Review article

Intensification of sewage sludge composting

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Abstract: *The effect of commercial enzymatic preparations on sewage sludge composting was studied. The process of composting was carried out in industrial conditions with addition of selected enzymatic preparations. The sludge was mineralized in aerobic conditions. It was found that when the tested preparations had been added, the mineralization of organic matter in the composted material was much improved. In a control prism in which no enzymatic preparations were added, more beneficial changes of factors that had an influence on fertilizing value were observed. The range of changes in the factors being analyzed show that the most intensive transformations are reported in the first 8 weeks of the process. After that period the intensity of transformations decreases significantly and differences in changes of the tested parameters are very small.*

Keywords: *biotechnology, sewage sludge utilization, environmental protection, waste management.*

Introduction

Municipal sewage sludge is a by-product of the treatment of domestic sewage. The produced sludge constitutes about 2÷3% of treated sewage volume. The sludge contains over half of the load of pollutants supplied with the wastewater to the treatment plant. Processing and management of sewage sludge constitute one of the main problems related to the operation of wastewater treatment plants [1-5].

The Waste Management Act defines municipal sewage sludge as that coming from the plants for treatment of sewage sludge conveyed from septic tanks and other systems used for treatment of municipal sewage and other sewage of a composition similar to that of municipal sewage [6].

This definition is identical to the concept of sewage sludge assumed in the European Union Directives on environmental protection and municipal sewage treatment [7,8].

The characteristics of sewage sludge change and depend on a sewage type and treatment method. The percentage of industrial effluents and also their composition can have a deciding effect on the formed sludge quality.

Sewage sludge is characterized by the following properties [9,10]:

- significant hydration amounting to 99% for raw sludge,

- high content of organic biodegradable compounds reaching up to 75% dry matter,
- large content of fertilizing components (nitrogen up to 8.75% dry matter, phosphorus up to 8.28% dry matter, potassium up to 0.8% dry matter, calcium up to 8.11% dry matter, magnesium up to 0.72% dry matter),
- diverse content of heavy metals (lead, cadmium, mercury, nickel, zinc, copper, chromium); their highest content is found in the sewage coming from sewage treatment plants located in heavily industrialized cities,
- varying degrees of health hazard (*Salmonella*, eggs of intestinal parasites *Ascaris sp., Trichurius sp., Toxocara sp.*), the biggest one occurring in raw sewage, the smallest one in the stabilized and hygenized sludge,
- small content of organic hazardous substances (PAH, chlorinated compounds – PCB).

The content of organic matter and such elements as nitrogen, phosphorus, potassium, calcium and magnesium causes that sewage sludge has big fertilizing and soil-forming value. These properties determine the biological usability of sludge [11-13].

In the years 2000-2007 in Poland a 35% increase of sewage sludge was observed, in the year 2007 in the municipal wastewater treatment plants 486.1 thousand tons of sludge in terms of dry matter was produced. It is assumed that from 1 m^3 of treated sewage 0.25 kg d.m. of sludge is produced. An increase in the quantity of produced sewage sludge is a result of building new facilities based on active sludge technology and an increase of the degree of sewage effluent treatment due to the modernization of the already existing treatment plants or the use of chemical reagents in treatment processes [14, 15].

Sludge produced in 2007 in wastewater treatment plants was managed as follows [16, 17]:

- 35.3% was stored temporarily in wastewater treatment plants,
- 21.4% was used in land reclamation, including farmland,
- 20.8% was stored at dumping sites,
- 17.6% was used in agriculture,
- 4.6% was used in the production of compost and fertilizers,
- 0.3% was treated thermally.

Basic requirements of sewage sludge management are given in the Waste Management Act according to which sewage sludge management is a priority over all other utilization methods, especially over the deposition at dumping sites. Sewage sludge management is preceded by the processes whose aim is to stabilize and decrease the mass and volume of sludge.

According to paragraph 43 of the Act, sewage sludge can be used [6]:

- in agriculture, meant as cultivation of all types of crop yields introduced to commerce, including crops for fodder production,
- in land reclamation, including farmlands,

- in the adoption of lands for determined purposes following from waste management plans, spatial management plans or development orders,
- in the cultivation of plants for compost production,
- in the cultivation of plants not to be used for consumption and fodder production.

Sludge management methods listed in the Act are called biological use [18,19].

