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APPLICATION OF POST-FILTERED DIATOMACEOUS EARTH FROM BREWING INDUSTRY IN COMPOSTING

Research has been conducted on composting of diatomaceous earth after beer filtration and selectively collected organic waste. The content of post-filtered diatomaceous earth (PFDE) in experimental composts was 10, 30 and 50 wt. %. During composting, the temperature of the compost heaps was measured as a parameter characterizing the intensity of biochemical changes. The model of dependence of temperature on the composting time was used to compare the temperatures in all experimental mixtures which revealed that the composting in all mixtures was on a similar level. In mature composts, bacteria of Salmonella group and parasites of alimentary canal were not isolated. The content of organic substance on the level above 30% in dry mass and the content of fertilizer parameters (N, P, K) presents the possibility of using composts as organic fertilizers. Micro-plot field experiments were conducted in order to verify the influence of produced compost on the size and quality of plant yield. Vegetable plants were tested in two vegetative seasons in two doses (40 t/ha and 60t/ha) of each compost. Depending on the plant species, the compost containing 30 wt.% or 50 wt. % of diatomaceous earth after beer filtration turned out to be the best one.

1. INTRODUCTION

Post-filtered diatomaceous earth (PFDE) is an industrial waste which is mainly produced in the food industry, especially from the branches of brewing, vegetable, fruit, potato and wine [1]. Post-filtered diatomaceous earth serves as the filter which separates mechanical pollution in liquid products. The average amount of diatomaceous earth used in the production of 10 m^3 of beer is 1200 kg [2].

Beer filtration is designed to remove these residues which settle at the bottom of tanks when beer has been kept stationary in one place. These residues can include proteins, resins and dormant yeast cells. Beer filtration also aims to improve the biological

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constancy of beer by separating the remaining yeast cells [3, 4]. Post-filtered diatomaceous earth waste from the brewing industry contains organic substances within the range determined by the filtration process itself and the pollution level of filtered beer. Post-filtered diatomaceous earth is solely a carrier of organic substances and not organic waste. Waste management should always deal with waste utilization [5]. It is a challenge to reduce the increasing flow of waste. The development of an efficient waste recycling approach will help to explore new opportunities for urban and environmental protection [6]. It is therefore waste which is rarely recycled and used. Composting as a method of organic recycling creates an opportunity to obtain a valuable substitute for natural fertilizer [7–9]. With regard to a considerable part of mineral fraction in post-filtered diatomaceous earth waste from the brewing industry, the content of amorphous silica is at thelevel of 61% in dry mass. Thus, co-composting this waste with other waste of organic type is the best method. Waste balancing deemed to composting needs to be done in such a way so that the content of organic substance in waste deemed as a loss in roasting would be at least on the level of 30% [10].

The modification of compost properties through the addition of appropriate materials is a popular field of compost research. However, post-filtered diatomaceous earth has not been evaluated for this purpose at this point in time. The main goal of this study was to investigate the impact of post-filtered diatomaceous earth waste from the brewing industry on the course of temperature during compost ripening on compost heaps, fertilizer value of composts and part of pollution, and the influence of compost with PFDE on plant yield.

2. MATERIALS AND METHODS

During the experiments, selected organic fraction of municipal waste has been prepared to be used in composting and production of compost with PFDE. The temperature and characteristics of the composting course and fertilizer values of produced composts have been determined. The experiments in composting were conducted on a technical scale. Next, in micro-plot field experiments, the influence of mature compost containing PFDE on the size and quality of yields have been examined.

Preparation of materials and specimens. Biodegradable kitchen waste collected selectively from households and waste from vegetable warehouses were utilized in the experiments. The preparation of compost mixtures mainly consisted in grinding of the organic waste in a grinder. Then the waste was mixed with ground tree branches and bushes in the ratio of 3:1. The mixtures were thereafter composted in a bioreactor functioning for 7 days according to Herhof's technology [11]. After unloading the bioreactor, compost was divided into 4 parts equal in weight. PFDE was then added to three parts of the fresh compost[3] in different proportions (10 wt. %, 30 wt. %, and 50 wt. %.), the fourth part of the compost was PDF free. They were designated as PFDE-10, PFDE-30, PFDE-50, and PFDE-0.

