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IMPACT OF EFFECTIVE MICROORGANISMS BACTERIA ON LOW-INPUT SEWAGE SLUDGE TREATMENT

Six-month experiments have been carried out using pilot installations of low-budget methods of sewage sludge treatment. Sewage sludge was processed using vermiculture or plants such as willow or reed. The study was also conducted in a solar dryer. In some parts of the research, effective microorganisms were used. The results of the sediment research, including: contents of organic and mineral matter, hydration reaction, contents of nitrogen and phosphorus, as well as the indicators of the sanitary condition, were presented. The results confirmed a perceptible influence of the effective microorganisms on the structure of the dry mass of dairy sewage dewatered on reed and willow plots or transformed into vermicompost. A slight, however, apparent difference in a faster and more effective mineralization of organic substances contained in the sludge after half a year of processing, as well as significant reduction of the number of potential pathogenic bacteria was observed.

1. INTRODUCTION

We owe the discovery of effective microorganisms (EM) to professor of horticulture Teuro Higa from the University in Ryukyus on the Japanese Okinawa Island. At the beginning of the eighties of the 20th century Higa gathered a collection consisting of a few dozen of grafts of diverse microorganisms, i.e. bacteria, viruses, protozoans, some fungi and algae. The majority of them were one-cell microorganisms. The mix of organisms collected by Higa was derived from that unusual soil as well as from the masseter of cows raised there and from microorganisms gained from dairies producing milk products in Okinawa [1].

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For over 20 years of study, from more than two thousand grafts, Higa [2] has selected 82 aerobic and non-aerobic microorganisms able to live together in a perfect coexistence. The mix of microorganisms can turn out to be a very universal agent to be used in many fields of our daily life. Many of microorganisms have been used in this combination for centuries or even longer for production of food such as bread, sauerkraut, yogurt, wine, beer etc. EM as a collection of the organisms was provided with a great number of specialized biological tools like enzymes, which ensure their survival and development not only in the soil but also in diverse environments such as water reservoir bottoms (lakes, ponds, garden ponds, etc.), bedding in animal dwelling places, waste dumps, tanks for liquid manure, channels of municipal wastewater and sewage sludge from wastewater treatment plants etc.

A set of enzymes utilized by individual grafts enables degradation of organic matter. Microorganisms cooperating together produce substances which ensure their survival in an aggressive environment full of hostile fungal pathogens. EM effectively draw out microelements trapped in minerals and at the same time transform them into forms easily absorbed by the environment. The composition of EM comprises mainly anaerobes thanks to which chemically free oxygen is released into the environment in the metabolic processes. This is of great importance for the protection of contaminated environment since the antioxidation effect of these microorganisms is very strong. It is worth mentioning that EM technology ranks among others in the prestigious group of so-called authentic technologies. Since the EM was invented, studies on a possible use of the EM in many fields of the environment engineering have been carried out across the world. Many national and international studies confirm the effectiveness of the EM usage in agriculture, e.g. for soil recovery, increase of plant production or intensification of animal production [3, 4]. Some research conducted in India showed a positive effect of compost with EM on the growth and farming of rice [5]. A similar positive impact of the EM on the soil shows their inventor Teruo Higa [6].

However, not all the studies so clearly indicate a positive impact of the EM on crops and soil cultivation. Studies conducted in 2003–2006 in Zürich, where the EM and the Bokashi substrate were utilized for supplying the soil during cultivation, have shown only a slight influence of EM on the size of crops and the soil quality [7]. In the research conducted in South Africa, contrary to expectations, inoculation with effective microorganisms did not positively influence the composting process of pine bark alone or when mixed with the two organic materials tested: goat manure and sewage sludge [8]. Studies on the effect of the EM on the functioning of municipal wastewater treatment plants and the quantity and quality of generated wastewater sludge have also been carried out. Szymański and Patterson [9] at the municipal wastewater treatment plant in Harbour and five mini-sewage treatment plants in the region of Armidale, Australia, have demonstrated, among other things, slightly effective changes in the quantity of wastewater sludge generated at a treatment plant and the increase of the BOD concentration in the wastewater. It was also confirmed that with best conditions established for the EM in reservoirs, a decrease in the co of solid particles (suspension) and a smaller quantity of the sludge, as well as decreased odor severity were observed [10]. Similar results were obtained by Jóźwiakowski [11].

