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Factors influencing chemical quality of composted poultry waste

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KEYWORDS

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Compost;
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Abstract The need for organic recycling is justified in the case of poultry waste because after ensuring hygienization there is a chance of obtaining a compost with substantial fertilizer value. Organic recycling of slaughter waste has its justification in sustainable development and retardation of resources. In the research being described, composting of hydrated poultry slaughterhouse waste with maize straw was carried out. Combinations with fodder yeast and postcellulose lime were also introduced in order to modify chemical and physicochemical properties of the mixtures. The experiment was carried out within 110 days in 1.2 × 1.0 × 0.8 m laboratory reactors. Temperature of the biomass was recorded during composting, and the biomass was actively aerated through a perforated bottom.

Composting of substrates selected in such a way caused losses of some elements in gaseous form, an increase in concentration of other elements, and changes in relationships between elements. The ability to select substrates influences compost quality. This ability is determined by chemical indicators. Among other things, compost evaluation based on carbon to nitrogen ratio shows the intensity of the composting process and possible nitrogen losses. The addition of slaughter waste to maize straw reduced the content of individual fractions of carbon in the composts, whereas the addition of postcellulose lime intensified that process. The addition of fodder yeast significantly increased the phosphorus content in the compost. Since iron compounds were used in the processing of poultry carcasses, composts that were based on this material had an elevated iron content. The applied postcellulose lime significantly increased the copper, zinc, chromium, nickel, and lead contents. Proper selection of substrates for composting of hydrated poultry slaughterhouse waste allows to obtain a compost with chemical properties that create favorable conditions for natural application of that compost. Addition of large quantities of postcellulose lime to the composting

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process leads to obtaining an organic-mineral substratum for cultivation or to obtaining an agent that improves soil properties.

1. Introduction

It was shown that chemical composition of the composts obtained from poultry slaughter waste and plant biomass may meet minimum requirements for organic fertilizers (Preusch et al., 2002; Kopeć et al., 2014). These authors also confirmed that organic recycling of waste from the poultry industry that takes sanitary safety into account should be the fundamental method for recovering the nutrients for plants and organic matter for soil. When facing the problem of managing animal waste not suited for consumption, it is important to find balance between sanitary risk, technological problems, and quality of the product. In such cases, composting plants often do not meet legal requirements which impose technological regime (Bolan et al., 2010). In order to hygienize categories 2 and 3 the materials of 2nd and 3rd categories it is required to reach proper temperature of biologically treated material, maintain this temperature for a specific time, and to record these parameters. A product obtained as a result of biogasification or composting is subjected to microbiological tests (Gelegenius et al., 2007). A well-elaborated composting process, with the use of proper microorganisms, and proper selection of substrates do not cause difficulties in meeting these requirements. Discussion on the share of microorganisms in the context of presented material was shown in another paper (Kopeć et al., 2015). Lack of interest in biological treatment of slaughterhouse waste results from additional costs which are not compensated by possible gains from the obtained final product. These costs result from, among other things, the necessity of conducting tests on the biologically treated material and potential tests on the soil on which the product (compost) is to be used. Another problem is the large amount of the material which needs to be composted. The need for adding large amounts of plant biomass to waste generated by an animal processing plant is a considerable limitation. Neither a composting plant nor a biogas plant can be based only on animal products that are not suitable for consumption; in both cases a mixture of substrates must be also used, taking into account their structure and chemical composition (Larney et al., 2008; Vandecasteel et al., 2014). Availability of biomass for biological treatment depends on the local conditions of the composting site. Plant materials from agricultural production used in composting may be the maize straw, but also straw obtained after the harvest of maize which has a favorable for microbiological processes C:N ratio. In the case of monoculture crops of maize, straw is collected, e.g. for energy purposes. The obstacle may be high moisture of corn straw, and therefore, the use of this biomass in composting is justified (Roszkowski, 2013).

