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Study of Compost Based on Sewage Sludge and Different Structural Materials

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Abstract: The characterization of compost compositions on the basis of sewage sludge and structural materials (straw, sawdust, bark) composting is described. A comparison of the methods most often used for composting and characterization of structural materials is also presented. Sewage sludge and structural materials were mixed in different ratios and composted in piles (laboratory scale) for 3 months. During this time, the composting process was controlled using standard methods. The bioavailability of some xenobiotics in an agriculture experiment (using beans) was also investigated.

Keywords: sewage sludge; compost; composting; reclamation; bioaccumulation

1. Introduction

Composting is a natural method for the neutralization and management of the organic content of waste material. On the household scale, composting has been used from time immemorial and is probably the oldest form of recycling. The morphological composition (qualitative and quantitative) of waste materials has been subject to continuous changes in past centuries. Compost associated with people is waste rich in biogens and is a source of potential manure for agricultural application.

The Ancient Egyptians tried to use sediments as fertilizer to increase crop production. Bottom deposits of the Nile washed onto flood land were used to this end. Thus, almost all the agricultural production of ancient Egypt was concentrated on flood land. Compost has been used as manure for over 4000 years. Household waste and agricultural waste were collected in ancient China and transformed into compost [1,2].

In Poland, the first descriptions of rational composting were presented in a book written in 1563 by Anzelm Gostkowski. Almost one hundred years later, Jakub Ham described the advantages of compost in agriculture. The topic was developed in 1799 by Krzysztof Kluk, who recounted what can be composted with regard to hygiene and how [2].

Composting of municipal solid waste (MSW) and its use to fertilize soils started in Europe at the beginning of twentieth century. In England, waste was crumbled in London's district of Southwark and sold to neighboring farmers. In 1914, small chambers (reactors) made of wood or bricks were used to accelerate composting. Transforming of municipal solid waste into compost (as organic manure) on a technical scale began in the 1930s, but more rapid development of composting really started from 1950 in connection with the development of industry and urbanization [1].

Sewage sludge is a special form of waste material. The amount of sewage sludge is continually increasing with the development of modern methods of sewage treatment. Mechanical, biological and chemical wastewater treatment causes significant formation of sewage sludge. Depending on the quantity and chemical composition of the sewage, its agricultural use can cause some problems. Anthropogenic toxic materials (metals, pesticides) and pathogenic organisms (bacteria, parasite larvae) are just some of the problems. The qualitative and quantitative composition of sewage sludge is complex. It is

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rich in biogenic elements (carbon, nitrogen, phosphorus and others) that can improve the quality of soils used, for example, for agriculture. Soils enriched with compost produced from sewage sludge significantly improve soil quality. Additionally, they allow for the reintroduction of elements into the food chain. This fits into the idea of green chemistry (closed-circuit economy).

Composting is a technological process in which organic waste material is converted into a harmless and hygienic form. Composting can also occur through the natural processes of decay and molding, but they are time-consuming. The final product of this process is compost matter which is rich in organic manure.

Sewage sludge composting must reach several goals:

- sanitary;
- aerobic digestion;
- sludge dewatering;
- production of material that is safe for commercial and environmental applications.

The usefulness of waste material for composting is dependent on the original biological organic matter content. Waste material containing less than 30% organic matter is not suitable for the production of compost by industrial methods [3]. In Table 1, the basic physicochemical properties of sewage sludge and composts produced from it are presented [4].

Table 1. Physico-chemical and manurial properties of digested sludge and composts [4].

Parameter	Units	Digested Sludge	Classes of Composts		
			I	II	III
Total solids	% d.m.	45	-	-	-
Content of mineral matter	% d.m.	50	-	-	-
Content of organic matter	% d.m.	50	>40	>30	>20
Hydration	% d.m.	55	25–40	25–40	50
Total nitrogen	% d.m.	<2.0	>0.8	>0.6	>0.3
Total phosphorus (P_2O_5)	% d.m.	<1.5	-	-	-

where: d.m.—dry matter.

As mentioned earlier, the sewage sludge intended for composting should not exceed a certain content of heavy metals. Maximum allowable contents of selected heavy metals in sewage sludge or composts are presented in Table 2 [5]. The levels of other chemical compounds such as polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs) must be also evaluated in the raw sewage sludge [3,6,7].

Table 2. Maximum allowable contents of heavy metals in sewage sludge according to Polish regulations [5].