Many studies on the EM usage for purification of different kinds of wastewater have been conducted in China. The application of the EM to purify wastewater from the food industry containing a great amount of starch and wastewater rich in acrylonitrile has been examined at the University of Science and Technology Qingdao. In this case, EMs consisting of many aerobes and facultative anaerobic microorganisms were very effectively used in contact oxygen column [11, 12]. At the South China University of Technology was conducted a study on damage done to the DNA of EM by heavy metals and the effect of this on wastewater purification [13].

The scientists from the Hohai University in China conducted studies on the effectiveness of the dairy effluent purification with various EM doses [14]. In New Zealand the EM is produced from local microorganisms by the Nature Farming Society. It was demonstrated that EM additions can decrease the COD value and the amount of available phosphorus, improve the effect of the sludge sedimentation and decrease the odor severity [15]. Another research was conducted at the University of Guelph, Canada, on the effect of the EM combined with duck weed on the wastewater quality. The studies demonstrated that the application of the combination of the EM and duck weed significantly decreased the amount the ammonium nitrogen, total phosphorus, BOD and the amount of suspended solids in pools [16].

On the other hand, research conducted by the researchers from the Inha University in South Korea demonstrated that EM addition during the organic waste composting process significantly affected the compost ability to increase its ripeness, faster odor reduction and stabilization of ripe compost and allowed to achieve higher nitrogen binding in the soil [17]. The EM application affects also microbiological composition of the environment, i.e. water, wastewater, sludge, compost and soil. This is confirmed by the studies of numerous authors in Poland and abroad [9, 10, 12, 14].

The aim of the present study was to determine the impact of EM on the effectiveness of the sludge treatment from the dairy industry using low-cost methods of treatment. The results presented in this paper are new to this branch of science. The subject of this study involves the impact of the EM on the low-outlay methods of processing wastewater sludge from dairy effluent purification plants. This is especially important in a region where the milk production is one of the largest in Europe.

2. FIELD OF THE STUDY AND EXPERIMENTAL METHODS

The research was conducted using installations designed and made by the author. The installations are shown in Figs. 1, 2 (schemes) and 3, 4 (photographs).

