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CHEMICAL AND BIOLOGICAL PROPERTIES OF COMPOSTS PRODUCED FROM ORGANIC WASTE

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Abstract

The aim of the investigations was to determine the effect of composting municipal waste with various added substances (starch, edible oil or urea) on the content of selected forms of zinc, cadmium, copper and lead, the quality of organic matter and counts of some groups of physiological microorganisms. The above properties of compost may provide the basis for assessment of the composting process efficiency. The research object was biomass prepared from plant and other biodegradable waste generated in the area of Krakow. The biomass for composting was prepared from the following organic waste: deciduous tree chips, chicory coffee production waste, grass and tobacco waste. There were two stages of the composting process: I – lasting for 14 days, to obtain "heated" compost, and II – lasting for 210 days, when starch, edible oil or urea was added to the composted biomass. The total content of Zn, Cd, Cu and Pb determined in the analyzed composts does not pose a threat to the purity of the soil environment. The content of water-soluble forms of trace elements and forms bound to organic matter was affected by the loss of organic matter, chemical properties of a given element and the addition of supplement, mainly urea, to the composted biomass. Analysis of the fractional composition of humic compounds revealed higher values of the Cha:Cfa ratio in the composts with added edible oil or urea than in the other composts, which may indicate a much more advanced decomposition process of the material subjected to composting. Among the analyzed microorganisms, bacteria were most numerous in the composts. The introduction of urea to the composted biomass reduced microbial activity. Adding starch or oil stimulated microbial development and may have stimulated the composting process.

Keywords: municipal waste, composts, trace elements, organic matter, microorganisms.

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WŁAŚCIWOŚCI CHEMICZNE I BIOLOGICZNE KOMPOSTÓW WYTWORZONYCH Z ODPADÓW ORGANICZNYCH

Abstrakt

Celem badań było określenie wpływu procesu kompostowania odpadów komunalnych z różnymi dodatkami (skrobią, olejem jadalnym, mocznikiem) na zawartość wybranych form cynku, kadmu, miedzi i ołowiu, jakość materii organicznej oraz liczebność niektórych grup fizjologicznych mikroorganizmów. Wymienione właściwości kompostów mogą stanowić podstawę oceny efektywności procesu kompostowania. Obiekt badań stanowiła biomasa przygotowana na bazie odpadów roślinnych i innych biodegradowalnych powstających na terenie miasta Krakowa. Biomasę do kompostowania przygotowano z organicznych materiałów odpadowych, takich jak: zrębki z drzew liściastych, odpad z produkcji kawy zbożowej, trawa oraz odpad tytoniowy. W procesie kompostowania wyróżniono dwa etapy: I – trwający 14 dni, którego celem było uzyskanie „kompostu grzejnego"; II – trwający 210 dni, w którym do kompostowanej biomasy wprowadzono dodatek skrobi, oleju jadalnego i mocznika. Oznaczona ogólna zawartość Zn, Cd, Cu i Pb w badanych kompostach nie stanowi zagrożenia dla czystości środowiska glebowego. Na zawartość wodnorozpuszczalnych form pierwiastków śladowych oraz form związanych z materią organiczną miały wpływ: ubytek substancji organicznej, właściwości chemiczne pierwiastka oraz dodatek do kompostowanej biomasy, głównie mocznika. Analiza składu frakcyjnego związków próchnicznych kompostów wykazała wyraźnie większe wartości stosunku Ckh do Ckf w kompostach z dodatkiem oleju jadalnego i mocznika, niż w pozostałych kompostach, co może wskazywać na bardziej zaawansowany proces dekompozycji materiałów poddanych kompostowaniu. Spośród badanych drobnoustrojów najliczniejszą grupę w kompostach stanowiły bakterie. Wprowadzenie do kompostowanej biomasy mocznika spowodowało zmniejszene aktywności mikrobiologicznej. Dodatek skrobi i oleju stymulował rozwój drobnoustrojów i mógł sprzyjać intensyfikacji procesu kompostowania.

Słowa kluczowe: odpady komunalne, komposty, pierwiastki śladowe, materia organiczna, mikroorganizmy.