Metal	Soil Fertilization, Land Reclamation		Agrotechnical Composting
	Agricultural Exploitation	Non-Agricultural Exploitation	Drainage and Reclamation
	mg/kg d.m.		
Lead (Pb)	500	1000	1500
Cadmium (Cd)	10	25	50
Chromium (Cr)	500	1000	2500
Copper (Cu)	800	1200	2000
Nickel (Ni)	100	200	500
Mercury (Hg)	5	10	25
Zinc (Zn)	2500	3500	5000

The potential use of sewage sludge for composting is also limited by microbiological parameters. In Table 3, the biological–sanitary parameters of sewage sludge are described [5].

Table 3. Biological–sanitary quality of sludge according to Polish regulations [5].

Parameter	Admissible Value	
	Soil Fertilization	Land Reclamation
Pathogenic bacteria	Undetectable	Undetectable
Coliform index	Not less than 0.01	-
ATT	<10 per kg d.m.	<300 per kg d.m.

where: ATT—helminth egg factor.

These microbiological parameters can be improved by different methods. In practice, the addition of lime to sewage sludge to adjust the pH to ca. 10 and high-energy radiation are commonly used [8–11].

In practice, the composting process can be carried out in several ways [12,13]:

1. Pile method—mixing sediments with structural materials into piles and periodically mechanically aerating them;
2. Aerated pile method—a method similar to the pile method. The pile is placed on a porous base and aerated by a system of fans;
3. Oxygenic composting in reactors:
    - composting in silo reactors (vertical) operating in series. In the first phase, organic matter decomposes, and in the next phase, oxygen stabilization occurs;
    - tunnel reactor (horizontal), a single-stage system in which the compost mixture is gradually removed from the reactor as it matures;
    - a mixed system in which mixing and aeration are performed alternately, most often in a round, closed reactor.
4. Anaerobic reactors—fermentation of sewage sludge in closed reactors with biogas recovery.

Differences between the above methods are mainly in the mixing and delivery of air. These differences can cause considerable differences in the final product, because, for instance, bad mixing in piles can lead to reduction in the delivery of oxygen, lower temperatures and, finally, a lowering of the compost quality.

The scheme of a typical composting process is presented in Figure 1.

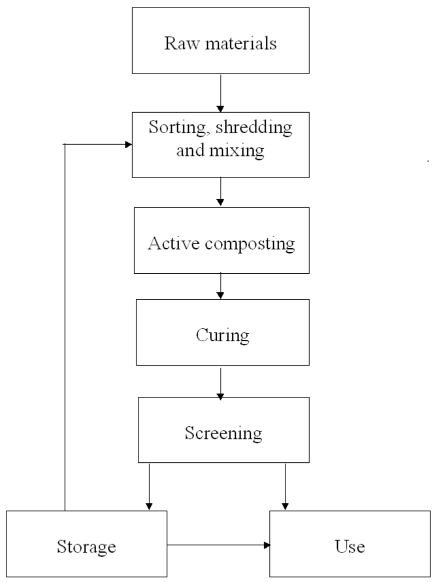

Figure 1. Flow chart of a typical composting process.

There are many parameters that influence the process. The most important parameters are presented in Table 4 [8].

Table 4. Parameters influencing composting process [8].

Parameter	Units	Value
Temperature	°C	55–60
Moisture (W)	%	40% < W < 60%
Aeration	$m^3/t \cdot h$	90–160
Time of composting	Weeks	<4
Time of ripening	Months	<6

In compost production, sewage sludge should be mixed with structural materials in suitable proportions. The C:N ratio for raw composting masses should be 30:1. The optimum C:N ratio after effective composting should be about 20:1 [8].

The most often used composting materials are municipal solid waste, wooden shavings, sawdust, straw, leaves and other matter such as the following [2].