Composting methods. PFDF was not composted in the bioreactor because its minute particles congested the ventilation holes at the bottom of bioreactor, especially in the first stage of the process. The prepared mixtures were separated into 4 experimental heaps, each containing 5 t of the fresh on average. Experimental heaps were placed under the roofing and the temperature was measured at 3 levels (at 1/3 of height from the bottom of the heap, at the centre of the heap, and under its surface). The heaps were aerated by turning them over with a mechanical loader. To prevent anaerobic decomposition, the heap was formed elsewhere so as to turn over each layer of mixture with a loader. The turning over of the compost heaps was executed once a week in the first month of composting, and once every 2 weeks for the remaining time of the composting process. This frequency was determined by a fall in temperature, which was measured at a point halfway up the heap. The heaps were humidified in order to maintain humidity at the level of 60%. The maturity of the experimental compost was verified using the Rottegrad Index Test [12] based on the relationship between the level of decomposition and the temperature as a result of the compost self-heating in Dewar's vessels. Composting experiments were conducted over a two year period. During this time, 16 compost heaps were formed: 4 heaps for each mixture under examination.

Analytical methods. Nitrogen content was examined by the Kjeldal method. Organic carbon content was determined by the Tiurin method and phosphorus content by the colorimetric method. Potassium and calcium were determined by the flame photometry; while magnesium and heavy metals through atomic absorption spectrometry [13].

The presence of *Salmonella* and parasite eggs of the alimentary canal was examined in accordance with Polish Standards (PN-Z-19000-1:2001, PN-Z-19000-4:2001). The occurrence of *Escherichia coli* and other Coli-type bacteria and in the compost was examined using the probe fermentative method [14].

Micro-plot field experiments. Lettuce, onion, and red beet were tested during the experimental phase. The micro-plot field was in the shape of a rectangle 2 m long and 1.5 m wide. The field experiments were conducted by the method of choosing blocks [15] in 4 repetitions. Against the background of unfertilized control objects (with soil not fertilized with compost), fertilizing was compared using 4 different types of the

[3]Due to diversity of terminology in the literature, the authors specify the meaning of fresh and mature compost. Fresh compost has the structure similar to that of the initial substances. Its temperature tends to rapidly increase during composting. Mature compost has a homogenous structure, initial substances are unrecognizable, and its temperature is equal to ambient temperature.

compost. Vegetable plants were tested in two vegetative seasons (in two consecutive years) with two doses (40 t/ha and 60 t/ha) of each compost.

The doses were estimated taking into consideration the balancing of organic and mineral fertilising according to general agricultural practice. Mineral fertilizers used in cultivating are listed in Table 1. Field experiments were conducted on leaching, brown soil of class IV of rye-potato complex of good quality, of agronomical category III (the content of fraction < 0.02 mm was 17%, light soils). The index of soil fertility was examined before the experiments.. The cuttings of lettuce were grown to the size of 20 per m^2, in a span of 20 × 25 cm. The onion (scallion) was grown to the size of 24 per m^2, in a span of 30 × 13 cm. The amount of seeds from beet root was 16 kg/ha, in the span of 30 × 6 cm. After thinning, the span was 30 × 10 cm. During the growing stage, plants were subjected to the action of fungicides, insecticides and herbicides.

Table 1

Mineral fertilizers used in cultivating

Plant	Type of fertilizer							
	Polifoska 6				Ammonium sulphate		Carbamide	
	Mass [kg/ha]	Contents [kg/ha]			Mass [kg/ha]	Contents [kg/ha]	Mass [kg/ha]	Contents [kg/ha]
		N	P	K		N		N
Lettuce	450	27	90	135	221	75	163	75
Onion	450	27	90	135	206	70	152	70
Beet roots	450	27	90	135	139	50	109	50

Statistical methods. The relationship between the temperature of the heap and the day of composting was elaborated using the computer programme Statistica 6.0 applying non-linear estimation and evaluating the model adjustment according to the ratio of explained variation. The plant yield in particular experimental objects was estimated by taking and weighing plants from the area of 1 m^2 of each plot and converting it to t/ha.

3. RESULTS

3.1. TEMPERATURE COURSE DURING THE COMPOST RIPENING ON THE COMPOST HEAPS

The temperature courses for all mixtures during composting are shown in Figs. 1–4. Based on them, it is difficult to make a comparative analysis and specify the following stages of the process.

In order to compare composting processes of particular types of mixtures through the temperature parameter, for each of them, the dependence of temperature of the compost heap on time of composting has been formulated:

$$T_p(t_d) = (\log t_d)^{A\exp(Bt_d)}$$

where: T_p is the temperature in the half-height of the compost heap, t_d – composting time, day, A, B – estimated parameters.

