Sources of Cd, Cu, Pb and Zn in biowaste

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Abstract

Biowaste, the separately collected organic fraction of municipal solid waste, can be reused for soil conditioning after composting. In this way, environmentally harmful waste management strategies, such as landfilling or incineration, can be reduced. However, frequent application of composts to soil systems may lead to the accumulation of heavy metals in soils, and therefore legal criteria were laid down in a decree to guarantee the safe use of composts. The heavy metal content of biowaste-composts frequently exceeds the legal standards, and thus raises a conflict between two governmental policies: the recycling of solid waste on the one hand, and the protection of natural ecosystems and public health on the other hand. In this study, the heavy metal content (Cd, Cu, Pb and Zn) of biowaste was compared with the natural background content of Cd, Cu, Pb and Zn in the different constituents of biowaste. For this, the physical entities of biowaste were physically fractionated by wet-sieving and subsequent water-elutriation. In this way, organic and inorganic fractions of different particle sizes were obtained and the content of Cd, Cu, Pb and Zn and the organic matter content of the different fractions were determined. On the basis of particle size, density and visual appearance, the particle-size fractions were assigned to various indoor and outdoor origins of the biowaste. It was found that a large amount of biowaste was not organic, but over 50% was made up of soil minerals due to the collection of biowaste constituents from gardens. The heavy metal content of the various fractions in biowaste was compared with the natural background contents of heavy metals in the constituents of biowaste, i.e. food products, plant material, soil organic matter and soil minerals, by collecting literature data. The heavy metal content in the fractionated physical entities of biowaste corresponded with the natural background concentration of its constituents and indicated that biowaste was not contaminated by other sources. However, the natural background content of biowaste constituents will result in heavy metal contents for biowaste-compost that will exceed the legal standards. It is advised that the legal standards for composts should be critically re-examined. The protection of soil systems could be better guaranteed if the input of heavy metals was evaluated for all inputs of fertilisers and soil conditioners, i.e. animal manures, various types of compost and artificial fertilisers.

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Keywords: Biowaste; Composition; Compost; Heavy metals; Municipal solid waste; Natural background levels

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1. Introduction

Solid organic wastes of biological origin can possibly be reused for soil conditioning. This method of waste treatment reflects the Dutch governmental policy of prevention and recycling of waste, replacing such traditional disposal strategies as landfilling and incineration. In the Netherlands, biowaste (the organic fraction of biological origin in residential municipal solid waste) is separately collected at source and composted (Lustenhouwer et al., 1987; Roosmalen and van de Langerijt, 1989). The separate collection of biowaste constituents of municipal solid waste and the development of methods of recycling have been intensified in the Netherlands during the last decade (VROM, 1992). The organic fraction of biological origin makes up 50% of the total amount of municipal solid waste. Biowaste is composed of organic waste products from indoors and outdoors. The indoor fraction is composed of organic matter collected in the kitchen (e.g. food remains and coffee filters) and indoor plant material, such as flowers and houseplants. The outdoor fraction is mostly collected in gardens and mainly consists of leaves, grass and branches, but also of garden topsoil. In this way, soil components can contribute to biowaste.

The application of compost to soil systems is of great concern because the frequent supply of compost may lead to the accumulation of heavy metals in the soil. Increased levels of heavy metals in topsoils due to atmospheric deposition from industrial activities and input via fertilisers, pesticides and animal manure have already been observed (Kabatapendias and Pendias, 1985). The heavy metal content of composts should be limited in order to guarantee the safe use of compost, as discussed by Chaney and Ryan (1993). In the Netherlands, the legal criteria for the quality and dosage of compost are laid down in the law concerning the quality and use of so-called other organic fertilisers: the BOOM decree (SDU, 1991). This law distinguishes two types of compost: compost and clean compost. The standards for heavy metals in compost and clean compost are listed in Table 1. Thus, the recycling of biowaste can possibly be thwarted when the heavy metal content of the compost does not meet the legal criteria for compost as laid down in the BOOM decree on the quality and use of other organic fertilisers (SDU, 1991).