INTRODUCTION

In the European Union, composting is one of the most widely promoted methods of the biological processing of biodegradable waste, which is arduous waste due to its high water content, which makes storage difficult. Composting may be defined as controlled, biological decomposition and stabilization of organic substrates, carried out under aerobic conditions to an adequate moisture content, during which process the temperature of the composted material rises to the thermophilic range (HORIUCHI et al. 2003, ISHII, TAKI 2003, WANG et al. 2004). The final product of well-conducted composting should be sanitary safe material, abundant in humus and biogenic compounds (HIMANEN, HANNINEN 2011).

A high content of organic substance and fertilizer components in some biodegradable waste makes it good raw material for composting. The factors which restrict later use of ready compost may be its immaturity or excess pollutants, including trace elements (GARCIA et al. 1995, BOWSZYS et al. 2009, SĄDEJ, NAMIOTKO 2010).

The variety of functions which organic matter performs in the environment means that both its quantity and quality in processed organic waste, including composts, should be taken into consideration while assessing the value of biologically transformed products (HUANG et al. 2006). In general, composting should improve the quality of organic matter, e.g. by increasing the share of its stabile forms in mature composts (HUANG et al. 2006). Inadequate conditions in which composting is conducted, e.g. insufficient aeration or wrong biomass composition, lead to quantitative and qualitative changes in microbial populations, which result in disadvantageous modifications of the quantitative and qualitative composition of organic matter in compost (KULCU, YALDIZ 2004).

The biochemical processes which occur during composting may activate initially inert trace elements (HSU, LO 2001), which, depending on how given compost is intended to be used, may create undesirable conditions for the plant growth and development. Thus, it is justifiable to assess not only the total content of trace elements in composts but also their mobile forms and those bound to organic matter. These forms usually constitute a considerable proportion of the total content and, under suitable soil conditions (GONDEK 2007, KANG et al. 2011, JAKUBUS 2012), may undergo fast degradation.

The organic fraction of composted waste, particularly the final product, contains a considerable amount of microbial biomass. Two groups dominate during the composting process: bacteria, including actinomycetes, and fungi. Changes in the composition of the microbial population depend mainly on the temperature maintained during the process, biomass aeration and the content of readily available forms of organic matter in the composted material. The temperature induces quantitative and qualitative changes of the microflora and causes sterilization of the product, i.e. compost (TIQUIA et al. 1996, HUANG et al. 2010, ZHANG et al. 2011).

The aim of the conducted investigations was to determine the effect of composting, mainly of municipal waste, with various added substances (starch, edible oil or urea) on the content of selected forms of trace elements, quality of organic matter and counts of some groups of physiological microorganisms, which may provide the basis for the assessment of composting process efficiency. It was assumed that the amount and composition of added substances would make composting easier.

MATERIAL AND METHODS

The object of the investigations was the biomass prepared from plant waste and other biodegradable waste generated in the urban area of Krakow. The biomass for composting was prepared from the following organic waste materials (in the waste catalogue marked by 20 02 code: waste from gardens and parks): deciduous wood chips (43.87% share in the biomass), grass (23.13% share in the biomass), waste (02 03 03) from chicory coffee production (21.94% share in the biomass) and plant waste (02 03 82) from the tobacco industry (10.96% share in the biomass). The moisture content of the mixed biomass was 45.30%, and the C:N ratio was 1:20. A 0.5 x 0.4 x 0.3 m (height x length x width) bioreactor was equipped with an aerating system and a system of post-process water draining. During the experiment, the biomass temperature and moisture content were controlled in order to maintain optimal conditions for the process. Biomass in the bioreactors was aerated in a 0.01 $m^3 \cdot min^{-1}$ system four times in 24 hours. For better aeration and homogenization, the composted biomass was taken out of the bioreactors once a week and mixed manually. Two stages were identified in the composting process: I – lasting for 14 days, aiming to obtain "heated" compost, and II – lasting for 210 days, when different substances were added (5% of the fresh mass of "heated" compost) to composted biomass. Selected properties of "heated" compost are presented in Table 1.