- Cereal straw. The main components are carbon, oxygen, hydrogen, nitrogen, phosphorus, potassium, calcium and magnesium. Soil-forming (humus) and manure components are carbon, nitrogen, phosphorus and potassium. Carbon constitutes about 45% of the dry mass of straw; nitrogen 0.40–0.70%; P_2O_5 0.20–0.35%; K_2O 1.0–2.0%. The C:N ratio in straw is about 80–100.
- Potato stalks are considerably richer in nitrogen, potassium, calcium and magnesium than cereal straw. Potato stalks can contain up to 2.5% nitrogen and over 4% K_2O with a C:N ratio of 20–30.
- Corn straw contains on average 1.0–1.2% N, P_2O_5–0.6% and K_2O–1%. The C:N ratio in straw of ripe corn is 35–45. This value is better than in the straw of four other cereals.
- Beetroot leaves in the ripe phase contain 1.5–2.0% N, 0.35–0.45% P_2O_5 and 2.5–3.0% K_2O in dry mass. The C:N ratio is 25–30. Sugar-beet leaves are rich in nitrogen and the C:N ratio can be up to 20–25.
- Papilionaceous plants are cultivated for green manure, and they are rich in nitrogen, with a C:N ratio up to 18–20.
- Two-leaved plants and weeds, depending on species, phase of development and ground fertility contain 1.5–5.0% N. When the organic carbon content is about 45%, the C:N ratio is up to 15–20 in young plants and 25–40 in older plants.
- Cabbage vegetable leaves as waste material from harvest and processing of crops contain 2–4% N and 40–45% C with a C:N ratio of 15–25.
- Leaves of root vegetables (beets, carrot and parsley) picked in the vegetative period contain more nitrogen than those in their late state of maturity. The average content of nitrogen during the vegetative period is about 35% N and at maturity it is about 2%.
- Animal droppings. They may differ slightly depending on the animal species (cow, swine, horse, bird, sheep, etc.). Cow dung is understood mostly as excrement together with straw litter of cereal plants. Most animals eat plant matter, but they digest it to different extents, and as such, the chemical composition of droppings can differ in terms of the carbon to nitrogen (C:N) ratio. The average content in cow dung is about 25% dry mass and it contains about 2.0% N, 1.2% P_2O_5, 2.8% K_2O in d.m. The C:N ratio in fresh animal feces is 25–30 or more. The C:N ratio in animal droppings after fermentation is 15–20.
- Wood of most plant species contains about 47–50% carbon and less than 0.1% nitrogen (e.g., in sawdust of pine 50.5% C and 0.16% N (C:N ratio = 308) was determined). The C:N ratio is about 500.
- Wood bark contains similar a quantity of carbon and nitrogen compared to wood, e.g., the wood bark of a thirty-year-old pear tree can contain about 46.3–52.5% C.

– Pear tree leaves contain 45% C.
– Tobacco waste material contains 35.4–37.1% C and 1.9–2.2% N. The C:N ratio is 15.5–18.9.
– Peats and organic silts, depending on their sort and degree of decay, can contain up to 99% organic matter and 5% nitrogen.
– Brown coal contains up to 90% organic matter and nearly 50% mineral matter. Similarly, brown wood coals contain small quantities of nitrogen.

In the composting process, there is a possibility of using other additives to improve the compost structure and, for example, adsorb heavy metals (zeolites, coal dust) [14–18].

Recently, chemometric methods have been applied to predict the composition and properties of composts [19,20].

Thanks to composting, sewage sludge with a mushy consistency changes into a cloddish structure. The final structure is easy to use in practical applications (agriculture, landfills).

In practical applications, it is necessary to determine the correct dose of compost. This is difficult and depends on many factors:

- quantity of nutrients;
- quantity of soil;
- admissible contents of heavy metals.

Monitoring environmental quality using plants is widely accepted as a reliable and inexpensive way to obtain information on heavy metal contamination. The main advantage is the possibility of long-term comparison without the need for expensive equipment. Such biomonitoring studies include the analysis of metal bioaccumulation in plants found in polluted areas. Among the indicator plants, one can also find plants potentially useful in phytoremediation.

The use of compost produced from sewage sludge requires tests to confirm its quality. For this purpose, bioaccumulation tests of selected heavy metals are used. Złota Saxa bean was proposed as a test plant. Heavy metals can be taken up by plants and possibly enter the food chain. From this point of view, bioaccumulation experiments are necessary.

The main aim of the research was to obtain high-quality compost from sewage sludge and various selected structural materials (straw, sawdust, bark). The characterization of compost compositions on the basis of sewage sludge and structural materials composting is described. A comparison of the methods most often used for composting and characterization of structural materials is also presented. Sewage sludge and structural materials were mixed in different ratios and composted in piles (laboratory scale) over a 3-month period. In this time, the composting process was controlled using standard methods [21]. The bioavailability of some xenobiotics in the agriculture experiment (using beans) was also investigated.

2. Materials and Methods

2.1. Reagents and Instrumentation

All chemicals were purchased from POCh Gliwice (Gliwice, PL) and were analytical grade (p.p.a.).