According to the study Guidelines (2010), the amount of poultry waste (code 020202 – animal waste tissue) generated in Polish slaughterhouses reaches on average 0.26 Mg (ranging between 0.17 and 0.31) per 1 Mg of the product, and 0.19 Mg (ranging between 0.13 and 0.23) per 1 Mg of the raw material. This waste is highly hydrated, and the fat content generates problems in treatment technologies. In terms of fertilizer value, biological treatment of organic waste is an important link in the circulation of elements (Staroń et al., 2014). It is an element of sustainability and matter circulation promoted in the European waste management (Wojdalski et al., 2015; Directive, 2008/98/EC). Proper biological treatment of waste leads to obtaining a stable and mature product. Standardization of the quality of composted materials by maintaining the chemical composition of compost is the essence of the process. Chemical composition and fertilizer value of compost depend on proper selection of substrates, and also on the application of bacterial inocula (Rodzynkiewicz et al., 2009). In the case of biogasification, effectiveness of the process of obtaining methane will be the evaluating factor (Myszograj and Puchalska, 2012). The above-mentioned elements are connected with the bio-economy and circular economy that are promoted in the EU (European Commission, 2012). Bioeconomy is the base for sustainability because it covers production of renewable biological resources and transformation of these resources and streams of waste into products with added value, such as food, fodder, bioproducts, and bioenergy. Sectors of the bio-economy and its branches of industry have a considerable potential for innovation that uses a wide range of sectors of science as well as supportive and industrial technologies.

The aim of the research was to determine the applicability and effect of adding poultry industry waste to the composting process on the chemical composition of the product (compost) which may be safely used in the environment. Due to the fact that the applied additions (postcellulose lime and fodder yeast) are waste materials that contain a lot of valuable nutrients and organic matter, an attempt was made to recover them, and the possibility of including the mentioned waste into circulation of nutrients in the bioeconomy was assessed.

2. Material and methods

2.1. Conditions and the scheme of the experiment

The research on composting of poultry industry waste was carried out within 110 days (from the end of April to the first days of August 2014) in 1.2 × 1.0 × 0.8 m bioreactors with perforated bottoms which enabled aeration. The laboratory reactors were covered against precipitation, but subjected to the effects of outside temperature and solar radiation, which had an impact on heat exchange of the composted material with the surroundings. Crushed maize straw (28.12 kg DM) was the basic component used in the composting process. Poultry industry waste in combinations with fodder yeast and postcellulose lime from waste paper processing was introduced to biomass prepared in such a way.

The scheme of the experiment covered the following treatments: 1. control – maize straw (M); 2. 15.4% poultry

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slaughterhouse waste, calculated to dry matter, was added to the maize straw (M + W); 3. 3 kg fresh matter of fodder yeast ($M + W + Y_1$) was introduced to the mixture from the second treatments; 4. 9 kg fresh matter of fodder yeast ($M + W + Y_3$) was introduced to the mixture from the second treatments; 5. 50 kg postcellulose lime (M + W + L) was introduced to the mixture from the second treatments.

Maize straw was used as the material with the optimal C:N ratio, and with favorable conditions for microorganism development and, thereby, for shortening the composting process. Due to its chemical composition, maize straw is a substrate which may be substituted by green waste. Slaughter waste was the product of category III and had the form of pulp – a mixture of fat, blood and animal tissues. The purpose of using postcellulose lime was to create an organo-mineral substrate for the plant cultivation, assuming that, in combination with biomass, there will be dilution of heavy metal contents.

Amounts of the waste materials that were introduced to the composted biomass were limited not only due to their physical parameters, but also due to moisture content of the feedstock. In terms of dry matter, proportions of the substrates used in individual treatments reached, respectively: M + W – 1:0.15; $M + W + Y_1$ – 1:0.15:0.10; $M + W + Y_3$ – 1:0.15:0.30; M + W + L – 1:0.15:1. After mixing the materials, the moisture content of the mixture was adjusted to 60%. Aeration of the biomass was conducted in cycles, 6 times a day at air flow of 15 dm^3 for 60 min, as well as by turning the biomass over manually once a week. Conditions of the composting process that take into account dry matter losses, temperature of the process, structure of the material, biological activity of compost, and basic groups of microorganisms are presented in the earlier work by Kopeć et al. (2015).

2.2. Determination of the content of macronutrients, trace elements, and fraction of humic compounds

Before and after the experiment, carbon, nitrogen and sulfur contents were determined in the organic material using the Vario Max Cube NCS thermal conductivity detector. The total contents of the other elements and organic matter were determined after incinerating the sample in a chamber furnace at 450 °C for 12 h. After cooling, the residue was treated with the mixture of concentrated nitric and perchloric acids (3:2) (v/v), and then left at room temperature for 24 h. After evaporation on a sand bath, the residue was treated with a 20% hydrochloric acid solution and heated (120 °C) for 2 h under a watch glass. After cooling, the content was transferred quantitatively to 50 cm^3 volumetric flasks, and filtrated through a qualitative filter (Faithful 2000). The contents of macronutrients Na, K, Ca, Mg and P and of selected trace elements were determined in the obtained solutions using the ICP-OES method on a Perkin Elmer Optima 7300 DV apparatus.