The primary goal of this study was to establish whether biowaste is contaminated with heavy metals from other unknown sources. For this, the heavy metal content of various organic and inorganic size fractions of biowaste was compared with the natural background content of heavy metals in the different constituents of biowaste. This comparison can also assess whether the collection of various biowaste components with an elevated heavy metal content should be prevented in future in order to reduce the heavy metal content of biowaste-derived composts. The heavy metal content (Cd, Cu, Pb and Zn) of the various fractions in biowaste were determined by fractionation of the biowaste on the basis of differences in size and density. The natural background content of heavy metals in the biowaste constituents, i.e. food products, plant material, soil organic matter and soil minerals, were obtained by collecting literature data on the natural background content of heavy metals in fruit, vegetables, flowers, house plants, leaf tissue, needles, grass and surface soils.

2. Materials and methods

2.1. Sample collection

Four samples of biowaste were collected at the composting facility of VAM Wijster, the Nether-
lands. The samples originated from Zaandam, Purmerend, Wolvega and an unknown location. To obtain a representative sample, approximately 50 l of biowaste was collected. To minimise aerobic or anaerobic conversion of the waste, the samples were stored at 4 °C when not directly used. Biowaste is composed of organic waste products from indoors and outdoors. It was assumed that the sample from the rural village of Wolvega was representative of outdoor biowaste. One sample was collected at the central collection container for biowaste at an apartment building in Wageningen and was assumed to be characteristic of indoor biowaste. Samples collected at the other locations were representative of mixed samples with an unknown ratio of indoor and outdoor biowaste.

2.2. Particle-size fractionation

A two-step separation process was used for fractionation of the biowaste: wet sieving followed by water-elutriation, as extensively described by Veeken (1998). Before fractionation, the biowaste sample was manually homogenised in a plastic container and 4–5 kg was used for physical fractionation. Constituents larger than 100 mm and impurities, such as plastics and tins, were removed. These components contributed less than 5% to the total dry weight of the sample. The separation process comprised a wet-sieving process, a water-elutriation process and a sedimentation unit (Fig. 1). A vibrating sieving apparatus (Labor-Siebemachinede Type VIBRO, Retsch, Germany) was equipped with stainless steel sieves (200 mm in diameter) with mesh sizes of 5.0, 1.0, 0.50, 0.20, 0.10 and 0.05 mm (Labor Analysensiebe, Retsch, Germany). The top sieve with a mesh size of 5 mm was filled with a sample of biowaste, and double-distilled water was sprayed over the sample using a showering device. The top layer was turned over several times until the water that ran through the bottom 0.05-mm sieve was clear. The material on the top sieve was removed and the procedure was repeated several times. Periodically, the material was removed from the other sieves to prevent blocking of the sieves. The water and the particles <0.05 mm were collected in an 80-l container.

The fractions 0.05–0.1, 0.1–0.2, 0.2–0.5 and 0.5–1 mm were exposed to the water-elutriation process in a glass elutriation column of 80 mm in diameter and 300 mm in height. First, a small part of the column was filled with a particle-size fraction. Then, double-distilled water was pumped through the bottom of the column with a peristaltic pump (Type 505S, Watson Marlow Bredel Inc, Wilmington, MA) and the organic particles were visually separated from the mineral fraction by varying the flow rate of the pump. The organic matter eluting at the top of the column (overflow) was collected in a 0.05-mm sieve. The mineral fraction at the bottom (underflow) was periodically removed by dismantling the column. The suspended solids < 0.05 mm were concentrated by separation in a semi-continuous tubular centrifuge (Sharples Super centrifuges, Jacobi Industries, Medford, NY) at 50 000 rev./min. The weight of all fractions was determined.

