particular sewage sludge characteristics during long-term processing in reference to the influence of EM addition.

Table 1
Changes in trace element content of dairy sewage sludge treated in a vermicomposting test facility (mg/kg DM)

		Pb	Cd	Cr	Cu	Ni	Zn	Hg	Mn	Fe
Sludge without EM										
Phase 0	Mean	2.33	0.46	15.95	59.40	15.27	322.80	0.10	152.60	7,437.67
	Std. dev.	0.05	0.02	0.16	0.50	0.27	3.86	0.01	2.52	62.82
Phase I	Mean	2.76	0.44	14.46	56.37	14.58	333.55	0.12	143.67	8,364.67
	Std. dev.	0.10	0.01	0.39	0.30	0.29	3.67	0.00	3.61	88.16
Phase II	Mean	5.33	0.38	13.78	54.17	12.37	353.44	0.13	140.60	8,666.00
	Std. dev.	0.11	0.01	0.12	0.45	0.23	6.65	0.00	2.42	60.01
Phase III	Mean	8.35	0.35	12.58	41.13	12.05	374.55	0.15	134.80	9,491.67
	Std. dev.	0.11	0.02	0.33	0.30	0.22	5.30	0.00	2.11	157.36
Phase IV	Mean	6.23	0.21	17.61	36.45	10.29	337.38	0.17	75.03	10,511.67
	Std. dev.	0.12	0.01	0.44	0.39	0.25	6.62	0.00	1.65	534.52
Sludge with EM										
Phase 0	Mean	2.33	0.46	15.95	59.40	15.27	322.80	0.10	152.60	7,437.67
	Std. dev.	0.05	0.02	0.16	0.50	0.27	3.86	0.01	2.52	62.82
Phase I	Mean	3.11	0.54	13.56	55.38	15.46	345.99	0.14	146.83	7,531.67
	Std. dev.	0.12	0.02	0.32	0.51	0.50	6.51	0.00	2.14	133.36
Phase II	Mean	7.24	0.65	13.17	52.44	16.43	374.79	0.16	142.00	7,628.67
	Std. dev.	0.21	0.03	0.16	0.63	0.36	4.49	0.00	1.65	135.77
Phase III	Mean	10.87	0.61	12.67	46.49	18.02	408.15	0.18	153.03	7,665.33
	Std. dev.	0.35	0.02	0.18	0.35	0.11	5.81	0.00	3.07	107.95
Phase IV	Mean	6.50	0.28	22.46	45.93	14.58	378.19	0.26	95.23	11,756.00
	Std. dev.	0.17	0.01	0.71	0.35	0.25	8.50	0.01	1.01	130.10

In reference to sewage sludge characteristics and its content of the examined macroelements (Table 1), the greatest EM influence was observed in the vermicomposting process. The achieved low *p*-value (from 0.0065 to 0.0084) and high value of test statistics (from 66 to 78) show that EM addition caused a significant decrease of potassium, calcium, magnesium and sulfur in sewage sludge during vermicomposting process and in mature vermicompost.

A similar effect was observed for pH. Adding EM to vermicomposting process, however, influenced the increase of phosphorous content in sewage sludge, its cumulation and higher dry mass content indicating its better mineralization.

Analyzing the results of the Wilcoxon test for significant differences in trace element contents for sludge inoculated or not inoculated with EM in the different treatments, it can be concluded that the vermicomposting process observed an increase in the content of the largest number of elements in sludge with EM, that is, lead, cadmium, nickel, zinc, mercury and manganese, with respect to sludge treated without EM. At the same time, very low numerical values of the test statistic (Stat from 0 to 4) were obtained, testifying to the high significance of the effect of EM on the differences between the contents of these micronutrients.

A general analysis of the results of the Wilcoxon test for the fractional distribution of metals in dairy sludge processed at the research facilities (Table 4) allows us to conclude that, most often, the addition of EM had the effect of reducing the percentage of metal content in fractions I and II (the most mobile), and increasing the percentage in fractions III and IV (the most stable). However, there were individual differences for individual heavy metals and dairy sludge processing. The metals for which the addition of EM to the treatment processes caused significant changes in their fractional distribution were lead, cadmium and zinc (significant changes were observed in each process in most of the four fractions). The least effect of EM on significant changes in the fractional distribution during dairy sludge processing was observed for copper (no significant changes in any fraction or changes in one or two fractions in each processing). Changes in the proportion of individual metal fractions should be considered in relation to the change in their overall content in the sludge.