After completion of the composting process, an analysis of the organic carbon content (organic C) was conducted in the composts by the oxidation-titration method. Extraction of humic acids (24 h) was conducted by the Schnitzer method (Griffith and Schnitzer, 1975), using a 0.5 mol dm^{-3} NaOH solution (C of the extract). Humic acid carbon (HAC) was separated from the extract by means of extract acidification with sulfuric acid to pH $\sim$ 2. The carbon content in both fractions was determined by the oxidation-titration method. The content of fulvic acid carbon (FAC) and non-hydrolyzing carbon (Cnh) was calculated from the difference of, respectively:

$$\mathrm{FAC} = \mathrm{C\ of\ the\ extract} - \mathrm{HAC}$$

$$\mathrm{Cnh} = \mathrm{organic\ C} - \mathrm{C\ of\ the\ extract}$$

Optical properties within UV–VIS range for 0.02% humic acid solutions in 0.1 mol dm^{-3} NaOH were determined using Beckman DU 640 spectrophotometer after dilution of the initial samples in 0.1 mol dm^{-3} NaOH at 1:5 ratio. Based on the established values of absorbance values at wavelengths of 465 (E4) and 665 nm (E6), values of the E4/E6 ratio were calculated.

2.3. Biological test

The analysis of germination power of the spring wheat seeds (Struna cultivar) in contact with the 1:10 extract from the composts was carried out under closed vessel conditions with carbon dioxide absorption and manometric measurement (OxiTop). The test of germination power was carried out for 50 cocci (with the mass of 1.000 grains reaching 38.6 g) in the period of 4 days.

2.4. Quality control of the analyses

Determinations in each of the analyzed samples were carried out in three replications. Accuracy of the analytical methods was verified based on certified reference materials and standard solutions: CRM IAEA/V – 10 Hay (International Atomic Energy Agency), CRM – CD281 – Rey Grass (Institute for Reference Materials and Measurements), CRM023-050 – Trace Metals – Sandy Loam 7 (RT Corporation). The standard deviation (SD) value was calculated for the obtained results of determination.

3. Results and discussion

Composting is one of the basic trends in recovery and organic recycling of waste. Through biological transformation of waste materials one can obtain a product of standard value suitable for use as a fertilizer or as an agent improving soil properties (Kucharczak et al., 2010). Composting of materials such as poultry slaughterhouse waste, fodder yeast or postcellulose lime is a great challenge, particularly due to various physical and chemical properties of these materials.

In some cases, fodder yeasts lost their suitability for animal feeding and thereby they can be regarded as waste material. In this situation, they can be used as the substratum in the composting process. The use of such materials in biological treatment of waste can be justified primarily by the possibility to narrow the C/N ratio in the obtained compost. On the other hand, the addition of postcellulose lime to the composted biomass is supposed to change the environment reaction into alkaline and possibly hygienize the compost. Undoubtedly, controlling the proportion of individual substrates (maize straw – M; slaughter waste – W; fodder yeast – Y; and postcellulose lime – L) makes it possible to modify the quality of the obtained compost.

The waste substrates proposed for composting differed in chemical structure (Table 1). It resulted from the conditions

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Table 1 Chemical composition of substrates used in the composting process.