Temperature, pH and conductivity were determined using a CX-732 digital multimeter (Elmetron, Zabrze, Poland). Moisture and loss on ignition were determined using gravimetric methods at 378 K and 723 K, respectively. Total organic carbon was determined using a TOC-5000 analyzer connected with an SSM-5000 module (Shimadzu, Kyoto, Japan). Nitrogen was measured using the Kjeldahl method (Turbotherm and Vapodest 20, Gerhardt, Bonn, Germany) and finally determined spectrophotometrically (SQ 118, Merck, Darmstadt, Germany). Phosphorus was determined after wet digestion using a spectrophotometric method (SQ 118, Merck, Darmstadt, Germany). Calcium and magnesium were determined using a titration method with EDTA (EM-Bürette Hirschmann Laborgeräte, Eberstadt, Germany). Selected heavy metals and potassium were determined using the Perkin Elmer AAnalyst 800 (Shelton, CT, USA) atomic absorption spectrometer.

2.2. Study Sample

Table 5 shows a scheme of compost compositions. A sample of 10 kg each of the mixtures was prepared and composted for 90 days in a pile. Duplicate samples of 150 g were collected from each pile after 7, 14, 21, 28, 35 and 90 days for the chemical analysis. Each pile was mixed thoroughly after each sampling to allow sufficient excess of oxygen.

Table 5. Scheme of the multicomponent compost compositions.

Compost Compositions	Ratio [*v*/*v*]			
	Sewage Sludge	Straw	Sawdust	Bark
Sludge/straw/sawdust 5/4/1	50	40	10	0
Sludge/straw/sawdust 5/3/2	50	30	20	0
Sludge/straw/sawdust 5/2/3	50	20	30	0
Sludge/straw/sawdust 5/1/4	50	10	40	0
Sludge/straw/bark 5/4/1	50	40	0	10
Sludge/straw/bark 5/3/2	50	30	0	20
Sludge/straw/bark 5/2/3	50	20	0	30
Sludge/straw/bark 5/1/4	50	10	0	40
Sludge/sawdust/bark 5/4/1	***50***	***0***	***40***	***10***
Sludge/sawdust/bark 5/3/2	***50***	***0***	***30***	***20***
Sludge/sawdust/bark 5/2/3	***50***	***0***	***20***	***30***
Sludge/sawdust/bark 5/1/4	***50***	***0***	***10***	***40***
Sludge	***100***	***0***	***0***	***0***

Physicochemical properties of sewage sludge and selected structural materials (straw, sawdust, bark) used in compost production are presented in Table 6. These properties were determined according to standard methods [21].

Dewatered anaerobically digested sewage sludge was collected from the wastewater treatment plant in Toruń (Poland). The wastewater treatment plant (MOŚ) in Toruń (Poland) is a modern mechanical–biological sewage treatment plant. It produces ca. 80 tons of sewage sludge (side product) daily. In the beginning, sludge management was a great problem for MOŚ (removal to dumping site). For some years, all the sewage sludge was composted in piles together with the addition of cereal straw, corn, sawdust or other waste material (e.g., sewage sludge:straw:sawdust in a ratio of 1:0.5:0.5 v/v) in an area of 4500 m^2. The pile was aerated by a cyclic throwing process (2-month intervals). After this time, the compost was left to ripen on the ground (ca. 130 ha) at a site near to MOŚ intended for future soil reclamation.

Two types of sewage sludge were used in the experiments: without modification (series I) and limed (series II).

Part of the compost is ready for immediate use (e.g., on grounds and lawns in the city), while the remaining part of the compost is used to produce compost soil (mixing of compost and soil in the ratio of 1:1 v/v).

Straw was collected from a private farm near Toruń, bark and sawdust were collected from a sawmill in Nidzica (Poland).

Humic and fulvic acids were isolated using the Schnitzer methodology [22].

The samples were subjected to physicochemical analysis in 3 replications (raw sewage sludge or limed sewage sludge) or 6 replications (straw, sawdust, bark).

Table 6. Physicochemical properties of materials used in experiments.