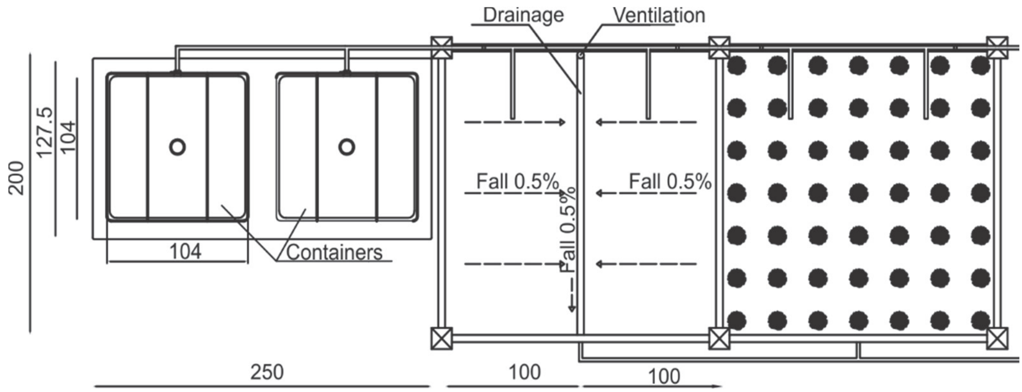

Fig. 1. Repeatable segment of the research installation – top view

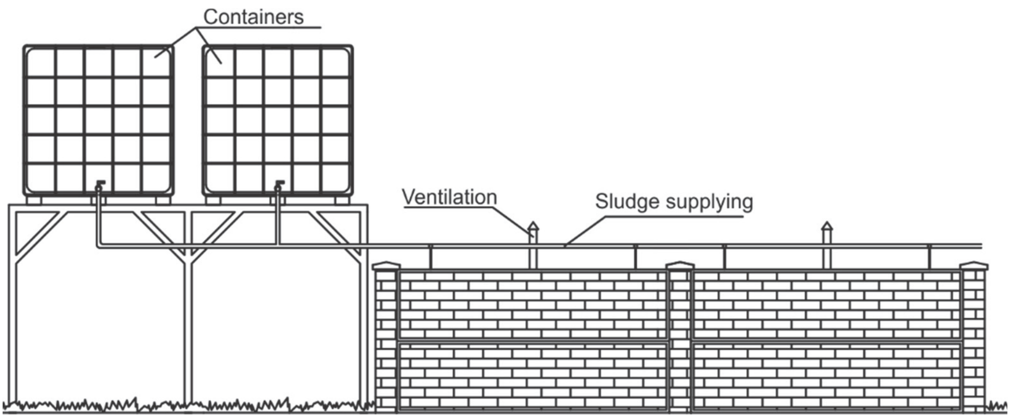

Fig. 2. Repeatable section of the research installation – side view

Fig. 3. Sludge transformed by the vermiculture; photographed by D. Boruszko

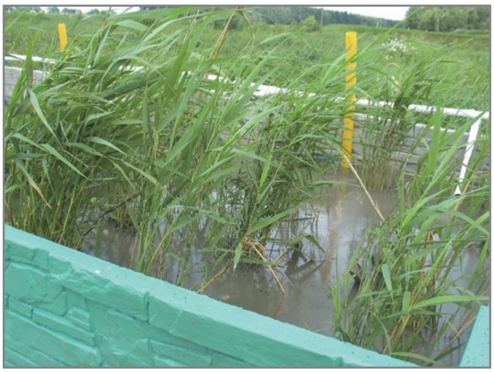

Fig. 4. Reed plot inundated with a dairy excessive sludge; photographed by D. Boruszko

The technical parameters of the installation are as follows.

- Energy willow:

– dimensions of a single experimental plot – length 2 m, width 2 m,

– number of experimental plots – 2,

– height of the plot filling planted – 60 cm (three filling fractions);

– plots with energy willow with one year's cutting from a private breeding of *Salix viminalis* – 4 pcs/m^2,

– feeding the installation with wastewater sludge from a dairy was started in spring at the quantity 0.5 kg dry mass (d.m.) of sludge per m^2 of the plot surface for one inundation, gradually increasing the sludge dose to 2.0 kg d.m. per plot surface and increasing the feeding frequency.

- Common reed:

– dimensions of a single experimental plot – length 2 m, width 2 m,

– number of experimental plots – 2,

– height of plot filling planted – 60 cm (three filling fractions),

– plots with reed were planted with one-year old reed cutting taken from a wastewater treatment plant in Zambrów, at the density of 5 pcs/m^2.

– feeding the installation with wastewater sludge from a dairy was started in spring at the quantity of 0.5 kg d.m. of sludge per m^2 of the plot surface for one inundation, gradually increasing the sludge dose to 2.0 kg d.m. per plot surface and increasing the feeding frequency.

- Vermiculture

– dimensions of a single experimental plot: length 2 m, width 2 m,

– number of experimental plots – 2,

– height of plot filling planted – 15 cm sawdust,

– plots with vermiculture were flooded only once with the same dairy wastewater sludge but of 86% hydration with 1.5 m^3 of sludge per one 4 m^2 plot. Prior to flooding, the plot was provided with a perimeter embankment of sludge of an active population of the California earthworm from the wastewater treatment plant in Zambrów.

- Solar driers

– dimensions of a single experimental plot – length 2 m, width 2 m, steel structure with polycarbonate plates,

– number of experimental plots – 2,

– the same wastewater sludge was fed once to the solar dryers, however, the hydration of this sludge was 86.8% and its quantity was 0.5 m^3 per one 4 m^2 dryer and the depth of the flooding was 12 cm.

Plots were drained and a system to discharge leachate and feed wastewater sludge from a dairy wastewater treatment plant was implemented. In addition, every installation (one planted with reed, one with willow and one with a solar drier) was supplied with a preparation of the company Greenland EM Technology, issued with a certificate of product originality by the Research Organization of Japan. This preparation was fed every 1–2 weeks, diluted with water at the dilution ratio from 1:200 to 1:20, onto the surface of plots and by spraying.

The weather monitoring station was situated at the experimental installation for a continuous monitoring of basic weather parameters, i.e. temperature, precipitation, humidity, wind direction, velocity and insolation.

Plants planted on plots were continuously watched. The subject of the physiochemical and bacteriological analysis were sludge fed to the plots and sludge discharged from research installations in the course of the vegetation period and at the end of this period. The study was carried out in the vegetation period from April to October 2010 in monthly intervals (7 series).