In the regulation of 1 August 2002 on municipal sewage sludge we can find requirements which must be met when municipal sewage sludge is used for the purposes mentioned in paragraph 43 of the Waste Management Act. This regulation defines among the others the maximum admissible content of heavy metals or pathogenic organisms in the applied sludge [20].

In the National Program of Municipal Sewage Treatment it is assumed that in the nearest future sewage sludge deposition will be limited. A preferred tendency in sludge management will be its biological use. The National Plan indicates also composting as the most appropriate method to prepare sludge for its use in soil [15].

Composting causes that sludge is stabilized, pathogenic organisms are destroyed, mass and hydration are reduced. Organic matter is used as a fertilizer, soil-structure forming and reclaiming material. Compost constitutes a valuable organic fertilizer which can replace cow dung. Composting can be used as a final process in sludge refining to obtain high-quality material for biological use, provided heavy metal standards are satisfied. This enables a production of mature, humic, fully stabilized material of soil smell and loose structure. The process requires mixing of the sludge with a structure-forming material, e.g. sawdust or straw. It is advantageous for the process to add biopreparations which enhance biomass decomposition [21-24].

Experimental

Materials

Sewage sludge

Excess sludge from a secondary settlement tank, taken after prior dehydration in a belt press. Sewage sludge composition is given in Table 1.

Straw

Wheat straw, pressed and cut into 5÷15 cm long pieces, was used as a filling material.

Commercial preparations to support composting processes

Preparation A

A preparation containing proteolytic enzymes, obtained in the process of biosynthesis with the use of *Aspergillus niger,* to hydrolyze proteins in technical applications.

Characteristics of the preparation:

- Proteolytic activity – 80 000 JH/ml,

- The unit of proteolytic activity (JH) determines the amount of enzyme which during hemoglobin decomposition in standard conditions (2% solution of hemoglobin denatured with urea at pH 4.0, temperature 30°C, reaction time 60 minutes) releases in 60 minutes such an amount of products soluble in trichloroacetic acid which in the reaction with Folin-Ciocalteu reagent is equivalent to one millimol × 10^{-4} tyrosine,
- Liquid of dark brown color,
- Completely soluble in water,
- Reaction of the preparation: pH 3.4÷3.8,
- Density: 1.21÷1.26,
- The presence of accompanying enzymes; pectinase, cellulase and glucoamylase appear at the highest concentrations,
- Optimum temperature of proteases activity in Preparation A: 35°÷50°C (optimum 45°C),
- Optimum pH range is 3.5÷5.0 (optimum pH 4.5).

Preparation B

Enzymatic preparation containing proteolytic enzymes, obtained in the process of biosynthesis with the use of genetically unmodified strain of *Bacillus subtilis* in the hydrolysis of proteins in technical applications.

Characteristics of the preparation:

- Proteolytic activity – 100 720 JH/ml,
- Liquid of dark brown color,
- Completely soluble in water,
- Reaction of the preparation: pH 5.1÷5.4,
- Density: 1.12÷1.15,
- The presence of accompanying enzymes; α-amylase appears at the highest concentration 30÷60 JAS/ml,
- The unit of α-amylase activity (JAS) determines such an amount of the enzyme which hydrolyzes 1 gram of starch to dextrins during 1 hour, at the temperature 30°C,
- Optimum temperature of proteases activity in Preparation B: 40°÷55°C (optimum 50°C),
- Optimum pH range is 6.0÷8.0 (optimum pH 7.0).

Methods

A composted mixture of the sludge and filling material (straw) was analyzed. The following determinations were made:

- dry matter,
- mineral matter,
- organic matter,
- total Kjeldahl nitrogen (TKN),
- phosphorus (orthophosphates),

- potassium.

The analyses were made using the methodology proposed by Hermanowicz and according to the standards approved by the US Environmental Protection Agency [25,26].

Experimental set-up and process run

The composting process was carried out in industrial conditions in a 6×6×4 m tank (length/width/depth). The tank was divided into three parts (boxes) in which excess sludge mixed with straw at the ratio 5:1 was composted. In the first box Preparation A was added in the amount of 0.83 liter per 1 m^3 mass of compost, in the second one Preparation B was added in the amount of 0.83 liter per 1 m^3 mass of compost. The third box was a control box in which composting was carried out without any addition of preparations. In each box there was 20 m^3 of composting material. To ensure proper biodegradation conditions, in all boxes a system was installed to spray the prisms with effluents generated during composting. The prisms were aerated through grates placed below the sludge being composted. The whole chamber was covered with canvas to avoid wetting of the compost mass by rain or snow and excess evaporation of the liquid with which the compost was moistened.