2.3. Analysis

Samples of biowaste were cut and homogenised in a 10-l stainless-steel commercial kitchen blender (Eduard Müller & Söhne, Saarbrücken, Germany) and 1–2 kg of the sample was dried at 70 °C for 24 h. Of the sample, 100–200 g was crushed with an agate planet ball mill (Planetary Ball Mills PM400, Retsch GmbH, Haas, Germany) to produce particles smaller than 0.1 mm. Part of the particle-size organic and inorganic fractions obtained were also air-dried and crushed with the agate planet ball mill. The dry matter content (DM) and organic matter content (% of DM) of biowaste and the fractions obtained were determined by drying at 105 °C and subsequent ashing of the dried samples at 550 °C, respectively (APHA, 1992). The heavy metal content of the ball-milled samples was determined by flame atomic-absorption spectroscopy (AAS) (SpectrAA 300, Varian Scientific Instruments, Palo Alto, CA) after aqua regia digestion as described by Lustenhouver et al. (1991). All analyses were carried out in duplicate.

3. Results

The discrepancy between the total mass of dry matter, organic matter and heavy metals before
Fig. 1. Flow-chart of the particle-size fractionation method.

and after the separation process was 2–5%, 2–4% and 3–10%, respectively. This is acceptable, considering the physical fractionation methods used and the heterogeneity of biowaste and particle-size fractions. It was assumed that the particles in biowaste were not disrupted during the separation processes and that heavy metals were not significantly redistributed among the particle-size fractions.

From the weight contribution and the content of dry matter, organic matter and heavy metals of the fractions obtained (results not shown), the distribution of mass and heavy metals as a function of the particle size was calculated for the organic and inorganic parts of the biowaste. The mass distribution of the organic and inorganic parts could not be directly assessed as the separation by water-elutriation in an organic overflow and an inorganic
underflow was not complete. This was due to the overlap in sedimentation velocity of large organic particles and smaller inorganic particles within one specific particle-size fraction. However, the mass distribution can be obtained if we assume an average ash content of 5% for organic matter (Houba et al., 1991) and of 100% for inorganic matter. The results of the calculations are presented in Table 2. Mixed biowaste is defined as biowaste with an average ratio of indoor/outdoor material. For this, the average result for all five samples is given. The indoor and outdoor biowastes were represented by the samples from Wageningen and Wolvega, respectively. For the experiment with indoor biowaste (Wageningen), fewer screens were used for size fractionation. The heavy metal content of the organic and mineral fractions could also not be directly assessed as a result of the overlap in sedimentation velocity of large organic particles and smaller inorganic particles within one specific particle-size fraction. However, if we assume that the heavy metal content of organic and inorganic particles within a single particle-size range is constant, the heavy metal content of the organic and inorganic particle-size fraction can be calculated using the following relations:

\[
H_{VM}^{\text{over}} = x_{\text{org,over}} H_{VM}^{\text{org}} + x_{\text{in,over}} H_{VM}^{\text{inorg}} \\
H_{VM}^{\text{under}} = x_{\text{org,under}} H_{VM}^{\text{org}} + x_{\text{in,under}} H_{VM}^{\text{inorg}}
\]

where \(H_{VM}^{\text{over}}\) and \(H_{VM}^{\text{under}}\) are the heavy metal content (in mg kg\(^{-1}\) DM) of the overflow and underflow fractions, \(x_{\text{org}}\) and \(x_{\text{inorg}}\) are the weight fractions of the organic and inorganic parts, and \(H_{VM}^{\text{org}}\) and \(H_{VM}^{\text{inorg}}\) are the heavy metal content (in mg kg\(^{-1}\) DM) of the organic and inorganic particles, respectively. Table 3 presents the results on the basis of Eqs. (1a) and (1b) for the fractions between 0.05 and 1 mm. The fractions >5 and 1–5 mm could not be separated into an organic and an inorganic part by the laboratory-scale elutriation set-up due to the limited capacity of the elutriation column. The fraction <0.05 mm could not be separated into an organic and an inorganic fraction because the inorganic and organic part were present in aggregates. For fractions that were not separated, the total content is given.

