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CONTENT OF ZINC IN PLANTS FERTILIZED WITH MUNICIPAL SOLID WASTE AND URBAN GREEN WASTE COMPOSTS

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Abstract

In a vegetation experiment, the effect of composts made from unsorted municipal solid waste and urban green waste on the content of zinc in plants has been analyzed. The municipal waste composts matured in heaps for 1, 3 and 6 months. They were applied in three rates: 10, 20 and 30 g kg^{-1} of soil. The compost made of urban green waste aged in a pile for 6 months and was added to soil in the amount of 10 g kg^{-1} of soil. It has been determined that the content of zinc in plants was varied and depended on the type and rates of compost used as well as the species of crops. Application of higher rates of composts did not invariably result in an increased concentration of zinc in plant tissues; on the contrary, in some cases the level of zinc determined in fertilized plants was lower than in the control. Much more elevated concentrations of zinc were found after the application of fresh compost made of municipal waste (maturing for one month in a heap). Fertilization of maize and barley with urban green waste compost produced a more favourable result than the application of analogous rates of municpal solid waste compost, as the plants contained less zinc. With respect to the other test plants, such as sunflower, mustard and phacelia, the application of composted green matter caused a considerable increase in the content of zinc, as compared with the treatments fertilized with composted municipal waste, at the same fertilization rates.

Key words: municipal solid waste, urban green waste, compost, zinc, plant, soil.

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ZAWARTOŚĆ CYNKU W ROŚLINACH NAWOŻONYCH KOMPOSTAMI Z ODPADÓW KOMUNALNYCH I ZIELENI MIEJSKIEJ

Abstrakt

W doświadczeniu wegetacyjnym analizowano wpływ kompostów wyprodukowanych z niesegregowanych odpadów komunalnych oraz z odpadów zieleni miejskiej na zawartość cynku w roślinach. Użyte komposty z odpadów komunalnych dojrzewały w pryzmach odpowiednio przez 1, 3 i 6 miesięcy. Zastosowano je w 3 dawkach: 10, 20 i 30 g kg^{-1} gleby. Kompost z odpadów zieleni miejskiej dojrzewał w pryzmie 6 miesięcy, użyto go w ilości 10 g kg^{-1} gleby. Stwierdzono, że zawartość cynku w roślinach była różnicowana w zależności od rodzaju użytego kompostu, wielkości dawek oraz gatunku uprawianej rośliny. Działanie zwiększonych dawek kompostów nie zawsze skutkowało wzrostem zawartości cynku w roślinach, a w niektórych przypadkach jego zawartość była niższa od stwierdzonej w obiekcie kontrolnym. Znaczny wzrost zawartości cynku w większości analizowanych roślin nastąpił po zastosowaniu świeżego kompostu z odpadów komunalnych po miesiącu dojrzewania w pryzmach. Nawożenie kompostem z odpadów zieleni miejskiej w przypadku kukurydzy i jęczmienia okazało się korzystniejsze niż identyczna dawka kompostu z odpadów komunalnych, ponieważ rośliny z tego obiektu zawierały mniej cynku. U pozostałych roślin: słonecznika, gorczycy i facelii zastosowanie tego kompostu spowodowało znaczący wzrost zawartości omawianego pierwiastka, w porównaniu z obiektami użyźnianymi kompostem z odpadów komunalnych, w przypadku tego samego poziomu nawożenia.

Słowa kluczowe: odpady komunalne, odpady z zieleni miejskiej, kompost, cynk, roślina, gleba.

INTRODUCTION

Elevated content of trace elements in soil may be a result of human activity. Progressing industrialization and increasing use of chemicals in agriculture contribute to soil pollution with trace elements. Waste of all types, including large amounts of organic waste, is another by-product of man's activity. It seems that the optimal form of organic waste utilization should be their introduction into natural processes (GONDEK, FILIPEK-MAZUR 2005, 2006). However, some organic waste may contain excessive quantities of heavy metals (FRITZ, VENTER 1988, RUTKOWSKA et al. 2003 a, b, SĄDEJ et al. 2003, 2004, RAMOS et al. 2004), which is their greatest disadvantage. Among such waste is municipal solid waste. Composts made from this type of waste used in overtly large rates can lead to an excessive concentration of heavy metals in soils (KABATA-PENDIAS, PIOTROWSKA 1987, CHWASTOWSKA et al. 1993).