Parameter	Sewage Sludge (Series I) n = 3	Limed Sewage Sludge (Series II) n = 3	Straw n = 6	Bark n = 6	Sawdust n = 6
Total nitrogen N_{tot} (% d.w.)	2.46 ± 0.35	3.35 ± 0.21	0.84 ± 0.07	0.33 ± 0.04	0.11 ± 0.01
TOC (% d.w.)	25.86 ± 0.29	25.07 ± 0.14	52.28 ± 1.25	40.19 ± 2.04	57.41 ± 4.23
C/N ratio	10.53	7.37	62.24	121.79	521.91
Moisture (%)	41.50 ± 3.65	75.65 ± 4.05	4.94 ± 0.63	35.93 ± 2.35	45.23 ± 3.31
pH	6.26 ± 0.54	13.16 ± 0.64	6.88 ± 0.46	4.15 ± 0.56	3.87 ± 2.47
Calcium Ca (Ca/CaO %d.w.)	3.73 ± 0.23	16.56 ± 0.47	0.76 ± 0.09	0.48 ± 0.07	0.20 ± 0.09
Magnesium Mg (Mg/MgO %d.w.)	0.46 ± 0.5	0.41 ± 0.3	0.17 ± 0.02	0.15 ± 0.03	0.10 ± 0.07
Loss of ignition (%)	56.58 ± 6.32	46.32 ± 7.19	93.04 ± 5.74	58.88 ± 7.85	95.61 ± 12.57
Potassium K (K/K_2O %d.w.)	0.32 ± 0.04	0.47 ± 0.07	1.12 ± 0.04	0.19 ± 0.05	0.22 ± 0.03
Phosphorus P_{tot} (P/P_2O_5 %d.w.)	0.33 ± 0.04	0.47 ± 0.07	0.36 ± 0.03	0.21 ± 0.04	0.28 ± 0.04
Lead Pb (mg/kg d.w.)	0.00	115.75 ± 16.38	4.00 ± 0.96	12.03 ± 1.26	5.02 ± 0.51
Cadmium Cd (mg/kg d.w.)	0.00	3.15 ± 0.04	4.00 ± 0.87	4.01 ± 0.92	4.02 ± 0.43
Nickel Ni (mg/kg d.w.)	209.15 ± 12.1	283.37 ± 11.5	0.00	0.00	0.00
Copper Cu (mg/kg d.w.)	363.62 ± 15.6	181.40 ± 19.5	12.00 ± 1.23	14.04 ± 1.24	19.07 ± 2.59
Zinc Zn (mg/kg d.w.)	1174.33 ± 105.6	660.93 ± 42.6	29.00 ± 2.65	38.10 ± 6.51	21.08 ± 3.05
Chromium Cr (mg/kg d.w.)	287.83 ± 24.36	130.52 ± 18.4	11.00 ± 3.01	21.05 ± 7.23	7.03 ± 1.25

3. Results

Below, only selected parameters for the mixture marked in Table 5 are discussed (series from sludge/sawdust/bark 5/4/1 to sludge).

The temperature inside the 10 kg samples was on average 285 K (Figure 2). It is sometimes recommended to increase the internal temperature to 323 K. The results show typical changes in temperature during composting. The temperature generally rises initially and then levels off. At some point, when microbial activity slows, temperatures begin to descend.

From a chemical point of view, the two most important nutrients are carbon and nitrogen. Organic carbon content (equivalent to the amount of organic substances in the mixtures) depends on the amount of sawdust added. It means that the organic carbon content and C/N ratio can be controlled by the approximate amount of sawdust and/or bark. When C/N ratio vs. time is examined (Figure 3), it is seen that for all samples the decrease in C/N ratio is observed, followed by a region with a constant ratio in the series I experiment. In series II, we can observe a different situation, in which the C/N ratio slowly increases.

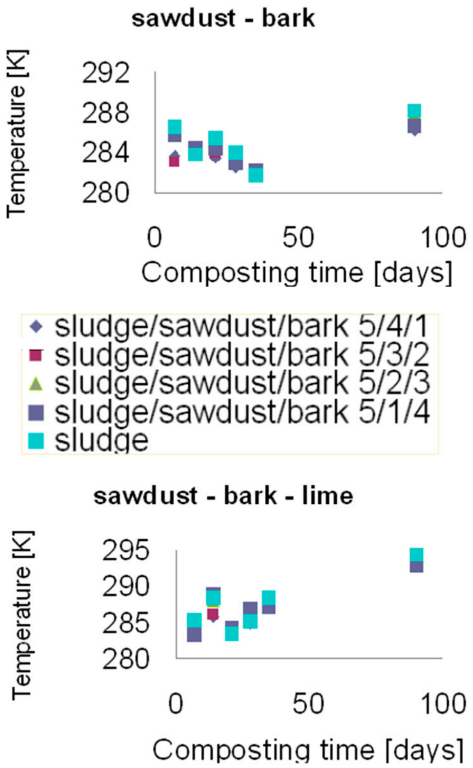

Figure 2. Relationships between temperature and time of composting raw and limed sewage sludge.