During the study of dairy sludge from solar driers, tests were conducted every 7 days for 5 weeks. The analysis included determination of the following parameters: hydration, dry mass, content of mineral and organic substances, concentration of biogenic elements (nitrogen and phosphorus) and sanitary indicators (*Escherichia coli*, enterococcus, total fungi and molds).

The physicochemical analysis included determination of the organic substance, reaction pH, contents of nitrogen (N) and phosphorus (P) according to PN-Z-15011 -3:2001. Phosphorus was determined by the molibdenous method after mineralization in sulfuric acid and hydrogen peroxide. Dry mass was determined according to the Polish Standard PN-EN 12880:2004.

E. coli were determined according to US EPA method 1681 [18]. Enterococcus were determined by the filtration method on a Slanetz–Bartley medium according to the PN-EN ISO 7899-2:2004 standard [19]. The total amount of molds and fungi was determined on a Sabourauda medium.

3. RESULTS

The dry mass contents of the dairy sludge during the experiment is shown in Fig. 5. The most effective dewatering of the sludge within the vegetation period was achieved at the installation with the energy willow with EM (increase in the dry mass from 4.5% to 25.9%). Somewhat lower was the effectiveness of dewatering achieved at the reed plot with EM (increase from 4.5% to 22.5%). In the sludge processed by the California earthworms combined with EM, the sludge dry mass increased from 13.2% to 20.9%. Lower effectiveness of dewatering dependent of the applied method was achieved in all kinds of sludge processed without the EM addition.

Figures 6 and 7 present the results concerning sludge mineralization. The highest decomposition of organic substances and increase of the contents of mineral substance were achieved in the sludge dewatered by reed with the addition of EM (organic substances decomposed from an initial content of 85.4% d.m. to 70.1% d.m. at a parallel increase of mineral substances from 14.6% d.m. to 29.9% d.m.). A lower mineralization degree of sludge was recorded for installations with energy willow and vermiculture.

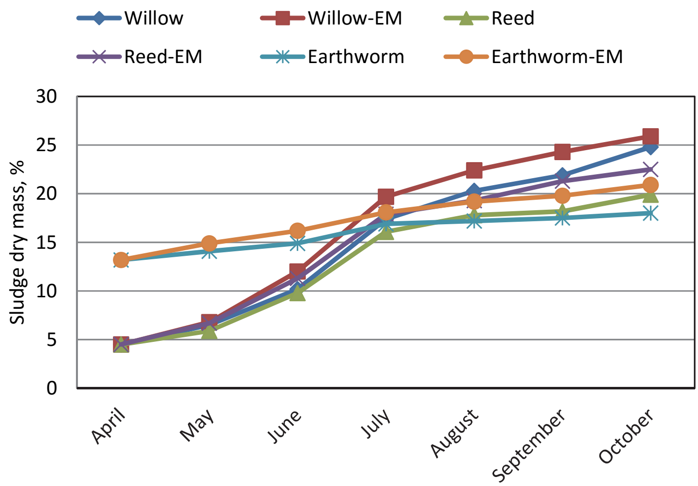

Fig. 5. Dry mass of the dairy sludge in the course of experiments under various sludge processing conditions

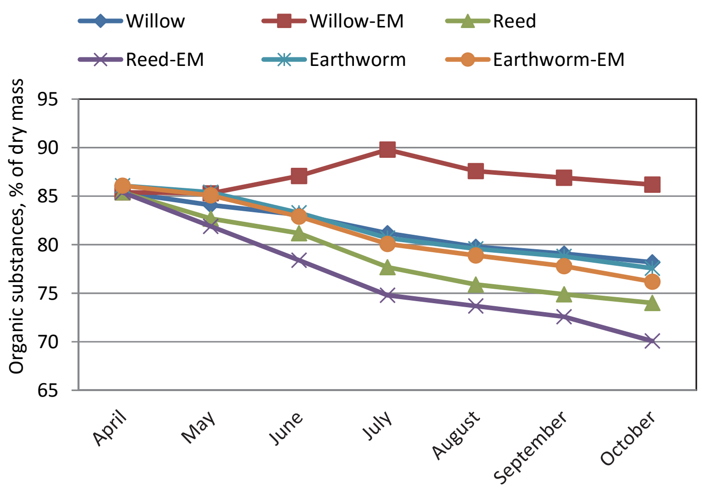

Fig. 6. Contents of organic substances in the dairy sludge during experiments under various sludge processing conditions

pH values of the processed sludge during the experiment are shown in Fig. 8. Over the entire study period, in the sludge transformed by Californian earthworm, pH did not change, remaining at the level of 7.2. The lowest acidity (pH = 5.8) was recorded in the sludge dewatered for 6 months on the plot with energy willow combined with EM.