These elements, once they have penetrated soil, are included in a food chain and can end up in a human organism (FERGUSSON 1990). Zinc is an element counted as a heavy metal. It is used as a component of metal alloys, for making paints and batteries and in the poligraphic industry. The main source of zinc emission are colour metal smelting plants as well as combustion of coal and crude oil.

SALGUEIRO et al. (2000) emphasize that zinc is one of the major elements which influence functions of a human body. On a global scale, this microelement is deficient in a daily diet of people, which is a serious problem due to the role zinc plays in a human body at different stages of its development. SZLEGIEL-ZAWADZKA (2001) points to the fact that zinc deficit in a man's body can lead to a variety of disorders, both concerning body systems and single organs. As a micronutrient, zinc is necessary for proper metabolism of proteins and carbohydrates. It is also involved in insulin synthesis and in maintaining the balance between acids and alkalis in an organism.

Regarding its influence on soil, zinc is considered to be a metal producing unwanted burden on this non-renewable element of the natural environment (GORLACH, GAMBUŚ 2000). It is among the most mobile elements in soil and its plant availability depends on the soil's reaction, decreasing in proportion to an increase in the pH values of soil. In contaminated soils, this element will accumulate mainly in roots of plants. Chlorosis, listed among some typical signs of excessive amounts of zinc in plants, appears due to depressed efficiency of photosynthesis, leading to inhibited growth of affected plants (KABATA-PENDIAS, PENDIAS 1999). When excessive levels of zinc appear in soil, the yield of crops can be largely depressed (BARAN et al. 2008).

The objective of this study has been to evaluate the content of zinc in plants fertilized with composts made from unsorted municipal solid waste and urban green waste.

MATERIAL AND METHODS

A pot experiment was conducted in a greenhouse of the University of Warmia and Mazury in Olsztyn. Kick-Brauckman pots were used for the trials, each filled with 10 kg of typical brown soil containing 1.12% organic matter. The soil had a texture of light loamy sand. The content of available phosphorus, potassium and magnesium was: 77 mg P, 170 mg K and 66 mg Mg per 1 kg of soil. The pH of the soil in 1 mol KCl was 5.50. The experiment consisted of 4 replicates.

The experiment compared the effects produced by two types of compost: made from mixed municipal solid waste generated according to the biothermic technology MUT-DANO, which matured in compost heaps for 1, 3 and 6 months, and made from urban green waste, which aged in a heap for 6 months. The composts for the experiment were taken on the same day, but they differed in the ageing time, therefore the initial material from which they were made was not identical but had similar characteristics. The agrochemical evaluation of the value of the municipal waste composts in different maturity stages had been presented in our previous paper (SĄDEJ et al. 2003). The composts made from municipal waste were applied in three rates:

10, 20 and 30 g kg^{-1} of soil, which corresponds to 30, 60 and 90 t per 1 ha, whereas the green waste compost was introduced to soil in the amount of 10 g kg^{-1} (30 t ha^{-1}). The experiment was carried out for three years. In the first year, maize (*Zea mays* L.) and sunflower (*Helianthus annus* L.) were grown, followed by spring barley (*Hordeum vulgare* L.) and white mustard (*Sinapis alba* L.) in the second year and lacy phacelia (*Phacelia tanacetifolia* Benth.) in the third year. The plants were harvested in the following maturity phases: maize during the panicle emergence phase, sunflower in the early inflorescence, spring barley in the phase of shooting, white mustard and lacy phacelia during the full inflorescence phase. In the third year of the experiment, mineral fertilization was applied to all treatments, in the following rates (in mg kg^{-1} of soil): 74 N, 31 P and 109 K.