Many literature sources, both foreign and domestic, document the influence of EM on the functioning of municipal wastewater treatment plants and the amount and quality of generated sewage sludge. Among other studies, the research conducted by Nathan Szymański and Robert A. Patterson in a municipal wastewater treatment plant in Harbour and in five household wastewater treatment plants (cesspits) in the area of Armidale, Australia. They confirmed that if proper conditions are made for EM in tanks, it can be observed that the solid particles (suspension) content decreased and the odor became less intensive [10]. Similar results were obtained by Jóźwiakowski [11] in the case of sewage sludge in household sedimentation tanks. Research was conducted at The University of Science and Technology Qingdao in China concerning the application of EM for treatment of food industry wastewater with a high content of starch and wastewater containing acrylonitrile. In this case EM was applied with high effectiveness in the contact aeration column [12]. Meanwhile, at South China University of Technology studies were conducted on the damage done to effective microorganism's DNA by heavy metals and its influence on the effectiveness of wastewater treatment [13]. At Hohai University in China research was conducted on the effectiveness of dairy wastewater treatment with the application of various doses of EM. In New Zealand, EM is produced from local microorganisms by Nature Farming Society. It was proven that adding EM can lower the content of chemical oxygen demand and the amount of absorbed phosphorous, enhances sewage sludge sedimentation effect, reduces odor intensity and moreover it decreases the amount of *E. coli* and salmonella in wastewater [14].

Table 2
Wilcoxon test results for selected characteristics and macroelements content in dairy sewage sludge treated in the research installations

	Reaction	Mineral substances	Organic substances	Dry mass	Total phosphorous	Total nitrogen	Total potassium	Total calcium	Total magnesium	Total sulfur
					Vermicompost					
p	0.0065	0.1333	0.1149	0.0102	0.0086	0.1621	0.0194	0.0065	0.0084	0.0065
Stat.	78	52	13	1	2	19	72	78	66	78
Int.	–EM	n.s.	n.s.	+EM	+EM	n.s.	–EM	–EM	–EM	–EM

Table 3
Wilcoxon test results for trace element content of dairy sewage sludge processed in research installations

	Pb	Cd	Cr	Cu	Ni	Zn	Hg	Mn	Fe
					Vermicomposting				
p	0.0084	0.0065	1	0.2145	0.0065	0.0065	0.0065	0.0128	0.1621
Stat.	0	0	39	21	0	0	0	4	59
Int.	+EM	+EM	n.s.	n.s.	+EM	+EM	+EM	+EM	n.s.