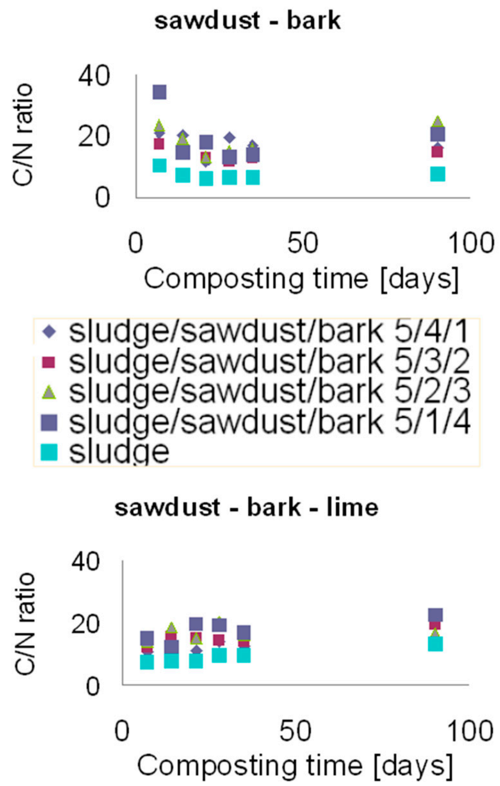

Figure 3. Relationships between C/N ratio and time of composting raw and limed sewage sludge.

It is important to stress that the C/N ratio varies along the cross-section of the pile. Because of that, it is rather impossible to obtain an absolute C/N ratio. The average C/N ratio can be evaluated from several samples collected from different parts of the pile. If the C/N ratio is too low, excess nitrogen is often lost as ammonia, resulting in odor problems. If the carbon content is too high, the available nitrogen is used up before the carbon material is completely decomposed.

The most important parameter that limits compost application is the content of xenobiotics, especially heavy metals. The contents of examined heavy metals do not exceed a certain level. The discussed mixture in comparison with admissible levels of heavy metals in three classes of compost quality is presented in Figure 4.

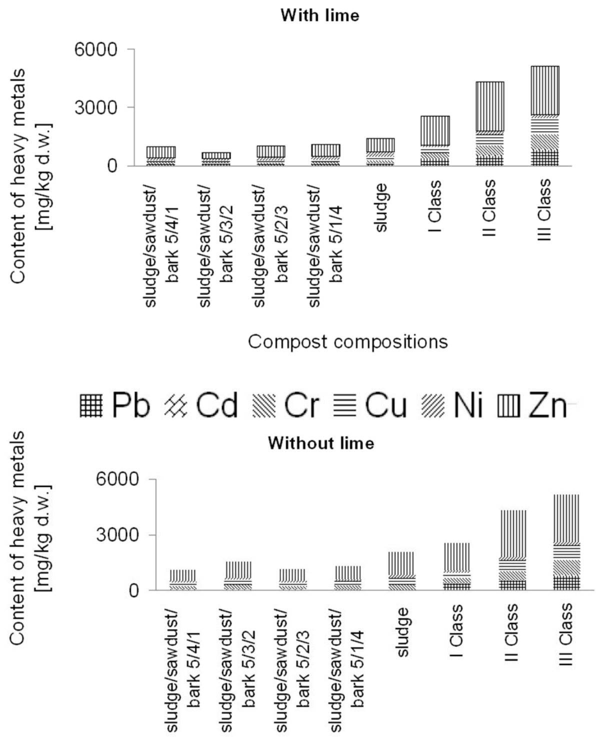

Figure 4. Content of heavy metals in composts of raw and limed sewage sludge.

The total content of selected heavy metals in the compost used in the experiments is low and does not exceed admissible standards [6]. Unfortunately, the content of selected metals, e.g., nickel, disqualifies it from agricultural use [6].

The presence of heavy metals in compost is a disadvantage. Heavy metals can be taken up by plants and possibly enter the food chain. From this point of view, bioaccumulation experiments are necessary. Bioaccumulation experiments (in a vase) were performed after physicochemical analysis of the soils. Limed sewage sludge was used in vase tests because it contains smaller amounts of mobile forms of heavy metals. The compositions of the soils used are presented in Table 7. The bean Złota Saxa was used in the experiments.

Table 7. Composition of soils used in plant experiments.

Vase No.	Garden Soil [%]	Compost Based on Limed Sewage Sludge [%]	Sand [%]
1	100	0	0
2	0	100	0
3	0	50	50
4	0	40	60
5	0	30	70
6	0	20	80
7	0	10	90
8	0	5	95

In each vase (volume 3 dm^3), four bean seeds were evenly spaced in special soils. Plants were watered with distilled water (100 cm^3) twice per week.