Immediately after the plant harvest, the yield and dry matter content of the plants were determined. The content of zinc in the plant material, composts and soil was determined using the atomic emission spectrophotometric method with inductively induced plasma, in an ICP-AES apparatus (manufactured by Leeman Labs), having previously mineralized the material in a 5 : 4 mixture of HNO_3 and $HClO_4$ in a heating block (manufactured by VEL) (Ostrowska et al. 1991).

The content of zinc in the soil used for the experiments (31.92 mg kg^{-1} d.m.) was assessed as natural according to the criteria elaborated by the IUNG in Puławy (Kabata-Pendias et al. 1993). The content of this element was however variable. The fresh compost made from municipal waste contained 934.5 mg Zn kg^{-1} d.m., but after a month's maturation its content rose to 1041.2 mg Zn kg^{-1} d.m. The highest concentration of zinc was found in the compost maturing for three months (1340.60 mg Zn kg^{-1} d.m.). After the next three months in a heap, the compost contained over 300 mg Zn kg^{-1} d.m. less zinc, whose concentration fell to 1031.35 mg Zn kg^{-1} d.m. The compost made from urban green waste which was kept in a heap for 6 months contained 649.55 mg Zn kg^{-1} d.m., i.e. about 1/3 less than the municipal waste composts. The above differences were most probably an effect of the differences in the properties of the initial material used for production of the composts.

RESULTS AND DISCUSSION

The lowest rates of the composts tested in the trials led to an increase in the dry matter yield of maize, sunflower and barley but depressed that of white mustard and phacelia (Table 1). The response of these plant species to increased rates of municipal waste composts was similar. It was demonstrated that the crops tended to respond more positively to the fertilization with the one- and three-month-old composts than with the compost which aged

Table 1

Yield of dry mass of aerial parts of plants (g pot^{-1})

Dose of compost (g kg^{-1} soil)		Species of cultivated plant				
		maize	sunflower	spring barley	white mustard	phacelia tanacetifolia
		year of cultivation				
		I		II		III
Control 0		58.8	15.9	9.9	4.4	47.2
Municipal solid waste compost heap-stored for 1 month						
10		69.5	16.4	14.1	3.7	43.5
20		87.6	19.9	14.3	3.2	46.3
30		85.2	17.9	14.6	3.1	48.8
Municipal solid waste compost heap-stored for 3 months						
10		72.9	16.1	14.3	4.4	45.8
20		86.7	14.3	15.4	4.5	44.9
30		81.9	28.3	16.4	3.8	45.6
Municipal solid waste compost heap-stored for 6 months						
10		71.0	16.0	12.9	3.8	42.9
20		74.6	21.3	15.7	3.2	42.7
30		84.4	19.6	14.5	3.2	48.9
Green waste compost						
10		63.2	23.3	13.4	3.1	47.0
$LSD_{0.05}$	dose of compost (d)	2.6	1.2	1.2	0.3	1.5
	phase of maturing (f)	1.5	0.7	n.s.	0.2	n.s.
	interaction: d·f	4.6	2.1	n.s.	0.6	2.6

for 6 months, and the fertilization with the compost maturing for one month produced the strongest response in maize and phacelia, whereas sunflower, barley and mustard were more responsive to the three-month-old compost. Fertilization treatments with six-month-old compost produced a weaker response in maize, mustard and phacelia compared to the other composts, while sunflower and barley responded better to the fertilization with six-month-old compost.

In respect of the yield of aerial parts of sunflower, barley and phacelia, the green waste compost was less effective than the municipal waste compost which matured for the same period of time. In the case of maize and mustard, the effect produced by the former compost was less favourable.

The results obtained in the present experiment are similar to those reported by JANKOWSKI (1997), although in his study the positive effect of compost application was also observed in the subsequent years of the trials. Increased dry matter yield of crops fertilized with municipal waste compost was also noticed by ZHELJAZKOV and WARMAN (2003). ŁABĘTOWICZ et al. (2002) concluded that dry matter yields rose as the applied rates of compost were higher, a tendency that was also observed in the present study. In turn, LEKAN et al. (1997) proved that dry matter yield of plants was significantly higher when the rate of municipal waste compost was as high as 200 t ha^{-1}.