Table 1

Selected properties of raw "heated" compost after removal from the bioreactor

Determination	Value ± SD
Dry matter (g kg^{-1})	549.8 ± 2.20
pH H_2O	6.52 ± < 0.01
Organic C (g kg^{-1} d.m.)	320.1 ± 7.16
Electrolytic conductivity (mS cm^{-1})	5.58 ± 0.07
Total forms (mg kg^{-1} d.m.)	
Zn	177.8 ± 3.3
Cd	0.67 ± 0.01
Cu	27.2 ± 0.5
Pb	11.52 ± 0.22

± standard deviation

The experiment comprised the following variants in two replications: C1 – raw compost without additions (control); C2 – raw compost + starch (edible product); C3 – raw compost + edible oil; C4 – raw compost + urea (chemically pure). After composting, all the materials were thoroughly mixed and then sifted through a 1 cm mesh, and 3 kg samples were collected for chemical and microbiological analyses.

The following were determined in the initial and composted material: dry matter content at 105°C (the process lasted for 12 hours); pH by a potentiometer in an aqueous suspension of compost at the 1 : 10 dry matter to water ratio, electrolytic conductivity by a conductometer, the total content of zinc, copper, cadmium and lead determined after sample mineralization in a muffle furnace (450°C for 5 hours) and dissolution in diluted (1:2) nitric acid. The determinations were made using the methods suggested by Baran and Turski (1996). The water soluble forms of these elements and their forms bound to organic matter were extracted using redistilled water and 0.1 mol dm^{-3} $K_4P_2O_7$ solution, respectively. The trace element content in the solutions and extracts was determined with the ICP-AES method on a JY 238 Ultrace apparatus (Jobin Yvon).

The total content of organic carbon was determined with the oxidation-titration method following sample mineralization in potassium dichromate. The humic compounds were extracted from the composts with distilled water for 24 hours (extracted C). In order to cause the coagulation of humic acids, some of the obtained extract was acidified with sulfuric acid to reach pH 2. After filtering, the precipitate of humic acids was dissolved in hot NaOH of 0.05 mol dm^{-3} concentration. The organic carbon content was determined in the extracts with the oxidation-titration method after sample mineralization in potassium dichromate. Fulvic acid carbon was calculated as the difference between the content of C extracted with water and the humic acid carbon content.

Microbiological quantitative analyses of dormant and vegetative forms of mesophilic bacteria and microbiological quantitative analyses of fungi, actinomycetes, and amylolitic, proteolytic and lipolytic bacteria were conducted using the serial dilution method. The analyzed material was cultured on general purpose and selective culture media, and after an adequate period of incubation colony-forming units were counted. The results were converted into 1 g of sample dry matter (Atlas, Parks 1997).

The analytical results are arithmetic means of four replications. The standard deviation was calculated for the mean values presented in the tables. Average pH values of the composts and standard deviation values were computed after converting pH to the hydrogen ion content.

RESULTS AND DISCUSSION

The dry matter content in the analyzed samples was differentiated by the composting process depending on the kind of an added component (Table 2). In comparison with the control compost (C1), the dry matter content increased in the biomass of composts made with starch (C2) and urea (C4).

Soil reaction is one of the most important physicochemical properties of waste substances and also a good indicator of the course of compost maturing. Based on the conducted experiments, a marked increase in the pH value was observed in the analyzed composts in comparison with the initial material ("heated" compost) – Tables 1, 2. Iglesias-Jimenez and Perez-Garcia

Table 2

Selected properties of organic materials after composting

Determination	Type of compost			
	C1	C2	C3	C4
Dry matter (g kg^{-1})	515.0 ± 20.2	645.9 ± 28.6	512.7 ± 21.7	544.3 ± 24.7
pH	7.85 ± < 0.01	7.84 ± 0.03	7.74 ± 0.02	7.58 ± 0.01
Electrolytic conductivity (mS cm^{-1})	6.31 ± 0.07	5.98 ± 0.06	5.90 ± 0.07	5.76 ± 0.27

± standard deviation,
C1 – raw compost without addition (control), C2 – raw compost + starch (food product),
C3 – raw compost + edible oil, C4 – raw compost + urea (chemically pure);

(1991) also demonstrated an increase in the pH value of composted waste. An increase in the pH value of composted biomass may be caused by an the content of soluble forms of alkaline elements, such as magnesium or calcium, increasing with time, as demonstrated by Drozd et al. (1996). Moreover, it may be the result of the degradation of organic compounds, mostly proteins, leading to the release of ammonia.