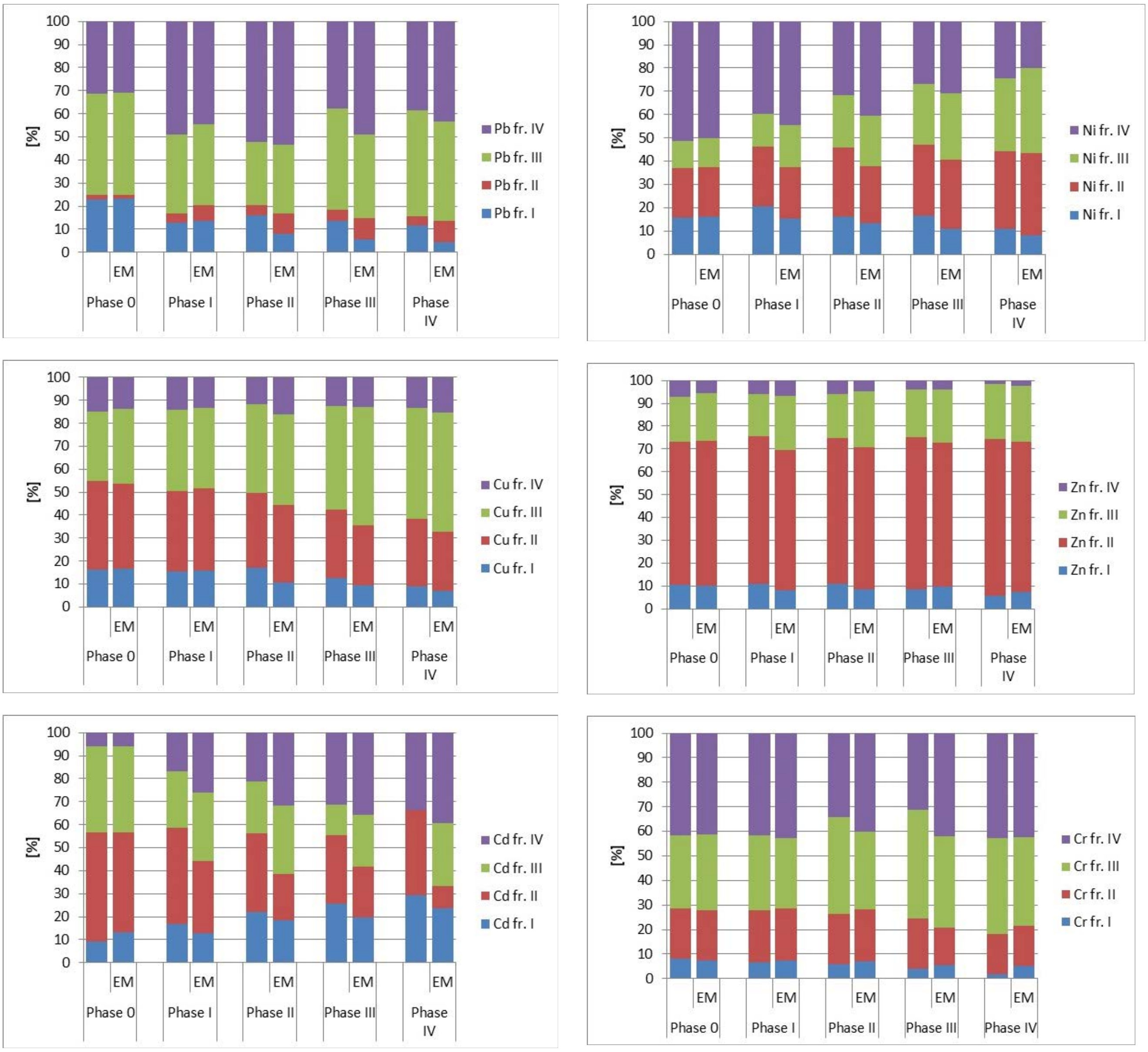

Fig 2. Changes in the percentage of heavy metal fraction in dairy sewage sludge treated in a vermicomposting test facility.

Further studies conducted at The University of Guelph in Canada on the influence of EM on dairy wastewater quality concerned duckweed. Research carried out in ponds showed that using both EM and duckweed significantly decrease the amount of ammonia nitrogen, total phosphorous, biochemical oxygen demand and the number of solid particles [15]. Applying EM also influences microbiological compositions of the environment, which are water, wastewater, sewage sludge, compost and soil. It was confirmed by multiple researches conducted within the country and abroad. Studies conducted at the Institute of Soil Science and Plant Cultivation in Pulawy on the application of EM in ecological agriculture showed a higher number of microbes and fungi in the soil surface layer [16]. Research carried out at Inha University in South Korea showed that adding EM to organic waste under composting process has a major effect on increasing compost maturity, faster odor reduction and mature compost stabilization as well as it allows achieving a higher degree of nitrogen bonding in the soil [17]. Similar results proving a positive effect of EM on the speed of composting process and quality of obtained compost were shown by [18–20].

However, not all research unanimously confirms EM's positive impact on soil and cultivation. Among literature data on the subject of EM's influence on composting process there are such which do not show a positive effect. Among others, Czekała [21] did not confirm any positive influence of applying EM on total nitrogen cumulated in compost or on the quality of compost obtained from sewage sludge [22].