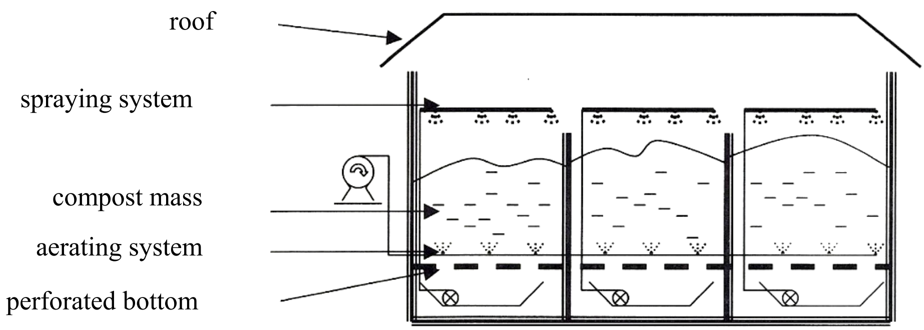

Figure 1. Schematic of the installation for sewage sludge composting

The composting process was carried out for 6 months. In this time, 300m^3 air/h was supplied to the composted mass. Samples from particular boxes were analyzed at the beginning of the process, and next after 4, 6, 8 and 24 weeks. The samples were taken always from the same sites in the prisms, and then they were mixed thoroughly to make them homogeneous.

In all samples the composting process was estimated on the basis of changes in dry matter, mineral and organic material, fertilizing value (N, P, K).

Results and Discussion

The determined composition of sewage sludge being composted meets requirements included in the regulation of 1 August 2002 on municipal sewage sludge [20]. The tested sludge can be used for the purposes mentioned in paragraph 43 of the Waste Management Act [6]. The determined concentrations of heavy metals are considerably lower than those mentioned in the regulation. The biggest environmental hazard are mercury, cadmium and nickel, whose concentrations were lower than the admissible values by 94%, 72.3% and 31.5%, respectively. The tested sludge meets also microbiological criteria, i.e. it does not contain *Salmonella* and the count of eggs of intestine parasites does not exceed the standard.

In the first 4 weeks, in the composted mixtures a systematic growth of dry matter concentration was observed (Figure 2). Its maximum value was determined in the 4th week of the process. In the prism with addition of Preparation B it was 0.213 $g_{d.m.}$/g. A lower content of dry matter – 0.193 $g_{d.m.}$/g was determined in the prism with addition of Preparation A. Since the fourth week of the composting process a systematic decrease of dry matter content is observed. After 24 weeks of composting dry matter concentration in the boxes with addition of Preparation B and Preparation A was 0.146 $g_{d.m.}$/g and 0.160 $g_{d.m.}$/g, respectively. Similar changes were observed in the control prism in which dry matter concentration after 24 weeks of the process was 0.152 $g_{d.m.}$/g.

Table 1. Physicochemical and microbiological composition of composted sewage sludge

No.	Indicator	Unit	Indicator value	Admissible maximum value for sludge used in agriculture and land reclamation for farming purposes*
1	Reaction	pH	7.67	
2	Hydration	%	80.90	
3	Dry matter in sludge	%	19.10	
4	Organic dry matter	% d.m.	48.70	
5	Total phosphorus	% d.m.	10.20	
6	Total Kjeldahl Nitrogen	% d.m.	13.90	
7	Ammonium nitrogen	% d.m.	0.43	
8	Calcium	mg/kg d.m.	56.00	
9	Magnesium	mg/kg d.m.	2.97	
10	Zinc	mg/kg d.m.	1170.70	2500
11	Lead	mg/kg d.m.	102.90	500
12	Cadmium	mg/kg d.m.	2.77	10
13	Copper	mg/kg d.m.	124.50	800
14	Chromium	mg/kg d.m.	30.70	500
15	Nickel	mg/kg d.m.	31.50	100
16	Mercury	mg/kg d.m.	0.30	5
17	*Salmonella*	Count in 100g	0	0
18	Eggs of intestine parasites *Ascaris sp., Trichuris sp., Toxocara sp.*	Count in 1 kg d.m.	8	10

* According to the regulation of 1 August 2002 on municipal sewage sludge [20].