Excess soluble salts in composts applied to soil may distort the balance in the soil solution, retarding the plant growth. A good indicator of compost salinity is electrolytic conductivity. The electrolytic conductivity of water solutions depends on the kind of soluble substances, their concentration and temperature. The value of electrolytic conductivity in the analyzed composts, irrespectively of the added substances, was higher than in "heated" compost (Tables 1, 2). The elevated value of electrolytic conductivity in the composts at the termination of composting resulted from the progressing mineralization of organic matter, which causes the release of mineral components, responsible for a higher value of the electrolytic conductivity of the analyzed materials. In the previous investigations conducted by Gondek (2006) and Dimambro et al. (2007), much lower values of electrolytic conductivity were determined both in composts based on non-segregated municipal waste and in ones produced from plant and other biodegradable waste.

The total cadmium content was on a similar level, regardless of the compost (Table 3). The content of cadmium extracted with water (Cd H_2O) was between 5 and 10-fold higher in the compost with urea than in the other ones.

The highest cadmium content was determined in organic matter compounds. The share of this Cd form in the total content was between 15% in the compost with starch (C2) and 24% in the compost without additions (C1).

The total zinc content was the highest in the compost with no additions (Table 3). According to the limits set for heavy metals in composts by the European Commission, the analyzed materials (irrespectively of the added substance) belong to the second class in respect of the content of zinc

Table 3

Content of trace elements in organic materials after composting

Determination	Type of compost*			
	C1	C2	C3	C4
	(mg kg^{-1} d.m.)			
Cd H_2O	0.060 ± < 0.01	0.051 ± < 0.01	0.032 ± < 0.01	0.350 ± 0.10
Cd $K_4P_2O_7$	0.420 ± 0.01	0.357 ±0.01	0.329 ± 0.01	0.253 ± 0.01
Total Cd	0.86 ± 0.02	0.81 ± 0.05	0.81 ± 0.01	0.91 ± 0.09±
Zn H_2O	11.69 ± 0.10	9.51 ± 0.27	9.19 ± 0.20	64.20 ±0.79
Zn $K_4P_2O_7$	193.4 ± 5.1	165.3 ± 3.7	181.8 ± 5.9	125.7 ± 8.0
Total Zn	273.1 ± 1.2	251.8 ± 1.7	255.2 ± 1.0	245.8 ± 1.0
Cu H_2O	6.64 ± 0.24	5.74 ± 0.20	5.83 ± 0.70	26.43 ± 0.73
Cu $K_4P_2O_7$	4.63 ± 0.88	4.90 ± 0.70	6.02 ± 0.16	2.90 ± 0.18
Total Cu	37.96 ± 0.51	36.78 ± 0.46	38.17 ± 0.40	44.50 ± 1.52
Pb H_2O	0.49 ± 0.07	0.41 ± 0.07	0.33 ± 0.03	2.30 ± 0.10
Pb $K_4P_2O_7$	5.27 ± 0.72	5.28 ± 0.76	5.29 ± 0.33	4.63 ± 0.16
Total Pb	14.87 ± 1.00	15.36 ± 1.09	15.62 ± 0.40	15.49 ± 2.36

± standard deviation
* explanation as in Table 2

(Wasiak, Madej 2009). The content of water-extracted zinc was the highest in the compost with urea. The share of this zinc form in the total content in the composts with starch, edible oil or without additives did not exceed 5%. In the compost with urea, the share was on average over 6-fold higher. The highest amounts of zinc in the composts were determined in forms bound to organic matter. On average, the share of organically bound zinc with reference to the total zinc content in the composts with starch, edible oil or without additives reached almost 70%, being almost 20% lower in the compost with urea. The content of various zinc forms change dynamically during waste composting. Drozd and Licznar (2004*b*) showed that the content of soluble zinc forms decreased in the first weeks of composting. The moisture content of the composted waste may have significantly affected the content of mobile forms of this element. According to Drozd and Licznar (2004*b*), a higher moisture content of composted waste decreases the content of water soluble forms of this element. In the authors' own investigations, adding urea to composted waste caused an increase in the content of water extracted zinc. Drozd and Licznar (2004*b*) also point to the increased solubility of zinc compounds in composted waste depending on added nitrogen. According to Rosik-Dulewska and Mikszt (2004), the content of zinc bound to organic matter in composts from municipal waste did not exceed 30% of the total content of this element. In the authors' own research, the share was twice as high.