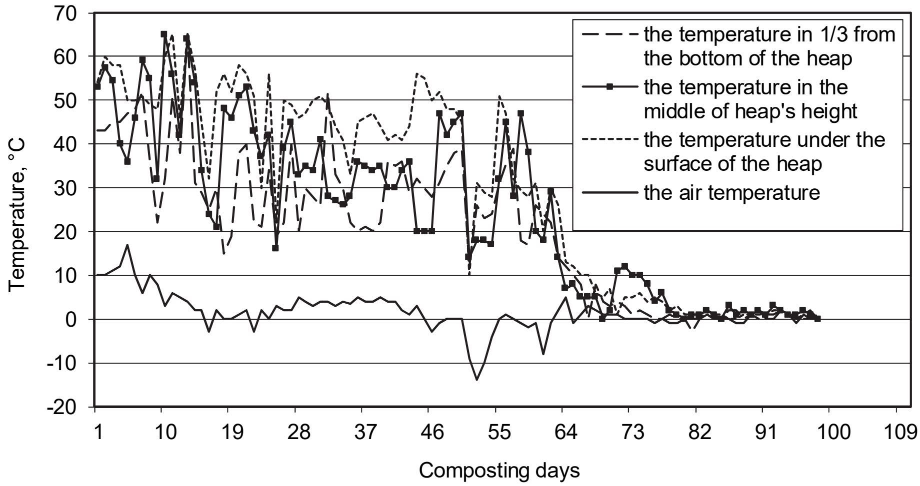

Fig. 1. The temperature courses for the PFDE-0 compost

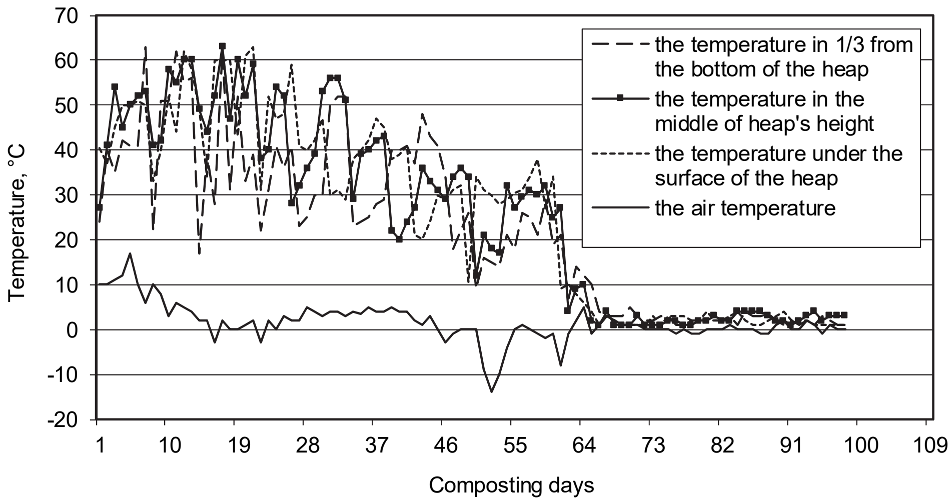

Fig. 2. The temperature courses for the PFDE-10 compost

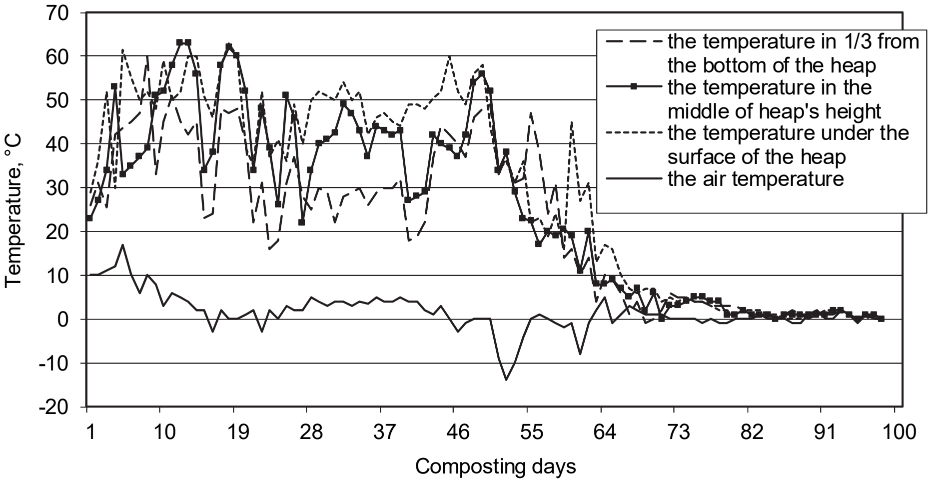

Fig. 3. The temperature courses for the PFDE-30 compost

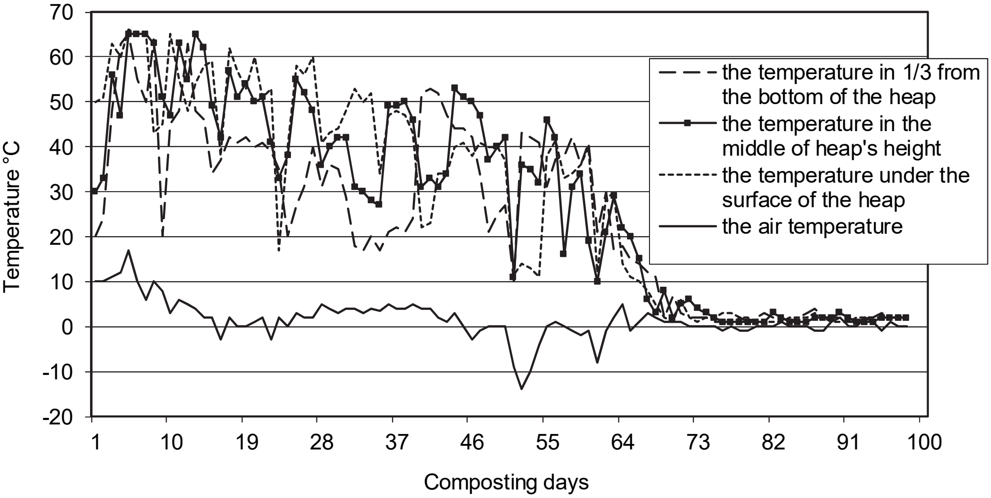

Fig. 4. The temperature courses for the PFDE-50 compost

In all cases, high and essential correlation coefficients between the labelled value and the expected value of the temperature on the corresponding day of composting were obtained (Table 2). The comparison between the courses of the temperature determined by the formula for each experimental compost allows us to observe that regardless the compost type and addition of PFDE, the course of the temperature is maintained at a similar level (Fig. 5).

Table 2

Evaluation of the applied model for various composts

Type of compost	Standard error		Correlation coefficient	Error(RMSE)[a]
	Parameter A	Parameter B		
PFDE-0	76.5654	–0.0329	0.7745	12.7973