Parameters	Unit	Substrates			
		M – maize	W – slaughter waste	Y – fodder yeast	L – postcellulose lime
Dry mass	$g \cdot kg^{-1}$ DM	907 ± 2	92.4 ± 3	956 ± 1	563 ± 26
Ash		65.9 ± 0.1	17.3 ± 0.1	160.9 ± 0.2	754.9 ± 1.5
C_{total}		407 ± 1	375 ± 1	95.6 ± 1	188 ± 2
N_{total}		10.33 ± 0.61	10.25 ± 0.04	61.95 ± 0.18	7.09 ± 0.43
P_{total}		3.42 ± 0.12	1.79 ± 0.07	15.96 ± 0.15	1.23 ± 0.43
K_{total}		1.31 ± 0.05	0.02 ± 0.00	1.27 ± 0.11	0.13 ± 0.07
S_{total}		1.51 ± 0.03	27.4 ± 0.08	1.01 ± 0.01	0.72 ± 0.01
Ca_{total}		0.23 ± 0.02	0.19 ± 0.03	0.07 ± 0.00	51.4 ± 3.84
Mg_{total}		0.12 ± 0.00	0.02 ± 0.00	4.63 ± 0.00	0.45 ± 0.02
Na_{total}		0.02 ± 0.00	0.02 ± 0.00	4.63 ± 0.32	0.43 ± 0.04
Cu_{total}	$mg \cdot kg^{-1}$ DM	3.79 ± 0.37	6.97 ± 0.56	0.55 ± 0.07	141.9 ± 24.3
Zn_{total}		64.4 ± 3.8	35.1 ± 2.3	39.3 ± 0.5	328.7 ± 20.9
Mn_{total}		43.2 ± 1.5	16.6 ± 0.6	11.5 ± 0.1	152.6 ± 5.8
Fe_{total}		324.3 ± 0.1	3043.3 ± 53.5	67.3 ± 0.4	2066.3 ± 55.1
Cd_{total}		0.756 ± 0.261	0.055 ± 0.001	0.069 ± 0.035	1.100 ± 0.086
Cr_{total}		3.91 ± 0.10	2.24 ± 0.28	1.50 ± 0.11	41.56 ± 8.49
Ni_{total}		0.80 ± 0.14	1.22 ± 0.11	0.42 ± 0.08	9.24 ± 0.41
Pb_{total}		4.13 ± 0.68	0.64 ± 0.06	0.39 ± 0.09	39.28 ± 1.26

of maize cultivation agricultural engineering or from the technology that had been used to obtain the other waste materials. Among the analyzed waste materials, the highest degree of hydration and the lowest ash content were observed in the poultry slaughterhouse waste. Of course, in justified cases there is a possibility to modify this waste technically in order to adjust it for biological treatment processes (Rodzynkiewicz et al., 2009; Banach et al., 2010). Another thing that can draw one's attention to chemical composition of poultry slaughterhouse waste is relatively high sulfur content (27.4 $g \cdot kg^{-1}$ DM). Sulfur is not an element to which attention is paid in view of the composting technology, but it is important as a fertilizer component. Since the atmospheric emission of this element from industry is decreasing, more and more attention is being drawn to sulfur circulation in agricultural systems (Assefa et al., 2015). Waste applied to the soil environment plays an important role in this matter (Mierzwa-Hersztek et al., 2016).

Postcellulose lime obtained from waste paper processing had properties unusual for organic materials, and the ash content in this waste amounted to 75.5%. Moreover, the residual organic fibers coming from waste paper supplied low nitrogen and carbon content as well as high content of trace elements to biomass substrates. Substantial heavy metal content in postcellulose lime comes from processing of waste paper that contains printing ink (Tucker et al., 2000). The fodder yeast contained almost 6 times more nitrogen than the maize straw and poultry slaughterhouse waste.

The poultry slaughterhouse waste was also found to have substantial iron content (3043.3 $mg \cdot kg^{-1}$ DM), which undoubtedly resulted from applying compounds of this element during raw material processing (Kopeć et al., 2014). On the other hand, fodder yeast, as compared with other waste materials, contained higher contents of nitrogen, phosphorus, sodium, potassium, and magnesium (Table 1). According to Botha (2011), a substantial content of macronutrients in fodder yeast may have a significant effect on the quality of the obtained compost. The content of trace elements determined in the fodder yeast was significantly lower than in the plant material (maize straw). Unlike the organic substrates, postcellulose lime had many times higher content of all the determined trace elements (Table 1). The increased content of trace elements in this material may have been caused by residual printing ink (Mierzwa-Hersztek et al., 2013) or by the technological process of waste paper processing (Westholm et al., 2014).

The composting process resulted in losses of dry matter in relation to the starting mass of the substrates (Fig. 1). In general, each of the waste materials that had been added to the straw maize caused a reduction of biomass losses. In the case of net balance for the compost with the addition of postcellulose lime (treatments M + W + L), an increase in the rate of mineralization of the organic material in consequence of alkalization of the environment was observed (Christian et al., 1997; Saidi et al., 2008; Ieshita et al., 2012). Research studies carried out by Antonkiewicz et al. (2015) and Venelampi et al. (2003) also confirm the acceleration of the rate of