The total copper content in the composts with the addition of starch (C2), edible oil (C3) and in the control compost (C1) was on a similar level, i.e.

37.63 mg kg^{-1} d.m. on average (Table 3). About 7 mg kg^{-1} d.m. of the total copper forms was determined in the compost with added urea (C4). The total Cu content determined in the analyzed materials was much lower than the limit for copper in composts suggested by the European Commission (Wasiak, Madej 2009). The content of water-extracted Cu was the highest in compost with urea (Table 3). In comparison, the content of this copper form in the other composts was 20 mg lower. This copper form constituted over 30% of the total Cu content in the compost with urea, and slightly over 15% in the other composts. Irrespectively of the applieds ubstance, a relatively low share of copper bound to organic matter was detected in the total content of this element. According to Rosik-Dulewska and Mikszt (2004), the highest amount of copper in composted municipal waste, up to about 60% in the total content, is accumulated in the fraction bound to organic matter. The results of the authors' investigations conducted on municipal plant waste indicate that copper in the organic fraction did not exceed 20% of the total content of this element, which resulted from a considerable share of water-soluble forms. Wong and Selvam (2006) also showed that composting caused transformation of the copper residual form into mobile forms.

The total lead content in the composts was comparable and ranged between 14.87 mg and 15.62 mg kg^{-1} d.m. (Table 3). As in the case of cadmium, copper and zinc, the highest amount of lead forms was extracted with water from the compost with urea. The lead content in the forms bound to organic matter was much higher than the content of water-extracted forms. The content of water-soluble forms of lead in the analyzed composts was low, except for the compost with urea addition (C4).

The total content of trace elements in the composts depends above all on their content in the material from which the biomass for composting was prepared. Changes in the organic matter content, and especially its loss, are not without importance for the content and availability of trace elements. The authors' investigations indicate that the composting of biodegradable materials with various added substances causes an increase in the total content of trace elements, as confirmed by results of other authors (Lazzari et al. 2000, Nomeda et al. 2008). Czekała (2006) went further, suggesting that changes in the trace element availability in composted waste were connected with changes in the content of soluble forms of organic matter.

The organic carbon content decreased in all the composts in comparison with the content determined in "heated" compost collected after removal from the bioreactor (Tables 1, 4). Zorpas et al. (2003) and Liu et al. (2007) stated that the loss of organic carbon concerned mainly easily degradable organic compounds of composted biomass. Moreover, Drozd and Licznar (2004*a*) showed that the loss of organic carbon in composted waste depended on the biomass moisture content during the process. At a higher moisture content, the temperature of the composted mass was observed to be lower, especially during the thermophilic phase of the process.

Table 4

Fractional composition of humus in organic materials after composting

Determination	Type of compost*			
	C1	C2	C3	C4
	(g kg^{-1} d.m.)			
Organic C	309 ± 4.1	312 ± 37	302 ± 7.7	318 ± 60
Extracted C	23.17 ± 0.4	18.97 ± 0.10	17.61 ± 0.59	58.10 ± 2.71
C humic acids	9.89 ± 0.2	9.20 ± 0.20	14.53 ± 1.19	39.47 ± 1.94
C fulvic acids	13.28 ± 0.60	9.76 ± 0.20	5.27 ± 0.59	18.64 ± 0.78
Cha:Cfa	0.74 ± 0.05	0.94 ± 0.04	2.75 ± 0.01	2.11 ± 0.02

± standard deviation
* explanation as in Table 2

The analysis of the content of humic compounds revealed considerable diversity of both the content of extracted carbon and the content of humic acids (Table 4). Most carbon was extracted from the compost with urea (C4). The content of carbon extracted from the composts with starch (C2) and edible oil (C3) did not differ. The humic acid carbon content in the analyzed composts ranged widely, from 9.20 g kg^{-1} to 39.47 g kg^{-1} d.m. The highest amount of humic acid carbon was determined in the compost with urea (C4).