4. Discussion

4.1. Contribution of indoor and outdoor biowaste

The mass distribution of biowaste collected at an apartment building in Wageningen (indoor in Table 2) shows that the organic-matter fraction in biowaste from such buildings is high; 91% of biowaste from apartment buildings is of organic origin. Biowaste from the village of Wolvega (outdoor in Table 2) is much lower in organic matter content (39%), showing that a large part of the waste is made up of inorganic matter. The composition of biowaste strongly depends on the type of household. In cities, there are relatively more apartment buildings than in rural villages, which consist of low-rise houses (Cornelissen, 1989; van de Beek et al., 1989). Biowaste collected at apartment buildings mainly contains food remains, while a large part of biowaste collected at low-rise houses originates from gardens. Indoor organic waste consists of kitchen waste, flowers and house plants. The amount and composition of indoor waste is virtually independent of the time of year and the place of collection. Outdoor waste comprises, among other things, leaves, branches, grass and the topsoil of gardens, and its amount and composition varies greatly with time and place (Krogmann, 1999).

A study by TAUW (1990), in which components in biowaste were separated by hand, showed that the biowaste comprised 10% indoor waste, 50% garden waste and a fraction of 40% that was composed of unrecognisable small particles. This fraction probably originates from the topsoil of gardens. A study in Germany (Anonymous, 1992) showed that on average, 200–250 kg of biowaste per inhabitant per year is collected in villages, as opposed to 50 kg of biowaste per inhabitant per year at apartment buildings. Both studies indicate that approximately 20% of biowaste originates from indoor collection and 80% is collected outdoors.

When biowaste is subjected to a wet-sieving process, the different fractions of indoor and out-
Table 2
Mass distribution of organic and inorganic fractions in biowaste

<table>
<thead>
<tr>
<th>Fraction (mm)</th>
<th>Mixed Organic (%)</th>
<th>Mixed Inorganic (%)</th>
<th>Indoor Organic (%)</th>
<th>Indoor Inorganic (%)</th>
<th>Outdoor Organic (%)</th>
<th>Outdoor Inorganic (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;5</td>
<td>7 ± 2</td>
<td>48.9 ± 0.9</td>
<td>19 ± 1</td>
<td>4 ± 0.2</td>
<td>6 ± 1</td>
<td></td>
</tr>
<tr>
<td>1–5</td>
<td>3 ± 1</td>
<td>4 ± 0.2</td>
<td>0.8 ± 0.4</td>
<td>0.2 ± 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5–1</td>
<td>4 ± 1</td>
<td>23 ± 9</td>
<td>5.4 ± 0.4</td>
<td>2.0 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2–0.5</td>
<td>2 ± 1</td>
<td>21 ± 3</td>
<td>14 ± 2</td>
<td>2.0 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1–0.2</td>
<td>1 ± 0.2</td>
<td>6 ± 3</td>
<td>0.4 ± 0.4</td>
<td>0.5 ± 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.05–0.1</td>
<td>1 ± 1</td>
<td>3 ± 2</td>
<td>6.9 ± 0.4</td>
<td>2.5 ± 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.05</td>
<td>12 ± 6</td>
<td>6 ± 3</td>
<td>6.9 ± 0.4</td>
<td>7.1 ± 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquidc</td>
<td>5 ± 2</td>
<td>1 ± 1</td>
<td>6 ± 3</td>
<td>2 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totald</td>
<td>47 ± 2</td>
<td>52 ± 1</td>
<td>90.9 ± 0.9</td>
<td>100 ± 0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation (N=5).

a Fraction 0.2–2 mm.

b Fraction <0.2 mm.

c Fraction found in the liquid overflow after centrifuging the fraction <0.05 mm.