Table 2. Changes in determined parameters during composting process

Indicator	Unit	Compost without additions (control sample)		Compost with addition of Preparation A [0.83 dm^3/m^3]		Compost with addition of Preparation B [0.83 dm^3/m^3]	
		8 weeks	24 weeks	8 weeks	24 weeks	8 weeks	24 weeks
Dry matter	$g_{d.m.}/g$	-0.6%	-2.6%	+4.5%	+2.6%	+1.9%	-6.4%
Mineral matter	$g_{p.m.}/g$	+23.1%	+30.8%	+148.7%	+166.6%	+174.4%	+184.6%
Organic matter	$g_{v.c.}/g$	-14.6%	-21.4%	-43.6%	-52.2%	-55.6%	-70.1%
Total Kjeldahl Nitrogen	$g\ TKN/g_{d.m.}$	-75.5%	-78.7%	-16.0%	-27.7%	-21.3%	-19.1%
Potassium	$g/g_{d.m.}$	+102.6%	+115.8	+36.8%	+34.2%	+10.5%	+15.8%
Orthophosphates	$g/g_{d.m.}$	+441.2%	+482.6	+64.7%	+88.2%	+82.3%	+106.0%

Compost – a 5:1 sludge and straw mixture + denotes growth - denotes reduction

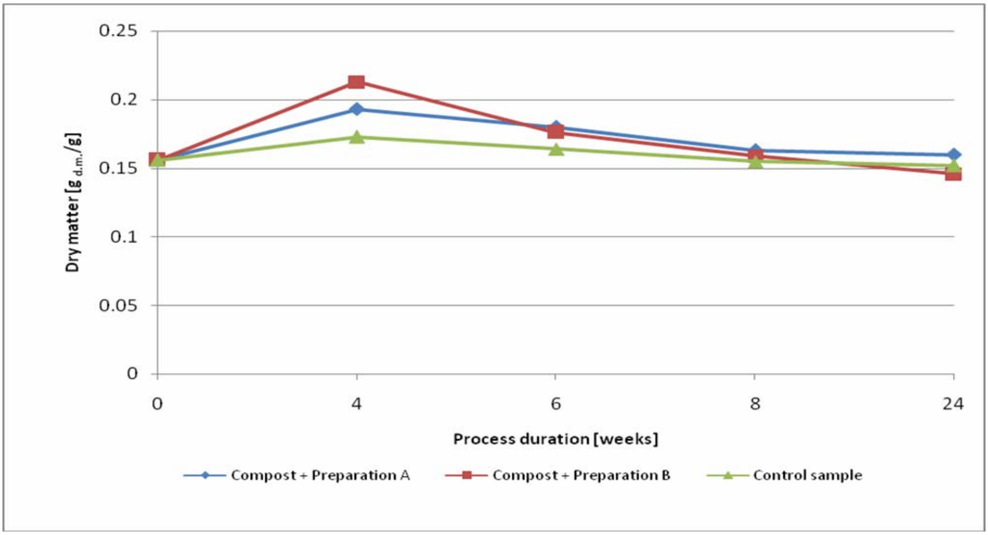

Figure 2. Changes in dry matter concentration during the composting process

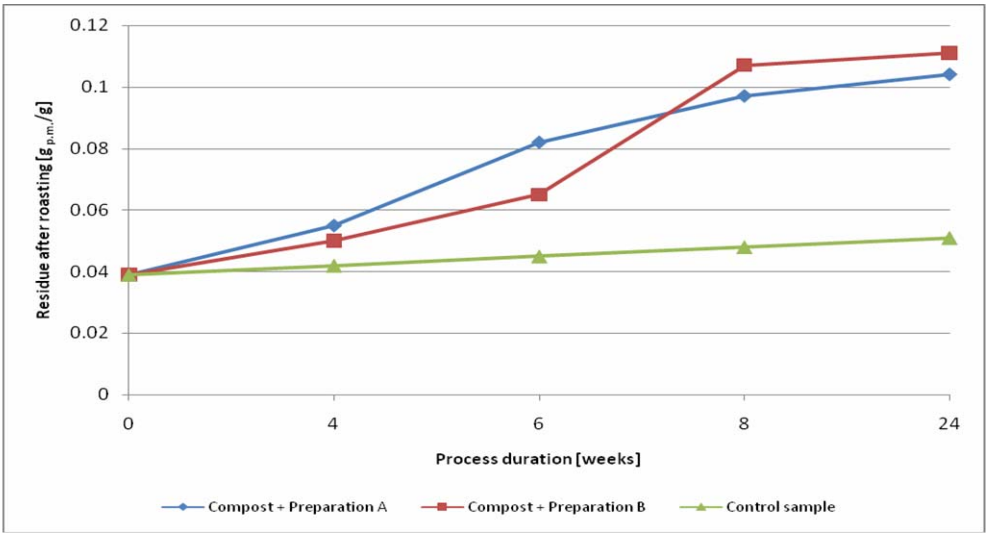

Figure 3. Changes of residue concentration after roasting during the composting process

During the composting process, in all prisms an increase of mineral matter concentration was reported (Figure 3). In the control sample this value grew from the initial 0.039 g $_{p.m.}$/g to 0.051 g $_{p.m.}$/g in the 24th week of the process. In the samples with Preparations A and B the mineral matter concentrations in the same period were higher in reference to the control sample by 203.9% and 217.6%, respectively. In the 24th week of the process in the compost containing Preparation B the mineral matter concentration was by 6.3% higher as compared to the prism to which Preparation A was added.