The fulvic acid carbon content ranged more narrowly, from 5.27 g kg^{-1} to 18.64 g kg^{-1} d.m. (Table 4). As in the case of humic acid carbon, the biggest amount of this fraction of humic compounds was determined in the compost with urea (C4).

The varied content of Cha and Cfa was reflected in the ratio of both fractions. The composts with edible oil (C3) and urea (C4) were characterized by markedly higher values of the Cha:Cfa ratio: 2.75 and 2.11, respectively (Table 4). Much lower values (less than one) of that ratio were found in the control compost (C1) and in the compost with starch (C2). The results of the research conducted by Raj and Antil (2011) on the maturity and stability of composts manufactured from agri-industrial waste indicate that the process led to the attainment of an optimal value of the Cha:Cfa ratio, i.e. 1.9. However, Inbar et al. (1990) stated that 1.5 was the optimal value of the above ratio. In practice, a relatively small difference between these two values of the Cha:Cfa ratio may mean significant changes in the level of mineralization of composted materials, which might not necessarily be favorable for properties of the final product.

The most numerous group of microorganisms in the analyzed composts were bacteria, in contrast to fungi, which were the least numerous (Table 5). In the compost with starch, the number of vegetative forms of bacteria was almost three times as high as in the compost with oil and 9-fold higher than in the control compost. In the compost with urea, the number of dormant forms of bacteria was higher than the numerical strength of this physiological

Table 5

Counts of microorganisms in organic material after composting

Microorganisms	Type of compost*			
	C1	C2	C3	C4
	(jtk g^{-1} d.m.)			
Vegetative bacteria	23 296 · 10^3	211 200 · 10^3	64 670 · 10^3	12 772 · 10^3
Endospore-forming bacteria	1 792 · 10^3	105 60 · 10^3	14 049 · 10^3	3 090 · 10^3
Fungi	426 048	1 003 200	1 583 300	412 103
Actinomycetes	11 200 · 10^3	19 712 · 10^3	23 192 · 10^3	824 · 10^2
Proteolytic bacteria	873 600	17 600	66 900	1648
Amylolytic bacteria	5 376 · 10^3	6 512 · 10^3	4 683 · 10^3	6 592 · 10^2
Lipolytic bacteria	269	229	11 596	82

± standard deviation
* explanation as in Table 2

group of microorganisms in the control compost (Table 5). The compost with urea contained over 8-fold fewer amylolytic bacteria compared to the numerical strength of this group of microorganisms found in the control compost (C1). The highest number of amylolytic bacteria (which decompose starch) was determined in the compost with starch addition.

Fungi and actinomycetes thrived best in the compost with oil, which was a processed source of carbon (Table 5). Fungi were the least numerous group of microorganisms in the compost. Adding urea to composted biomass considerably decreased the number of all groups of microorganisms. The highest reduction in the number of microorganisms was observed in proteolytic bacteria (*ca* 530-fold fewer than in the control) and actinomycetes (whose count decrased by about 136-fold) According to Ma et al. (2003), the efficiency of composting process depends on the composition of biomass subjected to biological transformation and on the metabolic activity of microorganisms. Among the physical parameters, an adequate reduction of the composted biomass volume and its aeration are essential for the right course of composting. According to Piotrowska-Cyplik et al. (2008), a better indicator in an assessment of the biological activity of composted material is their enzymatic activity. These authors claim that the above measure allows for the explanation of the mechanisms and dynamics of the composting process.

CONCLUSIONS

1. The total content of cadmium, zinc, copper and lead determined in the analyzed composts does not pose a threat to the purity of the soil environment. The loss of organic matter, the chemical properties of elements

and the type of the added substances, mainly urea, affected the content of their water-soluble forms and forms bound to organic matter.