Content of heavy metals is an important indicator of the heavy metal contamination of composts, especially the ones which are to be used in agriculture. With respect to zinc, the analyzed composts were characterized by very high quality as in none of the tested material the permissible quantity of zinc established by the Industry Standards for class I composts, i.e. 1500 mg Zn kg^{-1}, was exceeded.

Fertilization treatments involving the analyzed composts caused changes in the content of zinc in the test crops, which depended on the species of a grown crop and, to a lesser extent, on the type of compost applied.

The effect of municipal and urban green waste composts in the first year after their application led to an increase in the content of zinc, both in maize (Figure 1) and in sunflower (Figure 2). The content of zinc in the aerial biomass of both crops increased as the applied rates of composts rose, but the relative changes were smaller in sunflower. The effect of the compost maturity phase on the content of this metal was varied. Using the municipal waste compost that had the shortest maturation time (1 month) caused the highest increase in the content of zinc, both in maize and in sunflower. Application of composts which matured in heaps for longer time

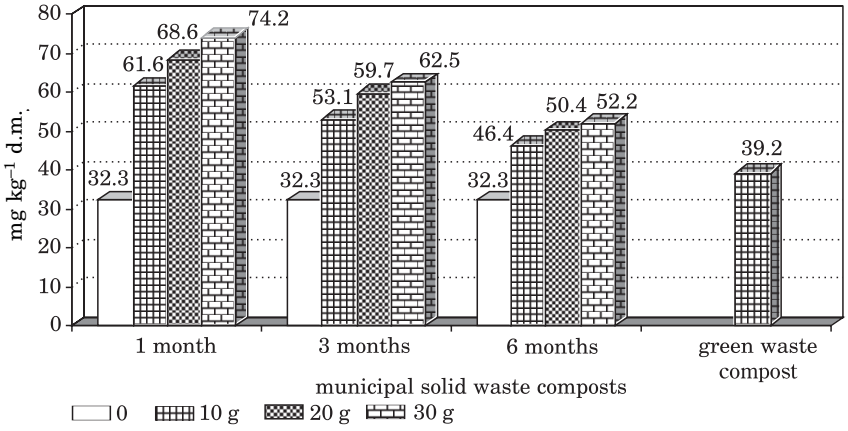

Fig. 1. Content of zinc in aerial parts of maize *(Zea mays* L.*)*

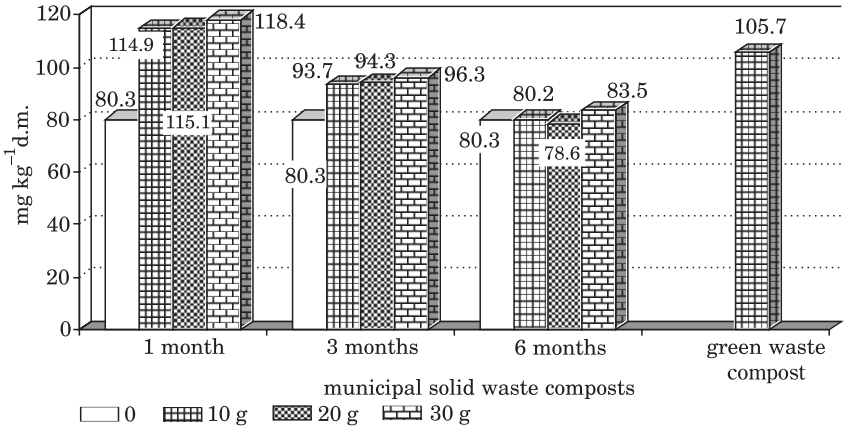

Fig. 2. Content of zinc in aerial parts of sunflower (*Helianthus annuus* L.)

led to a successive decrease in the concentration of zinc in both crops, which was a result of the fact that the yield of these plants was lower when older composts had been introduced to soil. Of the two test plants, much more zinc was determined in sunflower than in maize, and this tendency was observed in all fertilization treatments. The results of the tests are in accord with the proven thesis that dicotyledons contain more heavy metals than monocotyledons (Gambuś, Gorlach 1996). Petruzelli et al. (1989) demonstrated that compost fertilization led to altered levels of zinc in maize, with its concentration being dependent on plant organs. More zinc was found in roots than in kernels.