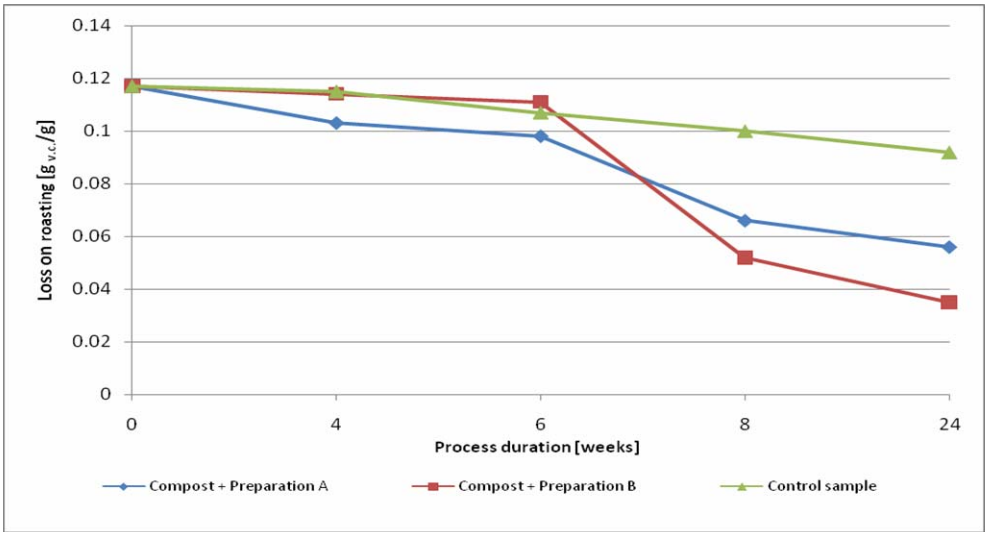

Figure 4. Changes in loss on roasting during the composting process

Changes in dry matter concentration illustrate transformations that occur during the composting (Figure 4). Up to the 6th week of the process the mineralization of organic matter contained in the composted biomass was relatively slow. In the control sample and in the prism with addition of Preparation B in this time the organic matter reduction was 8.5% and 5.1%, respectively. In the sample with Preparation A the loss of organic matter in the 6th week of the composting process was the highest amounting to 16.2% in reference to the initial concentration. After that time, in the composted prisms with addition of the preparations a remarkable reduction of organic matter content was reported. In the control sample in the 24th week of the experiment the organic matter concentration was 0.092 $g_{v.c.}/g$, while in the samples with Preparations A and B the concentration was lower by 39.1% and 62.0%, respectively.

Literature survey [27,28] confirms a similar character of changes of organic matter in the composting process.

The so far obtained results concerning changes in dry matter as well as in mineral and organic matter confirm that the composting process can be intensified and the most advantageous effects are reached for Preparation B.