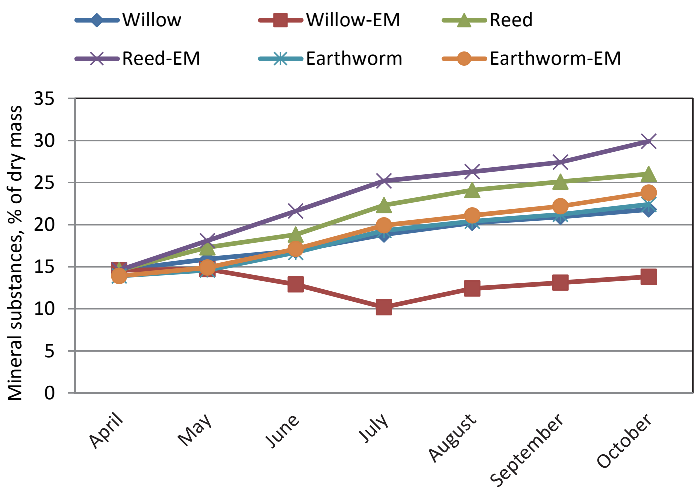

Fig. 7. Contents of mineral substances in the dairy sludge
during experiments under various sludge processing conditions

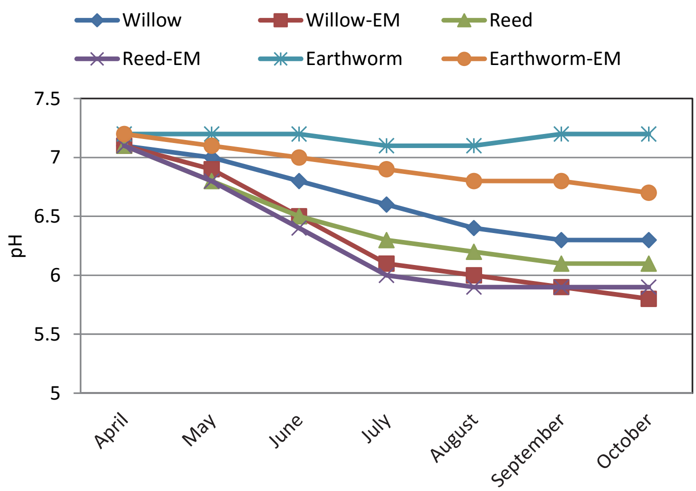

Fig. 8. pH of the dairy sludge during experiments
under various sludge processing conditions

The biogenic compound content (nitrogen and phosphorus) in the dairy sludge during the study is shown in Figs. 9 and 10. The highest reduction of the total nitrogen was achieved in the sludge processed by vermiculture with EM (from 9.1% d.m. to 6.1% d.m.), and the lowest in the sludge dewatered on the plot with energy willow and EM (from 9.3% d.m. to 8.6% d.m.). In the case of the sludge dewatered on the plots with willow and reed, the EM addition resulted in a higher nitrogen content in the sludge.

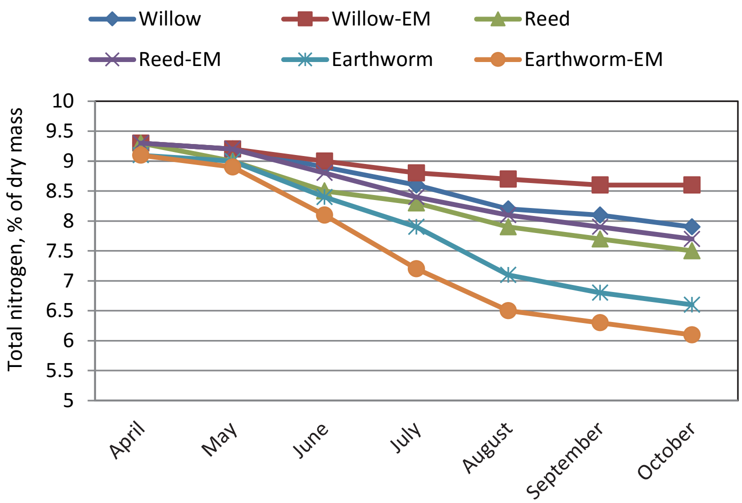

Fig. 9. Contents of total nitrogen in the dairy sludge
during experiments under various sludge processing conditions