Bioaccumulation experiments indicate that heavy metals were taken up by plants. The contents of nickel, chromium and copper in morphological parts of the plants are directly connected with the dose of compost in the vase. The highest contents of each evaluated heavy metal were observed in the roots, next to the stalk. The lowest contents of metals were observed in the leaves. Plants were analyzed after two months of growth. After this time, we observed a small root system and a high mass of above-ground parts in the plants.

Nickel was the heavy metal found in the highest concentration in plants. This is the result of its high concentration in raw sewage sludge, then in compost and finally in the soils used in experiments. The bioavailability of nickel is the highest in plants, which grew only on compost. There is no significant correlation between doses of compost in the soils and the contents of heavy metals in the morphological parts of plants. Similar effects were observed in the accumulation of chromium. The highest concentration was observed in the roots. A different effect was observed for copper (ground 70:30), and the highest concentration of copper was observed in leaves. This means that the bioavailability of copper is greater than that of nickel and chromium (Figure 5).

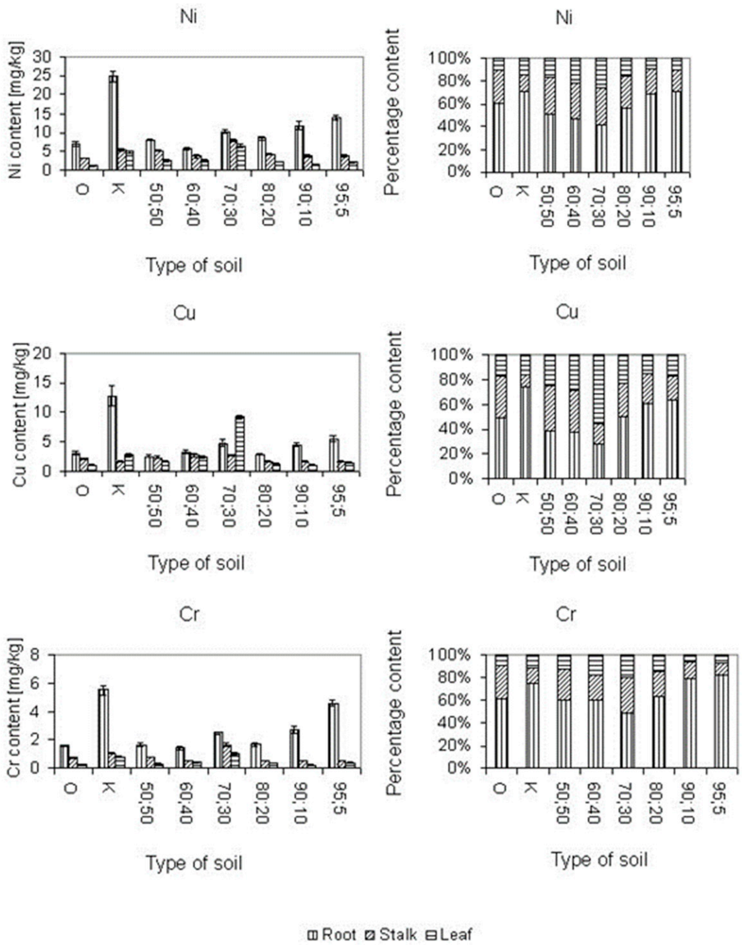

Figure 5. Content of heavy metals in morphological parts of plants.

Figure 6 shows nickel biomagnifications in morphological parts of plants. Fifty-one percent of the total content of nickel was accumulated in the roots. In other parts, the content of nickel decreased by about 20%. Probably, the content of nickel in beans will be lower than 10% of the total content of nickel.