	2.7637	0.0012		
PFDE-10	82.5145	–0.0346	0.8646	10.4949
	2.3267	0.0009		
PFDE-30	76.7497	–0.0322	0.8453	10.9837
	2.2539	0.0009		
PFDE-50	86.5294	–0.0330	0.8605	10.9922
	2.3555	0.0009		

[a]The error of the model that determines deviation from the observed value.

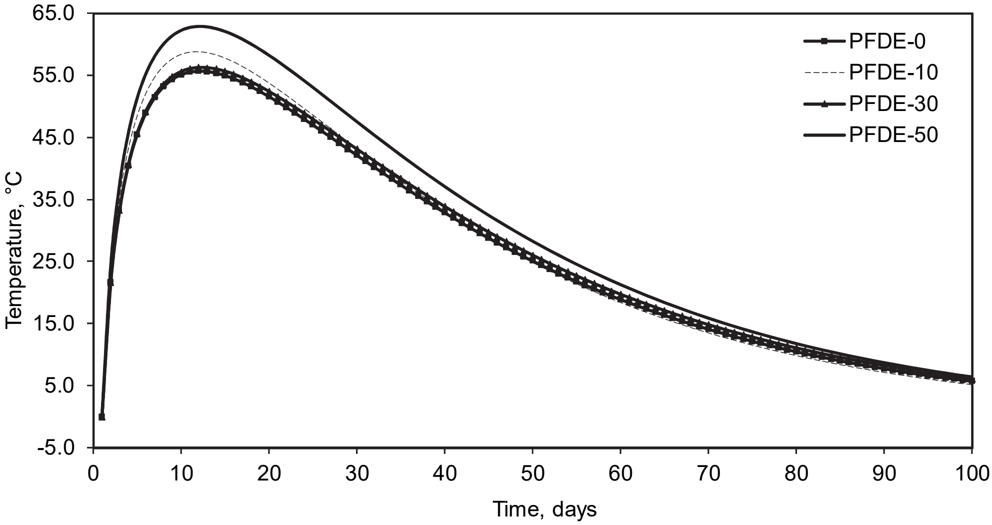

Fig. 5. Dependence of the calculated heap temperature on the composting time for the non-modified compost and modified composts

During the compost ripening on the compost heaps, the stages of this process were specified based on characteristic changes of temperature over time, related to the activity of particular groups of microorganism [16]. The termophilic stage, which is characterized by a sudden increase of temperature, was reached by all experimental heaps at the same time, about a week after the heaps were formed. Temperatures within the range of 50–60 °C were maintained on heaps PFDE-10, PFDE-30 and PFDE-50 over a period of more than 3 weeks, regardless of the measurements of both time and ambient temperature.