Maize fertilized with urban green waste compost accumulated less zinc than maize nourished with an identical rate of municipal waste compost. In respect of sunflower, the former compost caused an increase in zinc concentration in plants relative to all the rates of composts made from municipal waste and maturing for 3 and 6 months.

In the subsequent year of the experiment, the effect of composts was different than in the first year. Application of municipal waste composts tended to depress the content of zinc in the biomass of spring barley, below the level observed in the control pots (Figure 3). The most profound effect, reaching 20%, was recorded after the lowest rate of composts was applied. Slightly more zinc than in the control was found only in the object fertilized with 1-month-old compost added to soil at a rate of 20 g kg^{-1} soil. Analogously, application of compost made from green waste depressed the content of zinc in spring barley biomass compared to its concentration in control plants. This effect was similar to the results of using identical doses of municipal waste composts maturing in heaps for 1 and 6 months.

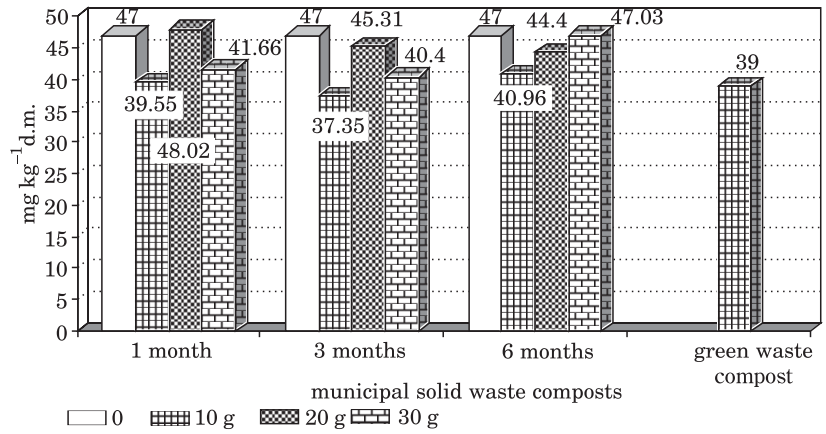

Fig. 3. Content of zinc in aerial parts of spring barley (*Hordeum sativum* L.)

Regarding white mustard, fertilization with municipal waste composts introduced to soil in a rate of 10 g kg^{-1} of soil depressed the content of zinc by about 24 to 54% compared to the content of this metal in the control plants (Figure 4). No unidirectional changes in the content of Zn caused by the larger rates of composts were found, except higher doses of 1-month-old compost depressing the content of zinc in plants to a similar extent, by about 30% compared to the lowest rate. The effect of the maturation period on the content of zinc in plants was in general similar to that observed in the first year of the tests, namely the more mature the compost, the lower the average content of zinc in the biomass of white mustard. Application of urban green waste compost produced an almost identical

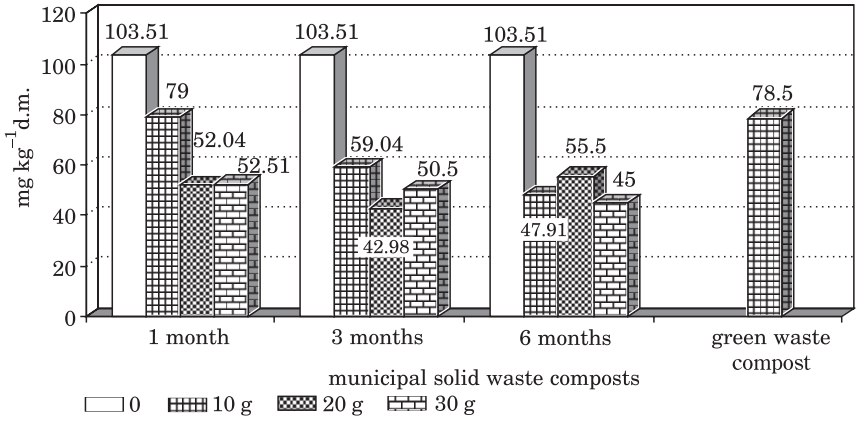

Fig. 4. Content of zinc in aerial parts of white mustard (*Sinapis alba* L.)