Own research confirmed that due to EM influence significant changes may occur in macroelements content in dairy sewage sludge treated with biological methods. The

Table 4
Results of the Wilcoxon test for the fractional distribution of trace elements in dairy sewage sludge treated at research facilities

	Pb				Cd				Cr				Cu				Ni				Zn			
Fr	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
	Vermicomposting																							
p	0.0292	0.0065	0.0293	0.0065	0.4415	0.0084	0.0113	0.0065	0.008	0.8837	0.664	0.0069	0.0877	1	0.0675	0.0848	0.6815	0.3163	0.0022	0.0065	0.4814	0.0065	0.0022	0.5111
Stat.	91	1	11	1.5	32.5	111	11	2	8	56	70	7	83	59	24	26	53	40	0	6	45	10	0	74
Int.	−EM	+EM	+EM	+EM	n.s.	−EM	+EM	+EM	+EM	n.s.	n.s.	+EM	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+EM	+EM	n.s.	+EM	+EM	n.s.

most significant effect (in reference to the number of parameters and the scale of change influenced by the EM formula) was observed in earth worm vermicomposting process and long-term stabilization in reed beds. The statistical methods applied for evaluating the results of own research (Wilcoxon test) point to a significant influence of the EM formula on different "behaviors" of many analyzed characteristics of the treated sewage sludge. The variety of changes in the treated sewage sludge characteristics was caused by the fact that microorganisms contained in the EM formula enter very distinct heterogeneous types of environment with domestic bacterial flora. Microorganisms present in the EM formula can thus, in various conditions or harmoniously, cooperate with the domestic microflora, or limit the development of one type of microorganisms by others, which in consequence influence in various ways the final content of various components in sewage sludge. Various effect of EM on different sewage sludge characteristics in different biological treatment processes were connected with synergistic or antagonistic reactions among particular microorganism species.

The study showed that composting by prism and vermicomposting with dairy sludge earthworms resulted in an increase in the total content of the elements studied in mature composts and vermicomposts. This phenomenon was particularly evident for: iron, lead, zinc and chromium. The highest increase was recorded for lead, the content of which increased on average from 2.5 to 6.9 mg/kg DM, that is, by about 165%, as well as assimilable iron on average from 50% to 90%. The total content of zinc and chromium increased from 5% to 58% on average. In contrast, the content of such micronutrients as copper, cadmium and manganese, as well as nickel in mature composts and vermicomposts were lower than the initial ones by an average of 5% to 55%. The content of mercury in dairy sludge during the composting and vermicomposting process was very low (0.1 mg/kg, DM) and oscillated around this value during the various phases of the process, to reach values slightly higher at an average of 0.2 mg/kg, DM in mature composts and vermicomposts.

Finished (mature) composts and vermicomposts can have widely varying levels of metals, which is mainly determined by their content in the initial biomass and from the kinetics of mineralization [8,9,23,24]. As stated earlier on the basis of experiments, the total elemental content of mature composts and vermicomposts increased. There are many reports in the literature indicating such a trend of changes in overall metal contents [25]. Some literature reports indicate even a very high increase of some elements during composting, even 2–3 times, for example, for copper, zinc or manganese [26]. In general, the authors emphasize the increase in metal content under the influence of the composting process. There are far fewer literature reports on the reduction of some metals content during composting or vermicomposting [27]. The most common indication is that micronutrients such as copper, zinc, and lead can be reduced in mature composts [28,29]. The obtained results of composting and vermicomposting of dairy sewage sludge are largely in line with the findings of other authors. Many works indicate the possibility of divergent effects of processes in composting and vermicomposting on the content of micronutrients in the final products, their concentration may increase or decrease. Thus, changes in the overall content of elements are the result of the loss of composted mass and their leaching from decomposed organic matter [30].

Some authors state, the changes in the overall contents of trace elements during composting are explained by changes in the reaction of composted biomass [26]. In addition, they emphasize that composts are very difficult research material characterized by a very high diversity and variability during composting.