The cooling stage was more sudden in the case of heap PFDE-10. It did not have any influence, however, on the total time necessary to complete the process. The equalization of the temperature of compost mass with ambient temperature was carried out in all experimental heaps simultaneously, after a period of about 75 days. As a result of conducting of self-heating tests, all experimental composts reached the maximum temperature of above 30 °C (Rottegrad Index V), which confirms the complete maturity of the compost.

3.2. FERTILIZER VALUE OF THE COMPOSTS AND METAL CONTENT

All the mature composts, regardless of the amount of the PDFE addition, were brown in color, loose in texture and characterized by the smell of fresh garden soil. The supplement of PFDE resulted in a decrease of organic substance in the composts PFDE-10, PFDE-30 and PFDE-50 in relation to the non-modified compost (PFDE-0) which was a consequence of the increase in the proportion of mineral fraction through this addition (Table 3).

Table 3

Fertilizer value of diatomaceous earth after beer filtration
and the mature compost containing post-filtered diatomaceous earth

Sample	pH in water	Content in dry mass [%]								
		Total N	Organic N	Organic C	Organic substance	P	Mg	K	Ca	C:N
PFDE	5.1	2.1100	1.8420	–	24.58	0.349	0.360	1.083	1.788	–
PFDE-0	8.9	1.8121	1.6826	19.20	43.94	0.420	0.480	1.416	2.631	11.41
PFDE-10	8.6	1.2831	1.1558	17.40	41.53	0.442	0.435	1.025	2.252	15.05
PFDE-30	8.6	1.3822	1.2081	23.80	39.36	0.403	0.405	0.916	2.131	19.70
PFDE-50	8.9	1.2956	1.1406	14.30	34.68	0.392	0.518	0.941	2.252	12.54

It does not, however, have a direct influence on the content of other fertilizer ingredients such as phosphorus, potassium, magnesium and calcium. The proportion of the aforementioned elements except for phosphorus was higher than in the content of average manure. A favorable ratio of carbon to nitrogen should be between 11.41 and 19.70 and considerably high values of pH (8.5–8.9 pH) have been obtained regardless of the dose of diatomaceous earth (Table 3). The heavy metal content was influenced by the content of heavy metals in selectively collected organic waste and the content of heavy metals in PFDE. The content of heavy metals in the produced compost is shown in Table 4. It is clear that in all the experimental composts, the content of heavy metals was on a lower level than the requirements set out within this range by Polish legislation. In the majority of European countries there are compost classes which at the same time allows the possibility of using the examined compost. Hogg et al. [17] present the maximum content of heavy metals for compost classes in EU countries as well as binding reference materials.

Table 4

Content of heavy metals in diatomaceous earth after beer filtration
and in the mature composts containing post-filtered diatomaceous earth

Sample	Content in dry mass [mg/kg]						
	Cr	Ni	Cd	Pb	Cu	Zn	Hg
PFDE	38.50	23.45	0.197	5.00	25.00	100.00	0.00044
PFDE-0	3.00	11.06	0.610	41.87	30.00	103.25	0.12100
PFDE-10	25.25	8.69	0.410	22.37	20.13	80.75	0.13400
PFDE-30	24.25	8.69	0.500	21.44	20.75	85.00	0.15600
PFDE-50	24.2	10.00	0.830	35.94	61.75	78.75	0.11800
Admissible value[a]	100.00	60.00	5.00	140.00	–	–	2.00

[a]The decree of Minister of Agriculture and countryside development on 18 June 2008 pertaining to conducting some regulations about fertilizers and fertilization (Dz.U. nr 119, poz. 765 in Poland).

In case of heavy metal pollution in the mature compost, the content of this pollution in organic waste designated for composting is of considerable significance, as indeed is the selective collection of organic waste. Selectively collected bio waste (kitchen and garden waste) contains a considerably lower level of heavy metal pollution in comparison with municipal waste [18]. The quality of the final product, that is the mature compost, is not only the result of composting but is also due to the choice of materials needed for composting.

3.3. SANITARY QUALITY OF THE COMPOST

In sanitary and parasitoligical examinations, the salmonella type bacteria and parasites of alimentary canal (*Ascaris* sp., *Trichuris* sp., *Toxocara* sp.) were not isolated. The titre of *Clostridium perfringens* were recorded at the level of $2\cdot 10^{-4}$; the titre of Coli-type bacteria for all the experimental composts was $2\cdot 10^{-3}$; and the titre of fecal Coli-type bacteria ranged from $2\cdot 10^{-2}$ to $6\cdot 10^{-2}$. According to sanitary evaluation of the soil [14], the experimental composts are polluted with coli-type bacteria. This, however, is pollution characteristic of compost made of waste.