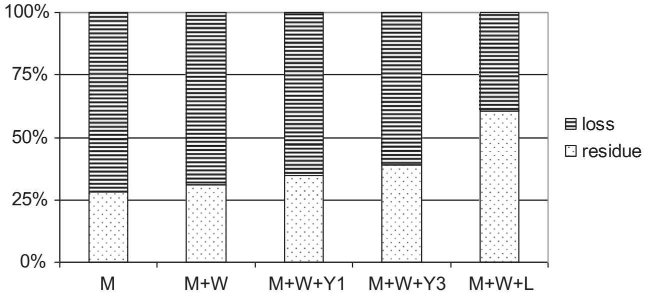

Fig. 1 Percentage of dry matter residue after composting (Kopeć et al., 2015) * M – mize; M + W – maize + slaughter waste; M + W + Y_1 – maize + slaughter waste + 1 × fodder yeast; M + W + Y_3 – maize + slaughter waste + 3 × fodder yeast; M + W + L – maize + slaughter waste + postcellulose lime.

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mineralization and hygienization of organic matter as a result of adding postcellulose lime.

Analysis of the C/N ratio in compost is one of many relative indicators of compost stability and provides information about the degree of its maturity (Mangkoedihardjo, 2006; Ieshita et al., 2012). It is assumed that the lower the ratio, the more mature the compost. It is also assumed that the carbon to nitrogen ratio in mature compost should be close to 10–15:1. However, taking into account the diversity of the materials which were subjected to composting, the above-mentioned criterion may be indicative only. In our research, the C/N ratio in composts was between 7.5 and 13.0 and pointed to biological stabilization of the products of transformation (Table 2). Jouraiphy et al. (2005) obtained a similar value of the C/N ratio to the one that was determined in our research in mature compost from sewage sludge. Wang et al. (2007) recorded higher values of the carbon to nitrogen ratio (~18) in the compost obtained from manure and straw. The C/N ratio in the analyzed composts was not as diversified as the C/S ratio (Table 2). In the case of this indicator, the addition of fodder yeast containing over 26 times less sulfur than slaughterhouse waste led to processes of more intensive mineralization of organic matter. The C/S ratio can be more reliable and stable due to lack or reduced losses of sulfur in gaseous form.

Composts are commonly used as a feedstock in biofilters for biological oxidation of some organic compounds of post-process gases (Hort et al., 2009; Frederickson et al., 2013). The main reason for using composts as a feedstock in biofilters is a large absorptive surface with considerable microbiological activity and with a great capacity to absorb pollutants and nutrients (Chanakya et al., 2007; Longieras et al., 2007). In this context, it is important to know the chemical composition of composts obtained on the basis of different substrates.

The fertilizer value of composts depends largely on the content of macronutrients – N, P, K, Mg, Ca (Meller et al., 2015). The obtained compost combinations were characterized by considerable diversity in terms of chemical composition (Table 3). Among the studied composts, compost with the addition of postcellulose lime had the lowest macronutrient content. However, taking into account the Polish criteria concerning minimum contents of nutrients for stable organic fertilizers (Directive, 2008/98/EC; Regulation, 2008), composts obtained on the basis of the proposed waste mixtures (except M + W + L combinations) fulfilled the requirements concerning nitrogen, phosphorus and potassium contents, which amount to, respectively: 3 g N·kg^{-1}, 2 g P_2O_5·kg^{-1}, and 2 g K_2O·kg^{-1}.

In the case of the compost to which 50 kg of postcellulose lime was added (M + W + L), guidelines for organic-mineral fertilizers should be applied. Qualitative requirements (including minimum nutrient contents) for this type of fertilizers are 10 g N·kg^{-1}, 5 g P_2O_5·kg^{-1}, and 10 g K_2O·kg^{-1}. Considering the criteria for organic-mineral fertilizers, compost produced with the addition of postcellulose lime requires correction of the chemical composition due to too low phosphorus and potassium contents. Research carried out by

Table 2 Proportions of carbon, nitrogen and sulfur in the analyzed composts (Kopeć et al., 2015).

Ratio	Combinations of composts*				
	M	M + W	M + W + Y_1	M + W + Y_3	M + W + L
C:N	10.5	7.9	7.5	8.0	13.0
C:S	89.4	51.6	26.1	16.3	100.6
N:S	8.5	6.6	3.5	2.0	7.7

[*] See Fig. 1.

Table 3 Contents of ash, macronutrients and trace elements in the composts.