2. The analysis of the fractional composition of humic compounds of the composts revealed varied effects of the added substances on the content of extracted carbon and on the value of humic acid to fulvic acid carbon ratio. Markedly higher values were determined for the Ckh:Ckf ratio in the composts with edible oil and urea, which may indicate a more advanced decomposition of the composted material.

3. Out of the the analyzed microorganisms, bacteria were the most numerous in the composts. The added substances (oil, starch and urea) modified the quantitative composition of the microflora in the composts.

4. By adding 5% urea to biomass in order to improve the C:N ratio, mineralization is accelerated, which in turn disturbs the microbiological process, causing undesirable changes in quality of the composts.

REFERENCES

Atlas R.M., Parks L.C. 1997. *Handbook of microbiological media*. CRC Press, Boca Raton.

Baran S., Turski R. 1996. *Specialist exercises on waste and sewage disposal*. Wyd. AR w Lublinie. (in Polish)

Bowszys T., Wierzbowska J., Bowszys J., Bieniek A. 2009. *Modification in the content of available zinc and copper in soil fertilized with bio-waste compost.* J. Elem., 14(1), 33-42.

Czekała J. 2006. *Copper and manganese chemical bounds in a sewage sludge composted with straw in a bioreactor under conditions of differentiated air supply.* Pol. J. Environ. Stud., 15(a): 30-35.

Dimambro M.E., Lillywhite R.D., Ran C.R. 2007. *The physical, chemical and microbial characteristics of biodegradable municipal waste derived composts*. Compost Sci. Utilizat. 15(4): 243-252.

Drozd J., Licznar M. 2004*a*. *Transformation of organic matter during composting of municipal waste in different humidity conditions and at different urea addition.* In: *Composts from municipal waste production, utilization and impact on the environment.* Drozd J. (Ed.). Wyd. PTSH, 130-140. (in Polish)

Drozd J., Licznar M. 2004*b*. *Changes in macro-and micronutrients during the composting of municipal waste in different humidity conditions and at different urea addition.* In: *Composts from municipal waste production, utilization and impact on the environment*. Drozd J. (Ed.). Wyd. PTSH, 151-170. (in Polish)

Drozd J., Licznar M., Patorczyk-Pytlik B., Rabikowska B. 1996. *Changes in chemical composition of municipal waste composts during the composting.* Zesz. Probl. Post. Nauk Rol., 437: 131-138. (in Polish)

Garcia C., Moreno L.J., Hernandez T., Costa F., Polo A. 1995. *Effect of composting on sewage sludges contaminated with heavy metals.* Biores. Technol., 53(1): 13-19.

Gondek K. 2006. *The content of various forms of heavy metals in sewage sludge and composts.* Acta Agrophys., 8(4), 825-838.

Gondek K. 2007. *Content of carbon, nitrogen and selected heavy metals in compost*. J. Elem., 12(1): 13-23.

Himanen M., Hanninen K. 2011. *Composting of bio-waste, aerobic and anaerobic sludges – Effect of feedstock on the process and quality of compost*. Biores. Technol., 102(3): 2842-2852.

Horiuchi J.I., Ebie K., Tada K., Kobayashi M., Kanno T. 2003. *Simplifield method for estimation of microbial activity in compost by ATP analysis*. Biores. Technol., 86: 95-98.

Hsu J.H., Lo S.L. 2001. *Effect of composting on characterization and leaching of copper, manganese and zinc from swine manure.* Environ. Pollut., 114(1): 119-127.

Huang D., Zeng G., Feng Ch., Hu S., Lai C., Zhao M., Su F., Tang L., Liu H. 2010. C*hanges of microbial population structure related to lignin degradation during lignocellulosic waste composting.* Biores. Technol., 101(11): 4062-4067.

Huang G.F., Wu T.Q., Wong J.W.C., Nagar B.B. 2006. *Transformation of organic matter during co-composting of pig manure with sawdust*. Biores. Technol., 97(15): 1834-1842.

Iglesias-Jimenez E., Perez-Garcia V. 1991. *Composting of domestic refuse and sewage sludge. Part. 1. Evaluation of temperature, pH, C/N ratio and cation exchange capacity*. Res. Conserv. Rec., 6: 45-60.