3.4. INFLUENCE OF THE COMPOST ON THE PLANT YIELD

The observations were conducted in cropping lettuce, onion and red beets regarding unfavorable influence of the examined composts (PFDE-0, PFDE-10, PFDE-30, PFDE-50) for 2 vegetative seasons. They did not have any unfavorable influence on the height and growth of these cultivated plants.

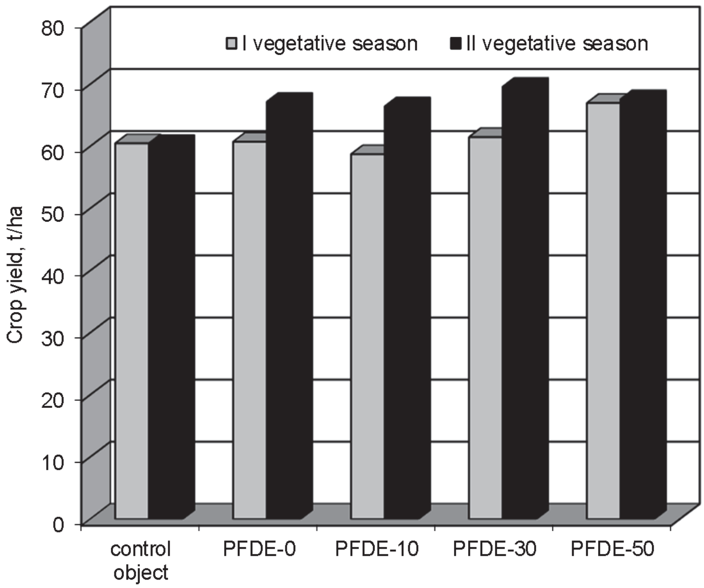

Fig. 6. Yield of lettuce crop (dose of the compost 40 t/ha)

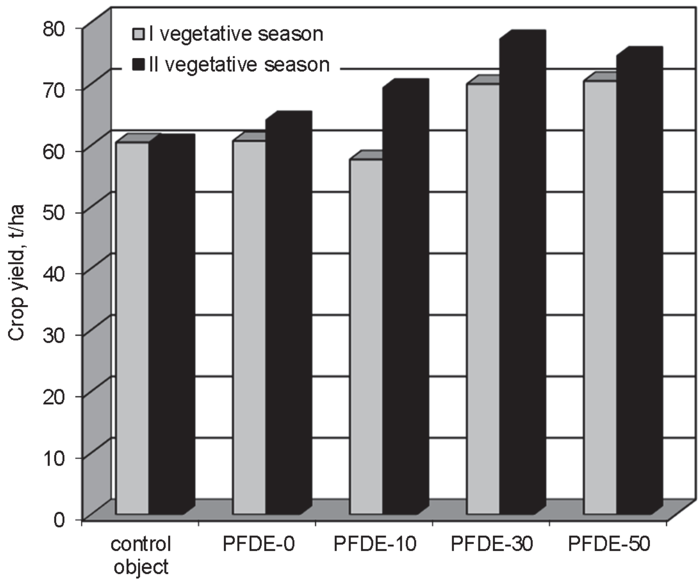

Fig. 7. Yield of lettuce crop (dose of the compost 60 t/ha)

Lettuce in the first vegetative season growing on the compost PFDE-0 in 40 t/ha and 60 t/ha yielded on similar levels ((Figs. 6, 7), of 61 t/ha and 60.5 t/ha, while crops from control plot fields gave 60 t/ha. The use of the compost PFDE-10 resulted in the decrease in lettuce crops for both doses of the compost. The produced crop was lower with regards to control crop by 3–5% . The highest crop of green lettuce mass in the first vegetative season was obtained using the compost PFDE-30, in the dose of 60 t/ha. The yield in this object was 72.5 t/ha which corresponded to 16% of crop surplus in relation to control objects. The application of the compost PFDE-50 in the dose of 60 t/ha resulted in growth of crop in relation to the control object by about 15% with value on the level of 71 t/ha.

In the second vegetative season, lettuce plot fields fertilized with the compost PFDE-0 yielded higher than the experimental ones. The crop growth with respect to control objects was by ca. 10 wt. %. The objects fertilized with the compost PFDE-10 in the doses of 40 t/ha and 60 t/ha yielded on a very similar level to control objects. Yields of lettuce in these objects were on the level of 65.1–68 t/ha. The second vegetative season gave yielding higher for objects fertilized with the composts PFDE-30 and PFDE-50 in both doses.