Parameters	Unit	Combinations of composts*				
		M	M + W	M + W + Y_1	M + W + Y_3	M + W + L
Ash	g·kg^{-1} DM	234.02 ± 0.60	252.92 ± 0.49	261.20 ± 0.80	254.82 ± 0.55	608.47 ± 859
N		35.31 ± 0.01	45.62 ± 0.02	47.26 ± 0.12	43.70 ± 0.05	18.12 ± 0.0 6
P		10.87 ± 0.34	15.78 ± 0.33	17.61 ± 0.61	19.25 ± 0.21	4.71 ± 0.22
K		3.09 ± 0.08	2.90 ± 0.02	2.50 ± 0.04	2.16 ± 0.04	0.82 ± 0.05
S		4.16 ± 0.03	6.96 ± 0.02	1.35 ± 0.01	21.5 ± 0.12	2.36 ± 0.01
Ca		0.65 ± 0.03	1.03 ± 0.02	0.80 ± 0.01	0.61 ± 0.02	34.27 ± 0.30
Mg		0.45 ± 0.01	0.44 ± 0.01	0.39 ± 0.01	0.32 ± 0.01	0.47 ± 0.01
Na		0.08 ± 0.01	0.11 ± 0.01	0.88 ± 0.01	1.85 ± 0.03	0.12 ± 0.03
Cu	mg·kg^{-1} DM	12.41 ± 2.20	29.87 ± 2.41	29.71 ± 0.45	21.23 ± 0.16	119.96 ± 1.82
Zn		269.9 ± 13.8	326.0 ± 7.6	293.9 ± 24.0	254.5 ± 4.0	327.9 ± 6.1
Mn		178.6 ± 51.1	185.5 ± 4.9	152.8 ± 3.9	118.8 ± 1.2	160.5 ± 0.9
Fe		1339 ± 116	13555 ± 302	11198 ± 237	8297 ± 153	5212 ± 206
Cd		1.259 ± 0.063	0.884 ± 0.047	0.922 ± 0.357	0.749 ± 0.005	0.931 ± 0.077
Cr		7.41 ± 3.33	12.35 ± 3.81	9.57 ± 1.18	8.03 ± 0.61	37.0 ± 1.70
Ni		3.45 ± 1.90	5.47 ± 1.14	4.42 ± 0.71	3.16 ± 0.21	8.47 ± 0.38
Pb		17.27 ± 1.38	13.59 ± 0.72	13.28 ± 1.30	17.32 ± 1.74	31.94 ± 0.26

[*] See Fig. 1.

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Gopinathan and Thirumurthy (2012) confirms that postcellulose lime contains small quantities of potassium and phosphorus.

One of the conditions for obtaining marketing authorization for compost is to maintain standard concentrations of trace elements, mainly chromium, cadmium, nickel, lead, and mercury. In the case of organic and organic-mineral fertilizers, permissible contents of these elements in 1 kg DM of fertilizer cannot exceed: 100 mg Cr, 5 mg Cd, 60 mg Ni, 140 mg Pb, or 2 mg Hg (Regulation, 2008, 2009). The permissible content of selected (Table 3) trace elements was not exceeded in any of the composts.

From the agricultural point of view, the contents of organic carbon and humic substances in composts are also important. The results of our research indicate that organic carbon content in the composts produced from maize straw (treatment M), from slaughterhouse waste (M + W), and in the compost with the addition of fodder yeast (M + W + Y) ranged from 145 g·kg^{-1} to 468 g·kg^{-1} (Table 4). The highest content of organic C was determined in the control compost (M). Substantial diversity in the content of this nutrient was associated with specificity and type of the starting materials that were used in the experiment.

Transformations of organic matter during the maturation stage lead to formation of high-molecular compounds that have the characteristics of organic acids which constitute one of the most important soil components and substantially influence its properties (Gusiatin and Kulikowska, 2012). The content of humic compounds (Table 4) extracted with NaOH in 0.5 mol dm^{-3} concentration (C of the extract) revealed relatively high diversity between the composts, particularly after applying the addition of postcellulose lime to the composted biomass (treatment M + W + L), (Table 4). Smaller differences applied to the share of extracted carbon (C of the extract) in the total organic carbon content of the studied composts. The biggest amount of carbon was extracted from the compost with the addition of triple dose of yeast (treatment M + W + Y_3), that is 137 g C kg^{-1} DM, which constituted 33% of the total organic carbon content. A comparable share of extracted carbon in the organic carbon content was determined in composts with a single dose of yeast (treatment M + W + Y_1), i.e. 31%, as well as in composts with the addition of postcellulose lime (treatment M + W + L), i.e. 33%.