effect to that of the lowest rate of municipal waste compost, remaining in a heap for one month, i.e. it lowered the content of zinc in mustard by about 24% versus the control plants, but the decrease was much smaller than produced by the same rate of six-month-old compost. This response of both plant species was observed although fertilization with composts had a different effect on their yields. Sunflower, for example, produced 30 to 60% higher yields whereas the yields of mustard did not change much or else dropped by 14 to 30% under the influence of composts.

In the third year of the experiment, when composts had been added to soil, the response of one of the test plants, namely lacy phacelia, was different from that observed in other plants grown immediately after the introduction of composts to the substrate or in the second year. Fertilization with municipal waste composts generally depressed the content of zinc in the biomass of lacy phacelia, but the differences were smaller than in the plant species discussed earlier in this paper (Figure 5). The largest decline in the concentration of zinc in plant tissues, reaching 18%, followed a fertilization treatment with 1-month-old compost. Among the objects fertilized with municipal waste compost, it was only the three-month-old compost applied in the lowest rate that caused an increase in the zinc concentration in phacelia biomass by about 6% compared to the plants from the control pot. Among all the objects fertilized with the lowest compost doses, the highest content of zinc, 18% higher than in the control plants, was observed when urban green waste compost had been applied, and the yields from both treatments were on a similar level. This response was different than the one noticed in the previous years for maize, sunflower and barley, but the same as occurred in white mustard.

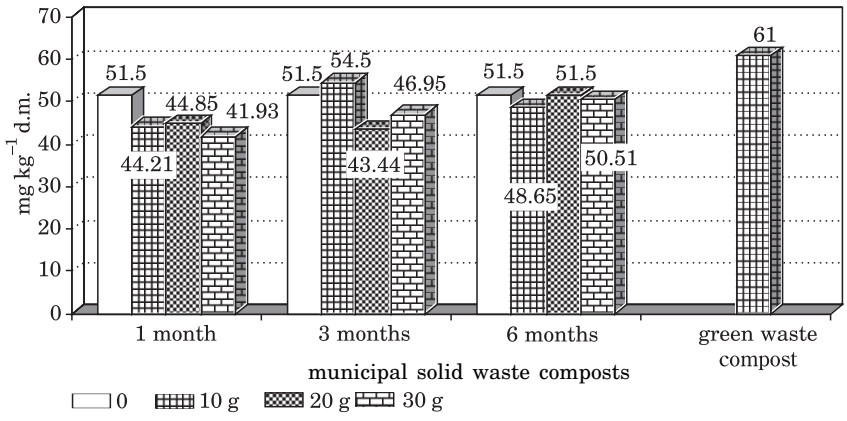

Fig. 5. Content of zinc in aerial parts of phacelia (*Phacelia tanacetifolia* L.)

Many authors (JANKOWSKI 1997, ŁABĘTOWICZ et al. 2002) suggest that, in general, application of municipal waste composts significantly increased the content of heavy metals in plants, in proportion to the increasing rates of such fertilizers. The authors' own results are partly in agreement with the cited references, as the increasing doses of composts did not invariably lead to an increase in the zinc content in plants. LEKAN et al. (1997) claim, however, that fertilization with municipal waste composts leads to higher concentrations of zinc in plants. Similar conclusions are formulated by STĘPIEŃ et al. (2006).

CASTRO et al. (2009) proved that fertilization with municipal waste composts significantly increased the content of zinc in lettuce versus the control, with the highest content of this element found in the second year of growing lettuce. GAJ and GÓRSKI (2004) demonstrated that composts introduced to soil raised the content of zinc in sugar beet but did not deteriorate the quality of the yield. The content of this element was varied and depended on the applied dose of compost. These authors determined that more Zn accumulated in sugar beet roots than in leaves. SCHUMAN et al. (2001) found out that compost fertilization led to a decrease in the content of zinc in plants, which meant that its toxicity declined, too.