d Due to the heterogeneity of biowaste and the fractions of biowaste and the experimental method of fractionation, the sum of the organic and inorganic fractions does not add up to exactly 100%.

door waste are separated and distributed over the screens. For indoor waste (Table 2), 70% of the organic part is larger than 1 mm, while for villages, only 40–50% is larger than 1 mm. A large part of the organic fraction from villages shows up in the smaller organic fractions and the fraction <0.05 mm. The difference is caused by the different composition of the organic waste. Indoor organic waste mainly consists of food remains and plants, while a large part of the organic matter from gardens contains soil organic matter from topsoil. The amount of soluble organic matter is high for apartment buildings (Table 2), because a significant fraction of food remains is readily dissolved in water (e.g. fats). The soluble fraction is much lower for garden waste because grass, leaves, branches, and soil organic matter contain low contents of water-soluble components. The suggestion that a large part of garden waste originates from the topsoil is confirmed by the large amount of sand (inorganic fraction between 0.05 and 1.0 mm) found in biowaste. Approximately 40% of biowaste from villages consists of sand, compared to only 3% for apartment buildings (Table 2). The fact that a large amount of soil is collected in gardens is also apparent from the large fraction < 0.05 mm, which is made up of silt, clays and humus. The fraction <0.05 mm is small for biowaste collected indoors (Table 2).

4.2. Natural background content of heavy metals in the constituents of biowaste

On the basis of the physical and chemical characteristics and visual and microscopic inspection of the fractions, the particle-size fractions were divided into four groups that were related to the following constituents of biowaste:

1. Organic fraction >1 mm: organic matter comprising food remains collected indoors, such as fruit and vegetable waste and prepared food products; organic matter of plant material not intended for consumption, such as flowers, house plants, grass, leaves, branches, etc.;

2. Organic fraction 0.05–1 mm: organic matter made up of more or less degraded and humified organic matter present in the topsoil of gardens and in potting compost;

3. Inorganic fraction 0.05–0.5 mm: sand present in garden topsoil; and

4. Organo-mineral fraction <0.05 mm: silt, clay and humus present in garden topsoil.
<table>
<thead>
<tr>
<th>Fraction (mm)</th>
<th>Heavy metal content (mg kg⁻¹ DM)</th>
<th>Non-separated fraction</th>
<th>Organic fraction</th>
<th>Inorganic fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cd</td>
<td>Cu</td>
<td>Pb</td>
<td>Zn</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>0.24±0.07</td>
<td>14±2</td>
<td>39±6</td>
<td>120±25</td>
</tr>
<tr>
<td>1–5</td>
<td>0.26±0.10</td>
<td>17±2</td>
<td>63±12</td>
<td>129±13</td>
</tr>
<tr>
<td>0.5–1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2–0.5</td>
<td>0.80±0.27</td>
<td>32±5</td>
<td>109±27</td>
<td>235±39</td>
</tr>
<tr>
<td>0.1–0.2</td>
<td>0.93±0.18</td>
<td>43±4</td>
<td>181±18</td>
<td>323±94</td>
</tr>
<tr>
<td>0.05–0.1</td>
<td>1.2±0.5</td>
<td>37±6</td>
<td>170±25</td>
<td>271±38</td>
</tr>
<tr>
<td>&lt;0.05</td>
<td>1.0±0.2</td>
<td>63±27</td>
<td>157±31</td>
<td>338±58</td>
</tr>
</tbody>
</table>

Values are mean±standard deviation (N=5).
Table 4
Natural background content of heavy metals of four classes of constituents collected in biowaste

<table>
<thead>
<tr>
<th>Metal</th>
<th>Heavy metal content (mg kg(^{-1}) DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Organic waste</td>
</tr>
<tr>
<td></td>
<td>Indoor(^a)</td>
</tr>
<tr>
<td>Cd</td>
<td>0.3±0.4</td>
</tr>
<tr>
<td>Cu</td>
<td>7±8</td>
</tr>
<tr>
<td>Pb</td>
<td>1±4</td>
</tr>
<tr>
<td>Zn</td>
<td>45±35</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation.