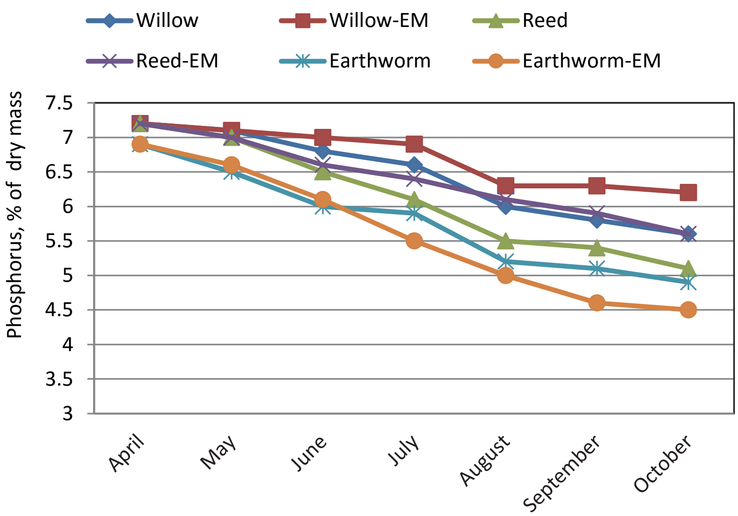

Fig. 10. Contents of phosphorus in the dairy sludge
during experiments under various sludge processing conditions

The phosphorus content, like that of nitrogen, was the lowest in the sludge transformed by the vermiculture with EM (the observed decrease was from 6.9% d.m. to 4.5% d.m.), and the highest one in the sludge dewatered on the plot with energy willow and EM (the observed decrease was from 7.2% d.m. to 6.2% d.m.). In the case of the sludge dewatered on plots with willow and reed, the EM addition resulted in a higher nitrogen content in the sludge.

Figure 11 shows the results obtained in solar driers. The drying time in both driers was 35 days. The decomposition of organic substances was slightly higher in the sludge dried with EM (from 86.1% d.m. to 68.0% d.m.) than in the sludge without the EM addition (from 86.1% d.m. to 70.7% d.m.). Similarly, in the case of nitrogen and phosphorus, the EM addition caused the final content of these elements in dried sludge to be slightly lower than that in sludge dried without EM.