The present experiments have clearly pointed to the need of including the content of heavy metals in composts into calculations of applicable rates of composts. This conclusion is confirmed by a simplified zinc balance, worked out during the study, which suggests that application of larger rates of composts leads to increased amounts of zinc in soil, even several years after a given fertilization treatment (Table 2). Zinc uptake by plants depended also on the type and rate of applied composts, species-specific characteristics of plants and volume of the yield they produced. The highest uptake of zinc was observed for the plants grown on soil fertilized with composts left in heaps for the shortest period of time. When the thee-year-long experiment was terminated, most zinc was found remaining in the soil fertilized with 3-month-old compost, which was a consequence of the initial content on zinc in this compost (Table 2).

WEBER et al. (2002) believe that the content of heavy metals in soil depends on the soil's type and the type of compost applied. Soils poor in organic matter are susceptible to pollution with heavy metals, but the organic matter introduced to such soils with the applied compost contributes to decreasing the amounts of heavy metals assimilated by plants growing on the fertilized soil. Moreover, quantities of heavy metals taken up by plants, apart from the type of soil and compost, depend on the species or even an organ of a cultivated crop.

GIGLIOTTI et al. (1996) demonstrated that compost fertilization caused a significant increase in the content of zinc in soil compared to an unfertilized treatment. Similar conclusions were drawn by GAJ and GÓRSKI (2004). SMITH (2009) states that heavy metals in composts are strongly associated

Table 2

Simplified balance of zinc for three years (mg pot^{-1})

Dose of compost (g kg^{-1}soil)	Zn added to soil with composts (mg pot^{-1})	Zn uptake by plants (mg pot^{-1})	Difference of balance (mg pot^{-1})
Control 0	-	6.53	-6.53
Municipal solid waste compost heap-stored for 1 month			
10	104.12	8.94	95.18
20	208.24	11.23	197.01
30	312.36	11.26	301.10
Municipal solid waste compost heap-stored for 3 months			
10	134.06	8.67	125.39
20	268.12	9.40	258.72
30	402.18	10.84	391.34
Municipal solid waste compost heap-stored for 6 months			
10	103.14	7.37	95.77
20	206.28	8.51	195.77
30	309.42	9.34	300.08
Green waste compost			
10	64.96	8.57	56.39

with organic matter, which reduces the share of their soluble forms and plant availability. Composting is a process which leads to reducing the bioavailability of heavy metals, therefore the environmental threat to human health or such as polluting fertilized soil and cultivated plants is minimal.

The results of the experiment have proven that plants fertilized with the tested composts did not contain excessive amounts of zinc and could be used as fodder plants, as the concentration of zinc attested in these crops was within the permissible range values as stated in the Framework Guidelines for Agriculture (Kabata-Pendias et al. 1993).

CONCLUSIONS

1. With respect to the amount of zinc, the analyzed composts were characterized by high quality, as none of them contained the amounts of zinc that would exceed the quantities established by the Industrial Standards for composts classified as class I. Green waste compost contained 30% less zinc than municipal waste composts.

2. The content of zinc in plants depended on a plant species and volume of dry matter yield as well as the type and rate of the applied fertilizer. The highest increase in the content of this bioelement in the biomass of most of the test plants was observed as a result of the application of 1-month-old municipal solid waste compost. The effect produced by the higher rates of composts did not invariably cause an increase in the zinc content.

3. Fertilization with urban green waste compost caused smaller accumulation of zinc in the biomass of maize and barley, but in the other crops (sunflower, white mustard, lacy phacelia) it typically led to a considerable increase in the content of this metals compared with identical rates of municipal waste composts.

4. Having completed the cycle of our trials, most zinc remaining in soil was found in the treatment consisting of fertilization with three-month-old municipal waste compost. In the soil fertilized with urban green waste compost there was about 50% less zinc than in the soil to which an identical rate of 6-month-old municipal waste composts was introduced. This was a consequence of the fact that there was less zinc in green waste compost.

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