An analysis of fractional composition of humic compounds extracted from the studied composts revealed a relatively small diversity in the content of humic acid carbon, with the exception of the compost with the addition of postcellulose lime – M + W + L, (Table 4). The content of humic acid carbon including in this compost was the lowest, which was also reflected in the value of the HAC/FAC ratio. However, it should be emphasized that in all composts the content of humic acid carbon was higher than the content of fulvic acid carbon. In their research, Jouraiphy et al. (2005) also indicated an increase in the content of humic acid carbon but a decrease in the content of fulvic acid carbon. The value of the HAC/FAC ratio in the analyzed composts amounted, on average, to 2.57, except the compost with the addition of postcellulose lime, for which the value of the ratio amounted to 1.32. Regardless of combination, the obtained values of the discussed parameter differed considerably from the 1.90 value which is considered by Raj and Antil (2011) as the optimum value for mature composts. On the other hand, Inbar et al. (1990) stated that the optimum value for this ratio was 1.5. A relatively slight difference between the quoted values of the HAC/FAC ratio may in practice mean considerable changes in the level of mineralization of composted waste materials, which may not necessarily positively affect final product properties.

Compared to the hemicellulose carbon content in the compost based on maize straw (M), the content of this fraction of humic compounds was higher in composts to which poultry waste was added (M + W) and in composts where poultry waste were added along with a single dose of yeast (M + W + Y_1). The hemicellulose carbon content in composts with a triple dose of yeast (M + W + Y_3) and with the addition of postcellulose lime (M + W + L) was lower by, on average, almost 30%. The share of hemicellulose carbon in the total organic carbon content was diversified,

Table 4 Fractional composition of humus in the studied composts.

Parameters	Unit	Combinations of composts *				
		M	M + W	M + W + Y_1	M + W + Y_3	M + W + L
Org. mat. 450 °C	g·kg^{-1} DM	766 ± 0.6	747 ± 0.5	739 ± 0.8	745 ± 0.5	392 ± 0,8
C org.		468.3 ± 17.2	385.5 ± 6.5	440.3 ± 2.1	411.0 ± 6.8	145.0 ± 14.7
C ekstrakt		133.7 ± 1.8	97.4 ± 8.7	111.6 ± 9.6	137.0 ± 3.0	49.0 ± 0.3
CKH		96.8 ± 1.7	70.8 ± 6.5	78.4 ± 10.1	98.3 ± 8.7	27.8 ± 1.3
CKF		36.8 ± 2.8	26.6 ± 2.8	33.2 ± 1.0	38.7 ± 5.7	21.1 ± 1.2
C non-hydrolyzing		334.6 ± 18.7	288.1 ± 5.7	328.8 ± 9.8	274.0 ± 5.8	96.0 ± 15.1
C hemicellulose		4.75 ± 0.79	8.65 ± 0.64	6.89 ± 0.75	3.90 ± 0.11	2.99 ± 0.03
C extract/C org.	%	28.6	25.3	25.3	33.3	33.8
CKH/C org.		20.7	18.4	17.8	23.9	19.2
CKF/C org.		7.9	6.9	7.5	9.4	14.6
C non-hydrolyzing/C org.		71.4	74.7	74.7	66.6	66.2
C hemicellulose/C org.		1.0	2.2	1.6	0.9	2.0
CKH:CKF		2.64	2.67	2.37	2.60	1.32
E4/E6		9.77 ± 0.39	12.83 ± 0.21	10.17 ± 0.65	8.63 ± 0.22	13.64 ± 0.71

* See Fig. 1.