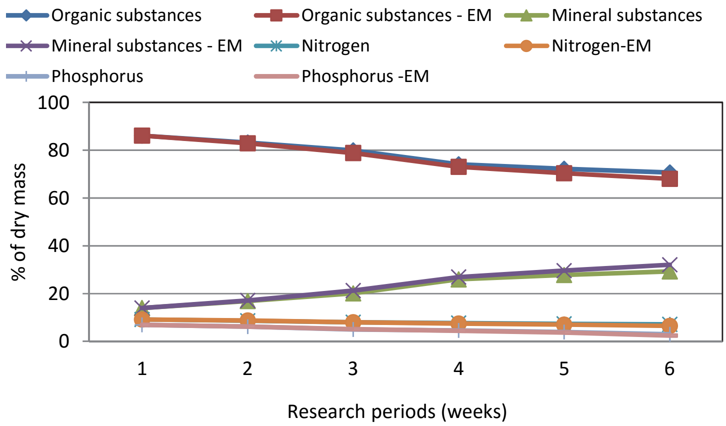

Fig. 11. The results of processing in the dairy sludge in solar driers

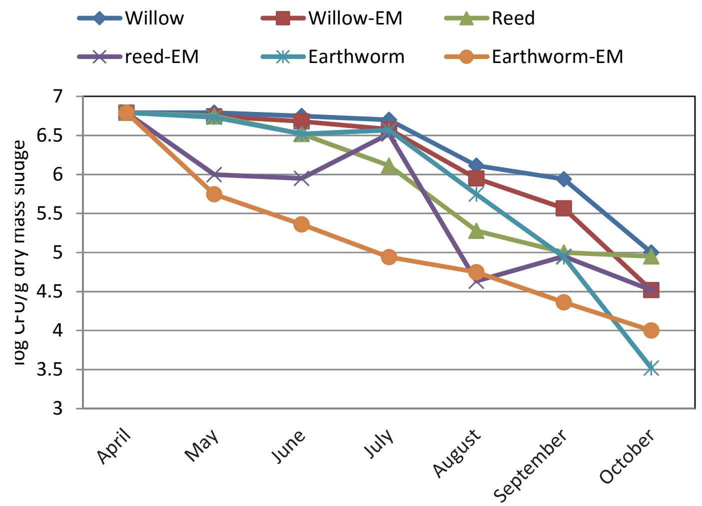

Fig. 12. Contents of *E. coli* in the dairy sludge during experiments under various sludge processing conditions

The results of the microbiological analyses of processed sludge are presented in Fig. 12 and Table 1. The highest decrease of the CFU number was recorded in case of *E. coli* and the lowest in case of fungi and mold. The EM addition to the sludge caused a greater final decrease in the quantity of examined microbiological indicators as compared to the sludge processed by the same method but without EM. The number of CFU of *Enterococcus*, fungi and mold, for the majority of processed sludge after 3 months of processing, was higher than in "raw" sludge although after 3next months, a clear reduction of this number was recorded. After a period of adaptation, growth of microorganisms was observed if the conditions such as availability of nutrients, temperature and the contents of moisture were favorable for this kind of microorganisms after application of sewage sludge.

Table 1

Results of the microbiological analysis in the processed sludge [CFU/g of sludge d.m.]

Microbiological indicator	Month of research	Willow	Willow with EM	Reed	Reed with EM	Vermiculture	Vermiculture with EM
E.coli	April	6.2×10^6	6.2×10^6	6.2×10^6	6.2×10^6	6.2×10^6	6.2×10^6
	May	6.2×10^6	5.6×10^6	5.6×10^6	1.0×10^6	5.4×10^6	5.6×10^5
	June	5.6×10^6	4.8×10^6	3.3×10^6	8.9×10^5	3.3×10^6	2.3×10^5
	July	5.0 E +06	3.8×10^6	1.3×10^6	3.3×10^6	3.7×10^6	8.7×10^4
	August	1.3×10^6	8.9×10^5	1.9×10^5	4.3×10^4	5.6×10^5	5.6×10^4
	September	8.7×10^5	3.7×10^5	1.0×10^5	8.9×10^4	8.7×10^4	2.3×10^4
	October	1.0×10^5	3.3×10^4	8.9×10^4	3.3×10^4	3.3×10^3	1.0×10^4
Enterococcus	April	7.5×10^4	7.5×10^4	7.5×10^4	7.5×10^4	7.5×10^4	7.5×10^4
	May	6.2×10^5	1.0×10^5	5.2×10^5	6.4×10^5	3.8×10^5	1.0×10^5
	June	6.2×10^5	4.2×10^5	7.9×10^5	8.2×10^5	1.0×10^5	4.8×10^4
	July	3.3×10^5	1.1×10^6	1.5×10^6	1.1×10^6	4.8×10^4	6.7×10^3
	August	1.0×10^5	6.7×10^5	7.8×10^5	5.1×10^5	3.8×10^4	4.4×10^4
	September	2.3×10^5	3.8×10^4	5.6×10^4	2.1×10^5	5.6×10^4	4.0×10^4
	October	4.8×10^4	2.1×10^4	6.2×10^4	4.4×10^4	3.8×10^4	2.3×10^4
Fungi and molds	April	9.5×10^6	9.5×10^6	9.5×10^6	9.5×10^6	9.5×10^6	9.5×10^6
	May	4.8×10^7	6.9×10^6	1.2×10^7	2.8×10^7	8.8×10^6	1.6×10^7
	June	7.3×10^7	4.2×10^7	8.6×10^7	3.3×10^7	5.6×10^7	9.2×10^6
	July	1.1×10^7	3.3×10^7	1.3×10^7	1.3×10^7	2.1×10^7	6.5×10^6
	August	6.6×10^6	2.1×10^7	4.8×10^7	4.8×10^6	3.4×10^7	8.5×10^6
	September	2.8×10^6	6.6×10^6	8.2×10^6	5.6×10^6	7.2×10^6	3.8×10^6
	October	3.3×10^6	1.9×10^6	4.3×10^6	4.3×10^6	3.5×10^5	5.5×10^6