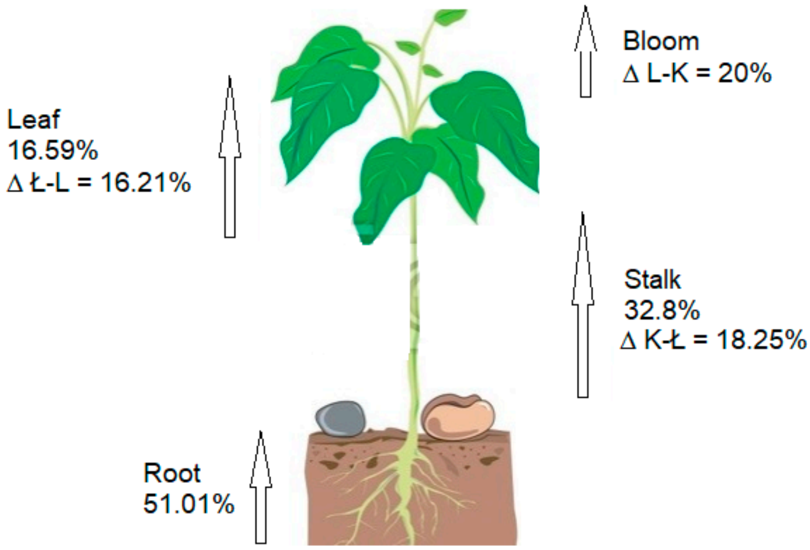

Figure 6. Nickel distribution in plant (soil contains 50% compost), ΔŁ-L—difference in nickel content between stalk and leaf, ΔK-Ł—difference in nickel content between root and stalk, ΔL-K—difference in nickel content between leaf and bloom.

The mobility of heavy metals resulting in uptake by plants is dependent on the content of organic matter (fraction 4 in Tessier sequential extraction) [23,24]. The stability of humic substance–metal cation complexes depends on the pH of the medium and increases with pH, the nature of the ions and the presence of different ions. Interactions between metal ions and humic substances are a result of the presence of functional groups in humic substances [19,20]. Figure 7 shows the content of examined heavy metals in compost organic matter fractions. Organic matter does not absorb nickel. The content of nickel in primary compost was ca. 209.15 mg/kg, but only 4.9 mg/kg nickel was determined in the humic and fulvic acids fraction. The content of humic acid–nickel complexes was higher than fulvic acid–nickel complexes. The content of nickel reduced in all fractions after the experiments finished (plant collection).

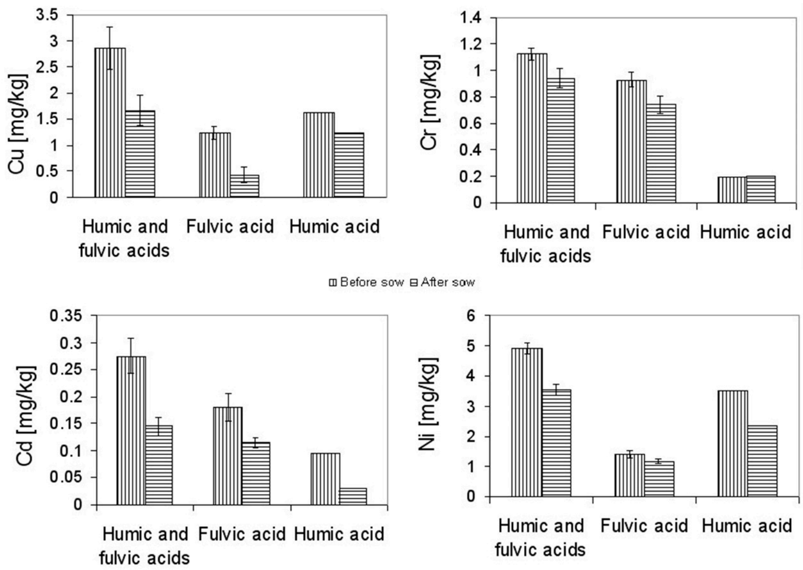

Figure 7. Heavy metals in the fraction of natural organic matters (NOMs).

The content of cadmium and chromium presented a different picture. Fulvic acid fractions contain more metals than humic fractions. The total contents of heavy metals in organic matter fractions were higher before sowing and lower after the plants were collected.

4. Conclusions

Waste material after production can and should return to the environment in order to complete natural element cycling. Composting vegetable mass and soil forming or use of compost as a manure is the best way to counter progressive degradation of the environment.

The possibility of compost application depends on the quality of raw material, production technology and state of maturity. The content of organic matter and C:N ratio are most important in the manurial values of compost. Factors that restrict the use of compost are its excessive content of heavy metals, pathogenic organisms and the presence of various plant seeds, which can lead to eutrophication.

The presented technology is cheap and safe and was successfully initiated in the wastewater treatment plant in Toruń (Poland).

In experiments, compost from the wastewater treatment plant in Toruń was used. The compost examined contained a high concentration of nickel (209.15 mg/kg). Compost with a high content of heavy metals cannot be used in agricultural applications. Beans grown on compost with a high concentration of nickel contain high concentrations of this metal.

Vase experiments show biomagnification of heavy metals in morphological parts of plants. The highest contents of each evaluated heavy metal were observed in the roots, then in the stalk. The lowest contents of metals were observed in the leaves.

The contents of nickel–organic matter fraction complexes were low. This is proof of the high mobility of nickel and its easy accessibility for plants. The rest of the examined metals were more strongly bound with organic matter, thus making their availability for plants lower.

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