\(^a\) Data on fruits, vegetables and some data on flowers and houseplants (Nriagu, 1978, 1979a,b; Houba et al., 1991); data on food products (CCRX, 1985, 1990); and data on separately collected food remains from households (Boxtel, 1982).

\(^b\) Data on grass, leaf tissue, needles, and clover (Guha and Mitchell, 1966; Smith, 1973; Crump and Barlow, 1982; Kabata-Pendias and Pendias, 1985; Fiedler, 1988).

\(^c\) Humus layer of leaves and needles (Nilsson, 1972; van Hook et al., 1977; Coughtrey, 1979).

\(^d\) Natural background levels of heavy metals in surface soils (Kabata-Pendias and Pendias, 1985; Lexmond and Edelman, 1987).

Various literature sources were consulted to obtain values for the natural background concentration of heavy metals in the above-mentioned classes of components. The results are summarised in Table 4. The heavy metal content of food products is low, especially for those heavy metals that are not essential plant nutrients, such as Cd and Pb. It is expected that the natural background content of heavy metals in plant material from gardens would be slightly higher in comparison to indoor waste, because outdoor plant material is more susceptible to anthropogenic contamination. The garden topsoil is built up of a humus layer and soil components. The heavy metal content of the humus layer is much higher than that of fresh plant material. The degradation of organic matter in the top layer of soil leads to a concentration of heavy metals. Moreover, heavy metals from natural atmospheric deposition are accumulated in the humified organic matter over time (Nilsson, 1972). The natural background concentration of heavy metals in soil depends on the mineral composition of the parent material and on the natural soil-formation processes (Kabata-Pendias and Pendias, 1985). The natural background content of heavy metals in soil increases with increasing lutum and organic matter content (Lexmond and Edelman, 1987). This is the result of the higher content of heavy metals in secondary minerals and the higher specific surface and binding strength of surface-specific groups of secondary minerals and organic matter.

### 4.3. Comparison of experimental and literature data

The heavy metal content in the particle-size fractions of biowaste were compared to literature data on the natural background contents of heavy metals in the constituents of biowaste (Table 5). The Cd, Cu, Pb and Zn content of the organic fraction > 1 mm is in the same range as the natural background content of heavy metals in indoor and outdoor organic matter (Table 5). The organic material within the size range 0.05–1 mm most probably originates from the humus layer and the topsoil in gardens. The heavy metal content in the organic fraction 0.05–1 mm is in good agreement with the values found in the humus layer (Table 5). On the basis of visual appearance, the inorganic fractions from 0.05 to 0.5 mm were completely made up of sand. The Cd, Cu, Pb and Zn content of these fractions is lower than measured for sandy soils (except for Zn), most probably due to the washout of small amounts of silt, clays and organic matter which are generally present in sandy soils (Table 5). The particle-size fraction < 0.05 mm is made up of the humus layer and soil components, i.e. lutum, silt and soil organic matter (or humus). The levels in these fractions are in good agreement...
with the heavy metal contents in soil with high contents of lutum and humus (Table 5).

The heavy metal content in the various organic and inorganic size-fractions of biowaste are in the same range as the natural background content of heavy metals in the constituents of biowaste. This indicates that the heavy metal content of biowaste is not increased due to contamination from other unknown sources.