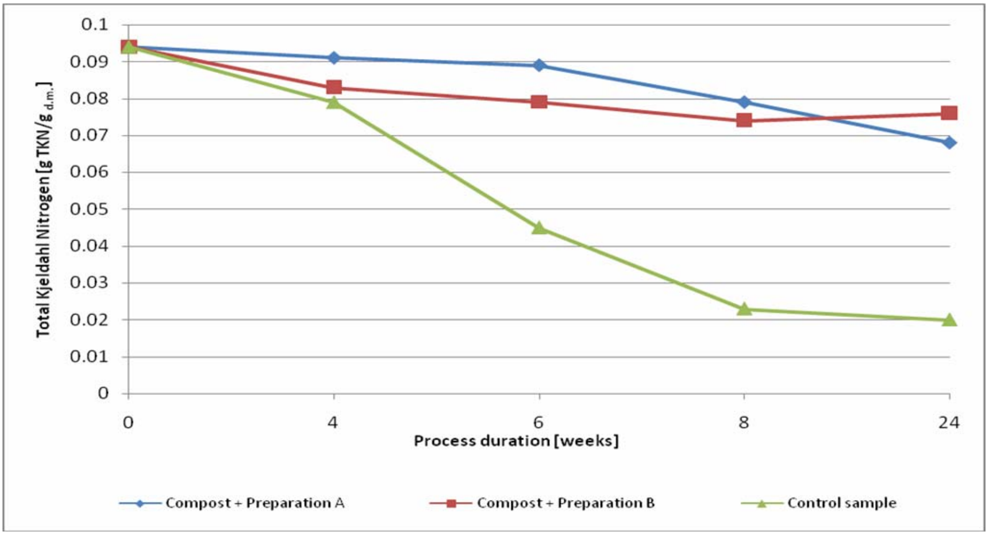

Figure 5. Changes of Total Kjeldahl Nitrogen (TKN) during the composting process

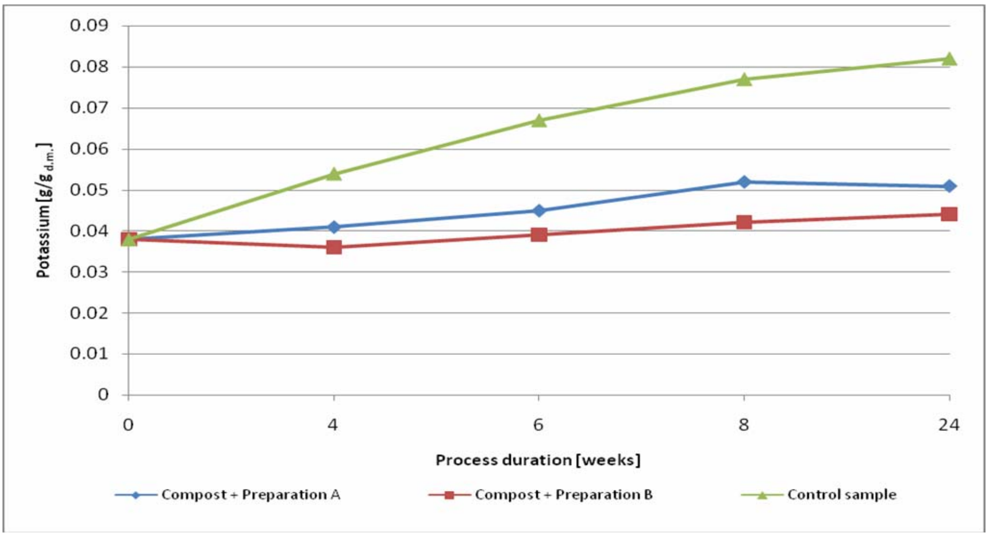

Figure 6. Changes in the concentration of potassium available for plants during the composting process

Fertilizing properties of the composted sludge were determined on the basis of changes in the concentrations of TKN (Figure 5), potassium (Figure 6) and orthophosphates (Figure 7).