The yield of crops of onion using the compost PFDE-0 in both doses in 2 vegetative seasons was higher by 5–10% with respect to control crops (Figs. 8, 9). The objects with the compost PFDE-10 in both doses yielded on a similar level (the mean value 48.5 t/ha), giving crop by 7–15% higher with respect to control objects. High crops were also obtained by application of the compost PFDE-30 (by ca. 14%). The application of 60 t/ha of the compost PFDE-50resulted in 21% growth of crop with respect to control objects. The crop field was 59 t/ha, for the control crop – 49 t/ha. The dose of 40 t/ha of the compost PFDE-50 brought the crop growth of about 15%.

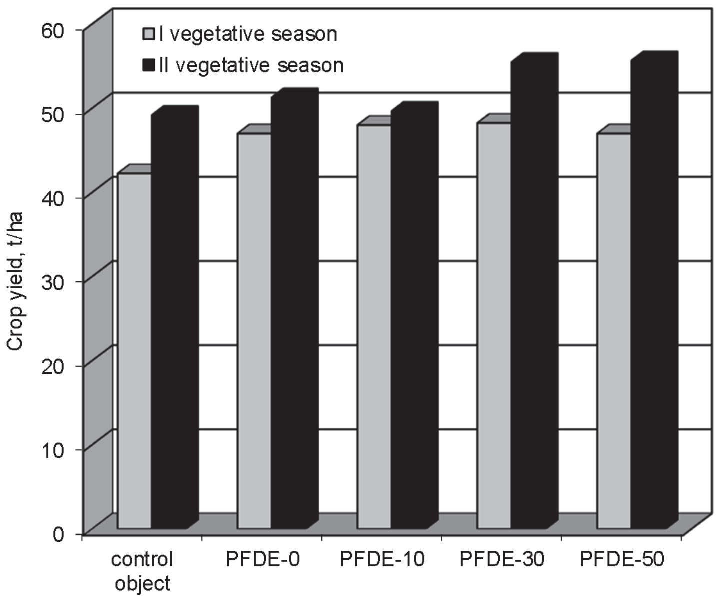

Fig. 8. Onion crop yield (40 t/ha dose of the compost)

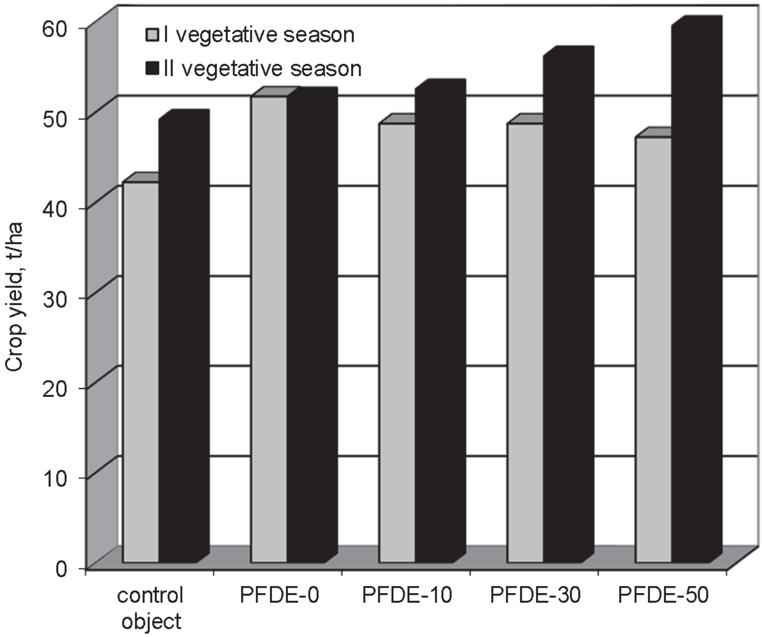

Fig. 9. Yield of onion crop (dose of the compost 60 t/ha)