4. Conclusions

The research conducted was comprehensive, and the results obtained indicate the need for further continuation regarding the transformation of components present in dairy sludge during its stabilization by natural methods. It seems particularly important to determine the role of microorganisms present in the EM preparation on the course of individual processes and transformations occurring in sludge stabilized under natural conditions. The innovation of the research consisted in a very comprehensive spectrum of applied natural methods of stabilization of sewage sludge from dairy wastewater treatment. The research results obtained are of utilitarian value and have the potential to have a major impact on the environment. They may contribute to a change in the approach to sludge from waste to product. The practical result of using the research was the implementation of the result of the research work in the wastewater treatment plant and proposing innovative solutions to improve the efficiency of the process of vermicomposting and processing of sludge in reed lagoons. The result of the research project was also the development of a conceptual design for a vermicompost mixer [31]. This was the basis for obtaining a 2021 patent (Device for mixing and aerating the substrate PL 237954 B1).

- The use of EM for sludge vermicomposting led to significant changes in the macronutrient content of dairy sludge processed by biological methods.
- In vermicomposts in the production of which EM was used, there was a higher content of phosphorus and nitrogen, but at the same time a lower content of potassium, calcium, magnesium and sulfur than in vermicomposts in the production of which EM was not used.
- The stabilized sludge meets the requirements of the current 2008 Ordinance of the Minister of Agriculture and Rural Development to be met by solid organic fertilizers and the 2015 Ordinance of the Minister of the Environment on municipal sewage sludge for natural use, with regard to heavy metals, which potentially qualifies dairy sludge as an organic fertilizer.
- Vermicomposting with earthworms of dairy sludge resulted in an increase in the total amount of trace elements tested in mature composts and vermicomposts. This phenomenon was particularly evident for: iron, lead, zinc and chromium.
- Processing of dairy sludge with regard to the content of most metals, an increase in their overall content can be observed. However, with regard to the mobility of the elements studied, it was shown that for most of them, the applied processing increased the percentage in the more stable chemical forms (fractions II, III, and IV), at the expense of the most mobile fraction.

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References

[1] A. Wójtowicz, C. Jędrzejewski, M. Bieńkowski, H. Darul, Model Solutions in Sludge Management, Polish Waterworks Association, Bydgoszcz, 2013 (in Polish).
[2] T. Higa, Effective Microorganisms: A New Dimension for Nature Farming, J.F. Parr, S.B. Hornick, M.E. Simpson, Ed., Proceeding of the Second International Conference on Kyusei Nature Farming, U.S. Department of Agriculture, 1994, pp. 20–22.
[3] T. Higa, An Earth Saving Revolution, Sunmark Publishing, 1996.
[4] IPPC Reference Document on Best Available Techniques in the Food, Drink and Milk Industries European Commission, 2006.
[5] D. Boruszko, Research of effective microorganisms on dairy sewage sludge stabilization, J. Ecol. Eng., 20 (2019) 241–252.
[6] W. Dąbrowski, Studies upon heavy metals contents in sewage sludge and reject water produced from its treatment in dairy wastewater treatment plants, Ecol. Chem. Eng., 15 (2008) 1041–1047.
[7] C.G. Bergs, K.H. Linder, Sewage sludge use in the federal republic of Germany, Eur. Water Pollut. Control, 17 (1997) 47–52.
[8] Q.-Y. Cai, C.-H. Mo, Q.-T. Wu, Q.-Y. Zeng, A. Katsoyiannis, Concentration and speciation of heavy metals in six different sewage sludge-composts, J. Hazard. Mater., 147 (2007) 1063–1072.
[9] I. Walter, F. Martínez, V. Cala, Heavy metal speciation and phytotoxic effects of three representative sewage sludges for agricultural uses, Environ. Pollut., 139 (2006) 507–514.
[10] N. Szymanski, R.A. Patterson, Effective Microorganisms (EM) and Wastewater Systems, Lanfax Laboratories Armidale, NSW Australia, 2003, pp. 347–354.
[11] K. Jóźwiakowski, Evaluation of the possibility of using EM-farming to optimise the performance of primary settling tanks, Polish Acad. Sci., 5 (2008) (in Polish).
[12] G. Zhou, J. Li, H. Fan, J. Sun, X. Zhao, Starch Wastewater Treatment with Effective Microorganisms Bacteria, 2010 4th International Conference on Bioinformatics and Biomedical Engineering, IEEE, Chengdu, China, 2010.
[13] S. Zhou, C. Wei, C. Liao, H. Wu, Damage to DNA of effective microorganisms by heavy metals: impact on wastewater treatment, J. Environ. Sci. (China), 20 (2008) 1514–1518.
[14] L. Liao, X. Shao, J.Z. Xu, M. Walter, Effects of Different EM Solution Addition Ratios and Incubation Methods on Dairy Effluents Treatment, 2008 2nd International Conference on Bioinformatics and Biomedical Engineering, IEEE, Shanghai, China, 2008.
[15] M.T. Rashid, J. West, Dairy Wastewater Treatment with Effective Microorganisms and Duckweed for Pollutants and Pathogen Control, M.K. Zaidi, Ed., Wastewater Reuse–Risk Assessment, Decision-Making and Environmental Security, NATO Science for Peace and Security Series, Springer, Dordrecht, 2007, pp. 93–102.
[16] J. Kowalska, Effective Microorganisms in Organic Farming – A Well Documentation, Instytut Ochrony Roślin – Państwowy Instytut Badawczy w Poznaniu, 2011.
[17] S.-U. Heo, S.-Y. Moon, K.-S. Yoon, Y.-J. Kim, Y.-M. Koo, Enhanced compost maturity by effective microorganisms, J. Biotechnol., 136 (2008) 22–71.
[18] D. Boruszko, Determining the effectiveness in vermicomposting of sewage sludges and the attempt to increase the effectiveness by applying bacterial microorganisms, J. Ecol. Eng., 17 (2016) 53–59.
[19] S. Sivasubramanian, S.K.R. Namasivayam, Evaluation of phenol degradation by effective microorganism (EM) technology with EM-1, Afr. J. Microbiol. Res., 7 (2013) 4117–4122.
[20] R.V. Misra, R.N. Roy, H. Hiraoka, On-Farm Composting Methods, Food and Agriculture Organisation of the United Nation, Rome, Italy, 2003.
[21] J. Czekała, Dynamics of the transformation of carbon and nitrogen compounds in the composting process of pine bark, J. Res. Appl. Agric. Eng., 58 (2013) 81–85.
[22] J. Dach, A. Wolna-Maruwka, Z. Zbytek, Influence of effective microorganisms addition (EM) on composting process and gaseous emission intensity, J. Res. Appl. Agric. Eng., 54 (2009) 49–55.