Inbar Y., Chen Y., Hadar Y. 1990. *Humic substances formed during the composting of organic matter.* Soil Sci. Soc. Am. J., 54: 1316-1323.

Ishii K., Takii S. 2003. *Comparison of microbial communities in four different composting processes as evaluated by denaturing gradient gel electrophoresis analysis*. J. Appl. Microbiol., 95: 109-119.

Jakubus M. 2012. *Phytotoxicity and speciation of copper and nickel in composted sewage sludge*. J. Elem., 17(1): 43-56,. DOI: 10.5601/jelem.2012.17.1.04

Kang J., Zhang Z., Wang J.J. 2011. *Influence of humic substances on bioavailability of Cu and Zn during sewage sludge composting*. Biores. Technol., 102 (17): 8022-8026.

Kulcu R., Yaldiz O. 2004. *Determination of aeration and kinetics of composting some agricultural waste.* Biores. Technol., 93(1): 49-57.

Lazzari L., Sperni L., Berlin P., Pavoni B. 2000. *Correlation between inorganic (heavy metals) and organic (PCBs and PAHs) micropollutant concentrations during sewage sludge composting processes.* Chemosphere, 41: 427-435.

Liu Y., Ma L., Li Y., Zheng L. 2007. *Evolution of heavy metal speciation during the aerobic composting process of sewage sludge.* Chemosphere, 67: 1025-1032.

Ma Y., Hang J.Y., Wong M.H. 2003. *Microbial activity during composting of anthracene contaminated soil.* Chemosphere, 52: 1505-1513.

Nomeda S., Valdas P., Chen S.Y., Lin J.G. 2008. *Variations of metal distribution in sewage sludge composting*. Waste Manage., 28: 1637-1644.

Piotrowska-Cyplik A., Cyplik P., Białas W., Czarnecki Z. 2008. *Wpływ sposobu kompostowania odpadów z przemysłu tytoniowego na wybrane parametry fizyko-chemiczne i enzymatyczne*. Acta Agrophys., 12(2): 487-498.

Raj D., Antil R.S. 2011. *Evaluation of maturity and stability parameters of composts prepared from agro-industrial wastes.* Biores. Technol., 102(3): 2868-2873.

Rosik-Dulewska Cz., Mikszta M. 2004. *Forms of selected heavy metals in composts from municipal waste as an indicator of environmental impact.* In: *Composts from municipal waste production, utilization and impact on the environment.* Drozd J. (Ed.). Wyd. PTSH, 171-185. (in Polish)

Sądej W., Namiotko A. 2010. *Content of zinc in plants fertilized with municipal solid waste and urban green waste composts.* J. Elem., 15(4): 679-692.

Tiquia S.M., Tam N.F.Y., Hodgkiss I.J. 1996. *Microbial activities during composting of spent pig – manure sawdust litter at different moisture contents.* Biores. Technol., 55(3): 201-206.

Wang P., Changa C.M., Watson M.E., Dick W.A., Chen Y., Hoitink H.A.J. 2004. *Maturity indices for composted dairy and pig manures.* Soil Biol. Biochem., 36(5): 767-776.

Wasiak G., Madej M. 2009. *Quality of Polish composts in the light of the criteria of the*

European Union and other countries. Eko Problemy. http://odpady.org.pl/plugins/content/content.php?content.2833 (in Polish)

WONG J.W., SELVAM A. 2006. *Speciation of heavy metals during co-composting of sewage sludge with lime.* Chemosphere, 63(6): 980-986.

ZHANG J., ZENG G., CHEN Y., YU M., YU Z., LI H., YU Y., HUANG H. 2011. *Effect of physico-chemical parameters on the bacterial and fungal communities during agricultural waste composting*. Biores. Technol., 102(3): 2950-2956.

ZORPAS A.A., ARAPOGLOU D., KARLIS P. 2003. *Waste paper and clinoptilolite as a bulking material with dewatered anaerobically stabilized primary sewage sludge (DASPSS) for compost production.* Waste Manage., 23, 27-35.