In the research of agricultural utilization of the dairy wastewater sludge, no attempt was made to use low-outlay methods to process it or compost production and use of EMs in order to produce more effectively artificial fertilizers and a quicker decompose organic matter discharged into the soil. Both national and international studies related to the production of compost, vermicompost, means of reclamation/restoration and natural fertilizers are primarily related to municipal sludge of a composition different than that of dairy sludge [20–23].

The results obtained confirmed a perceptible influence of the EM on the structure of the dairy sewage dry mass dewatered on reed and willow plots and transformed into the vermicompost. A slight, however, apparent difference in a faster and more effective mineralization of organic substances contained in the sludge after half a year of processing was achieved (reduction in the number of potential pathogenic bacteria). The highest decomposition of organic substances and increase of mineral substance was achieved in the sludge dewatered by reed with the addition of EM (mineral substances decomposed from a an initial content of 85.4% d.m. to 70.1% d.m. at a parallel increase of mineral substances from 14.6% dry mass to 29.9% dry mass). This is comparable to the results of the study on municipal sewage sludge and dairy wastewater, where lower amounts of sludge and a quicker decomposition of organic matter were achieved after adding EM [14–16].

Similarly, insignificant decrease of pH was observed, especially in sludge dewatered on willow and reed plots but also in vermiculture and solar drier systematically supplied with EM. This is confirmed by other researchers of municipal sewage sludge [9]. This experiment was undertaken check if the application of EM may reduce the volumes of sewage sludge produced in on-site wastewater treatment systems (septic tanks). During the application of EM, no appreciable reduction in suspended solids content was observed with minimal influence on pH. It was concluded that the use of EM has a minimal effect on the solids content within a wastewater treatment plant. However, the results suggest that the EM have some influence on certain parameters within on--site wastewater treatment systems (septic tanks) including the creation of optimum conditions within septic tanks, reflecting the conditions for EM [9]. The results of research conducted by Jóźwiakowski show that EM activate and support the processes of sewage treatment in primary settlement tanks. The most important effect of applying EM is reduction in sediment volume and nearly complete decomposition of scum and grease in the primary settlement tank, as well as total removal of odors. In a settlement tank exploited for 14 years, after applying EM there was a higher effectiveness observed in removing total suspended soils (from 30.0% to 77.7%) and organic substance measured by the decrease of COD value (from 24.4% to 47.4%) [10].

The presented results also demonstrate that the EM application causes a quicker reduction of nitrogen and phosphorus in the mass of processed dairy sludge. This may be proven by the fact that the use of EM resulted in faster decomposition of organic forms and higher bioavailability of these elements. Studies conducted in this field shall be extended to individual forms of these biogenic elements.

The results of microbiological analyses of processed dairy sludge demonstrate that some results correspond with those of other studies. Research of EM rejuvenation, EM addition to treat dairy effluents are conducted in the laboratory and field pond systems in New Zealand [14]. Results obtained show that EM addition to dairy effluents can decrease COD and available phosphorus content. Rejuvenated EM solution exhibits biological flocculation characteristics through increasing the amount of sludge sedimentation. There is little difference among the effects of a treatment, that is, effects of different EM addition ratios and incubation methods on pollutant removal in dairy effluent is not significant in those treatments [14, 15].

4. SUMMARY AND CONCLUSIONS

The use of the EM in low-outlay methods of processing sewage sludge which comes from purification of dairy sewage showed that continuation of studies in order to confirm the effect of the EM on the quality of sludge and process technical parameters is justified.

The EM application caused a more effective reduction in the number of potential pathogenic bacteria (*E. coli*), however, the overall content of bacteria during the first period of the said application increased, in particular the content of the enterococci, fungi and molds.

Methods of a low-outlay processing of the sewage sludge can be an inexpensive and efficient way to manufacture high-value fertilizers and soil improving means. Introduction of EM into these processes intensifies the effect of plants and microorganisms on creation of swampy environments for sludge purification (energy willow and reed) and the effect of the California earthworms on the vermicompost.

ACKNOWLEDGEMENTS

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