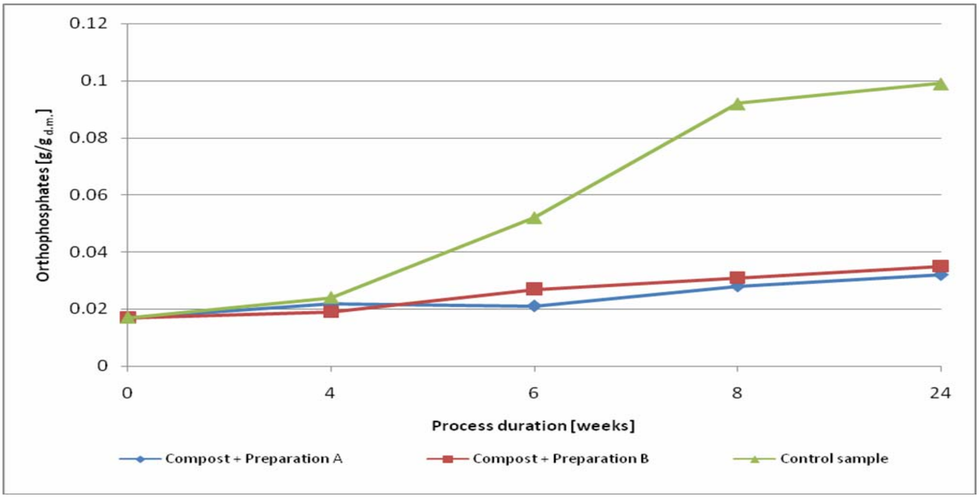

Figure 7. Changes in the concentration of orthophosphates during the composting process

TKN concentration in the control sample was decreasing steadily to reach 0.020 g TKN/g $_{d.m}$ in the 24th week of the process. In the samples with addition of Preparations A and B a decrease in TKN concentration was also observed, but the changes were slower. In the 24th week of the process, TKN concentration in the prism with addition of Preparation A was 0.068 g TKN/g $_{d.m.}$, while in the prism with Preparation B – 0.076 g TKN/g $_{d.m.}$

Bernal *et al.* in their studies on composting described a similar character of changes in TKN [29].

Changes in potassium content during the composting process are shown in Figure 6. An increase in the concentration of potassium available for plants is an advantageous effect of the composting process. The presence of potassium in a plant cell increases osmotic pressure which contributes to a more efficient use of water. Quantitatively, potassium is the nutrient most strongly absorbed by plants. It was proved that over 60 different enzymatic reactions which occur in vegetables are activated by potassium ions. Potassium stimulates also the synthesis of proteins, simple and complex sugars (starch and cellulose) as well as fats and organic acids, particularly citric acid and vitamin C. In the control sample during 24 weeks of the process a steady growth of potassium concentration was observed. In the 24th week it was 0.082 g/g $_{d.m.}$ In the prisms with addition of preparations supporting the process, a lower increment of potassium concentration was reported. After 24 weeks of the process it was 0.051 g/g $_{d.m.}$ for Preparation A and 0.044 g/g $_{d.m.}$ for Preparation B.

During composting a continuous growth of the concentration of orthophosphates was reported (Figure 7). In the first 4 weeks of the process changes were similar for all samples. After that time an intensive increase in the concentration of orthophosphates in the control prism was observed. In the 24th week of the process it was 0.099 g/g $_{d.m.}$ The concentration of orthophosphates in the prisms with addition of Preparations A and B was increasing systematically during the experiments. In the 24th week of the process it was 0.032 g/g $_{d.m.}$ for preparation A and 0.035 g/g $_{d.m.}$ for Preparation B. Prechtl *et al*. described in their studies a similar range of changes in orthophosphates [30].

An increase in concentrations of orthophosphates and potassium is due to the microbiological process of mineralization of organic matter contained in the composted material. These compounds are released by microorganisms from organic combinations and transformed into absorbable soluble forms [31].

In the control prism more advantageous changes in biogenic elements which determine the fertilizing value of compost were reported.

Conclusions

I. The tested enzymatic preparations improve the process of mineralization of organic matter in the composted material in reference to the control prism.

II. During composting, in the control prism a 78% reduction of TKN concentration was observed. In the prisms with addition of Preparations A and B the reduction was lower reaching 27% and 19%, respectively.

III. Addition of preparations enhancing the process of composting led to lower concentrations of potassium available for plants and orthophosphates in the composted biomass, by 42.1% and 66.2%, respectively, in reference to the control sample.

IV. Changes in the analyzed indicators show that the most intensive transformations took place during the first 8 weeks of the composting process. After that time the rate of changes decreases considerably, and differences in the concentrations of tested indicators are small. Due to this, it is economically justified to carry out the process for 8 weeks.

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