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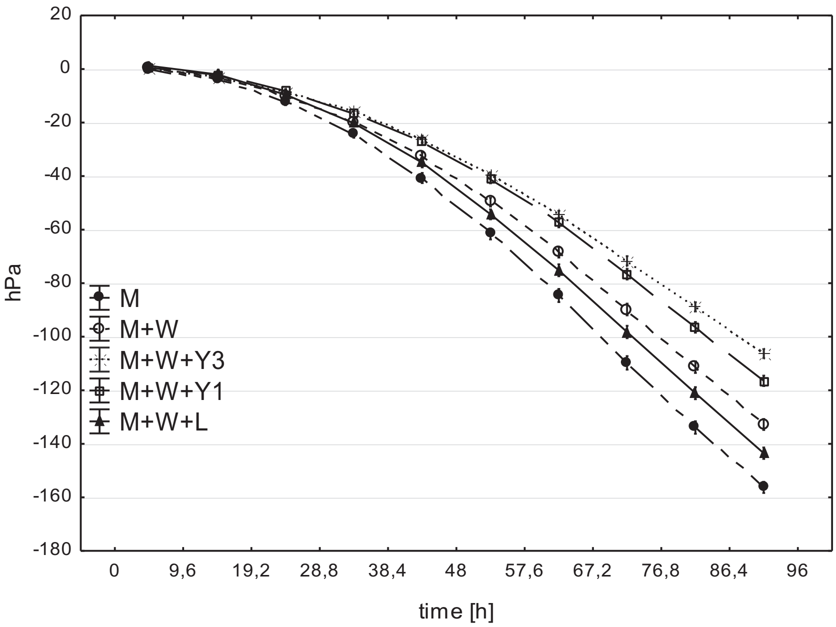

Fig. 2 Pressure changes caused by respiratory activity of the spring wheat seeds in contact with the extract from the compost (treatments as in Fig. 1) in the period of 360 cycles = 4 days.

ranging from 0.94% to 2.24% (Table 4). As in the case of the absolute content of hemicellulose carbon, also the highest share of this form of carbon in the organic carbon content was determined in the compost with the addition of poultry waste (M + W).

The content of non–hydrolyzing carbon in the composts with the addition of poultry waste fell within the range from 96 to 329 $g \cdot kg^{-1}$ DM (Table 4). This content was lower than the one assessed in the compost based on maize straw (M). The share of non-hydrolyzing carbon in the total organic carbon content in composts with the addition of slaughterhouse waste (M + W) as well as with the addition of poultry waste and a single dose of yeast ($M + W + Y_1$) exceeded 70%; in the compost with the addition of poultry waste and a triple dose of yeast ($M + W + Y_3$) as well as with the addition of poultry waste and postcellulose lime (M + W + L) it was lower, in both cases amounting to 66% of the total organic carbon content.

The calculated values of the E4/E6 absorbance ratio of humic acid solutions showed diversity depending on the type of addition introduced to the composting process. The highest values of the E4/E6 ratio were determined in the case of maize + slaughterhouse waste (M + W) as well as maize + slaughterhouse waste + postcellulose lime (M + W + L) combinations. Assuming the control compost (M) as the reference point, it may be concluded that the addition of slaughterhouse waste, a single dose of yeast, and postcellulose lime to maize generally slowed down the humification process of the composted biomass.

Stachowiak et al. (2006) as well as Gopinathan and Thirumurthy (2012) put forward the need for biological tests in the assessment of compost stability. The impact of the extracts on seed germination power confirms the ecotoxicity of the composts (Fig. 2). The experiment with spring wheat (Struna cultivar) showed that the most active seed growth took place in contact with the extract with the composted maize straw (M). The growth of caryopses was slower after adding the extract from composted maize straw with the addition of poultry slaughterhouse waste (M + W) and postcellulose lime (M + W + L). The weakest respiratory activity was found under impact conditions of the extract with materials with the addition of yeast. Increasing the dose of yeast reduced the growth of plant seedlings. Germination limitation and wheat growth confirm high salinity of the obtained extracts. In individual combinations of composts, the following values of electrolytic conductivity [$mS \cdot cm^{-1}$] were determined: M – 10.80 ± 0.11; M + W – 11.07 ± 0.36; $M + W + Y_1$ – 18.40 ± 0.01; $M + W + Y_3$ – 15.21 ± 0.11; M + W + L – 5.55 ± 0.58. This situation may apply mainly to a strong osmotic effect associated with reduction in water uptake.

4. Conclusions

Waste fodder yeast can be used for correcting the C/N ratio in a mixture of substrates intended to be used in composting. In the case of postcellulose lime that was created during waste paper processing and used for composting, there is a need for analysis of heavy metals taking into account introduction of compost into the environment. Applied poultry waste, fodder yeast and postcellulose lime reduced mineralization of the mixtures and slowed down the humification process of the composted biomass. The composted material with the addition of yeast in the ratio of 6.5:1:0.7 (maize straw: slaughterhouse waste: fodder yeast) increases the toxicity of the compost extract measured by the wheat germination power, and the increase in yeast share intensifies this relationship.

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