[23] L. Lazzari, L. Sperni, P. Bertin, B. Pavoni, Correlation between inorganic (heavy metals) and organic (PCBs and PAHs) micropollutant concentrations during sewage sludge composting processes, Chemosphere, 41 (2000) 427–435.
[24] E. Alonso Alvarez, M. Callejón Mochón, J.C. Jiménez Sánchez, M. Ternero Rodríguez, Heavy metal extractable forms in sludge from wastewater treatment plants, Chemosphere, 47 (2002) 765–775.
[25] S. Nomeda, P. Valdas, S.-Y. Chen, J.-G. Lin, Variations of metal distribution in sewage sludge composting, Waste Manage., 28 (2008) 1637–1644.
[26] G.-D. Zheng, D. Gao, T.-B. Chen, W. Luo, Stabilization of nickel and chromium in sewage sludge during aerobic composting, J. Hazard. Mater., 142 (2007) 216–221.
[27] S. Amir, M. Hafidi, G. Merlina, J.-C. Revel, Sequential extraction of heavy metals during composting of sewage sludge, Chemosphere, 59 (2005) 801–810.
[28] A.J. Whittle, A.J. Dyson, The fate of heavy metals in green waste composting, The Environmentalist, 22 (2002) 13–21.
[29] M. He, G. Tian, X. Liang, Phytotoxicity and speciation of copper, zinc and lead during the aerobic composting of sewage sludge, J. Hazard. Mater., 163 (2009) 671–677.
[30] A.A. Zorpas, D. Arapoglou, P. Karlis, Waste paper and clinoptilolite as a bulking material with dewatered anaerobically stabilized primary sewage sludge (DASPSS) for compost production, Waste Manage., 23 (2003) 27–35.
[31] D. Boruszko, J. Szusta, Conceptual Design of a Mixer for Vermicompost, Institute of Technology Innovation, Bialystok University of Technology, 2016 (in Polish).