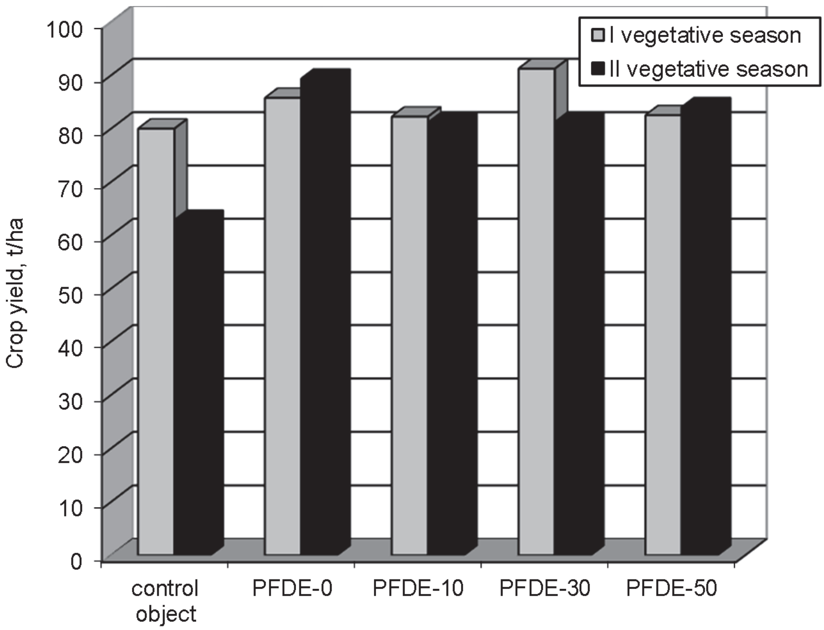

Fig. 10. Red beets crop yield (40 t/ha dose of the compost)

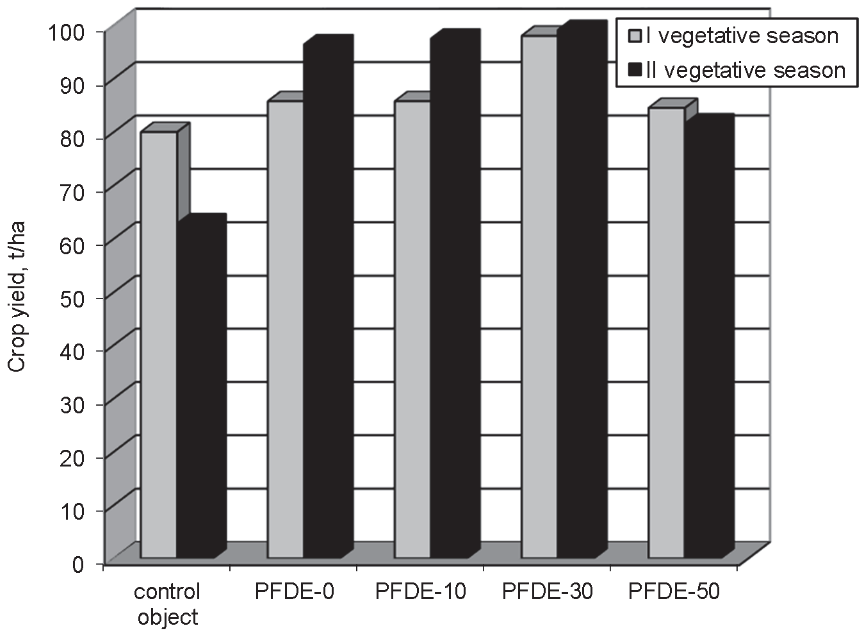

Fig.11. Yield of red beets crop (dose of the compost 60 t/ha)

In red beets crops (Figs. 10, 11), the experimental objects using the compost PFDE-0 yielded higher with respect to control objects. Crop yield of objects using the compost PFDE-0 in 40 t/ha and 60 t/ha are within the range of 85–96 t/ha, while the value of control crop was in the range of 63–80 t/ha. In red beets growing, the higher crops were obtained during fertilizing with the compost PFDE-30 in the dose of 60 t/ha. In this case the crop yield was 98.5 t/ha, being by 20% higher than the control one. In the second vegetative season, the crop increase by 58% with respect to the control object was the highest in the whole vegetative experiment. Yield of red beets growing on the compost PFDE-50 in both vegetative seasons and in both doses was higher than the yield of control object but at the same time the lowest for all applied composts.

4. CONCLUSIONS

- The addition of post-filtered diatomaceous earth to composting of organic fraction of communal waste does not disturb the course of this process on heaps, as evidenced by the temperature values in all compost mixtures.
- Fertilizer value of compost containing post-filtered diatomaceous earth is similar as the fertilizer value of compost from selected organic fraction of communal waste.

• Acid reaction of diatomaceous waste earth did not have an influence on lowering the pH value in mature composts.

• Addition of diatomaceous waste earth to the compost did not have a negative influence on the growth and development of tested vegetable plants.

• The most universal and enhancing crops composts for tested vegetable turned out to be composts containing 30 wt. % and 50 wt. % of post-filtered diatomaceous earth depending on the plant type.

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