4.4. Calculation of the heavy metal content of biowaste-compost

The agreement between heavy metal content of biowaste fractions and the original constituents of biowaste validates the calculation of the heavy metal content of biowaste-compost on the basis of the content in the original constituents of biowaste. For this, we have to take into account the concentration of heavy metals due to the degradation of organic matter during composting. The concentration factor (CF) for heavy metals during composting is a function of the initial organic-matter content and organic matter degradation:

$$CF = \frac{100}{100 - \frac{\text{OM}_{\text{ini}}}{\text{OM}_{\text{deg}}}}$$  \hspace{1cm} (2)

where \( \text{OM}_{\text{ini}} \) is the initial organic matter content (in % of DM) and \( \text{OM}_{\text{deg}} \) is the organic matter degradation during composting (in % of \( \text{OM}_{\text{ini}} \)). It is assumed that heavy metals do not leach from the biowaste during composting. In Fig. 2, the concentration factor is shown as a function of organic matter degradation for several initial organic-matter contents. The degradation rate of organic matter during composting depends on the composition and structure of the organic matter. Compounds such as carbohydrates, hemicellulose

Table 5
Comparison of the heavy metal content in the four main fractions of biowaste (in italics) and the natural background content of the original biowaste constituents

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Heavy metal content (mg kg(^{-1}) DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cd</td>
</tr>
<tr>
<td>Organic fraction &gt; 1 mm</td>
<td>0.24 ± 0.10</td>
</tr>
<tr>
<td>Indoor organic waste</td>
<td>0.3 ± 0.4</td>
</tr>
<tr>
<td>Outdoor organic waste</td>
<td>0.4 ± 0.2</td>
</tr>
<tr>
<td>Organic fraction 0.05–1 mm</td>
<td>0.61 ± 0.28</td>
</tr>
<tr>
<td>Humus layer</td>
<td>2 ± 1</td>
</tr>
<tr>
<td>Inorganic fraction 0.05–0.5 mm</td>
<td>0.05 ± 0.01</td>
</tr>
<tr>
<td>Soil sand</td>
<td>0.2 ± 0.3</td>
</tr>
<tr>
<td>Organo-mineral fraction &lt; 0.05 mm</td>
<td>1.0 ± 0.5</td>
</tr>
<tr>
<td>Humus layer</td>
<td>2 ± 1</td>
</tr>
<tr>
<td>Soil loess</td>
<td>0.2</td>
</tr>
<tr>
<td>Soil clay</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation.
and lipids are easily biodegradable (Schlegel, 1993). Cellulose is also easily biodegradable, but the degradation of cellulose is partially inhibited when it is incorporated in a lignocellulose complex (Tong et al., 1990). Lignin is considered to be recalcitrant under aerobic and anaerobic conditions in the short term (Schlegel, 1993). Thus, composting results in a high CF for food remains (e.g. lettuce, cabbage and potatoes) because these are largely made up of biodegradable organic matter. Plant material from gardens (e.g. branches, leaves, grass and flowers) on the other hand will have a lower CF due to high lignocellulose content (Tong et al., 1990; Chynoweth et al., 1992). Organic matter originating from the humus layer of soil is already degraded and largely humified and will have a CF value close to 1. Table 6 shows the heavy metal content in compost on the basis of the natural background content in fresh plant material and the humus layer.

<table>
<thead>
<tr>
<th>Heavy metal content (mg kg⁻¹ DM)</th>
<th>Cd</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh plant material</td>
<td>0.8±0.6</td>
<td>16±12</td>
<td>6±4</td>
<td>110±100</td>
</tr>
<tr>
<td>Humus layer</td>
<td>2.4±1.2</td>
<td>24±11</td>
<td>120±77</td>
<td>180±132</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation.

4.5. Application of biowaste-compost and manures as soil conditioners

The legal standards for heavy metals in compost as laid down in the BOOM decree are based on the recommendations made by the Technische Commissie Bodembescherming (Technical Commission for Soil Protection) concerning the quality of soil (Ferdinandus, 1989). The reference point of these recommendations is the requirement that the delivery of heavy metals (through precipitation, deposition, artificial fertilisers and animal manure) and the discharge of heavy metals (no increased plant uptake or leaching to the groundwater) in the soil system should be in balance (Moolenaar et al., 1997). However, the legal requirements for heavy metals apply only to composts derived from so-called other organic manures, as laid down in the BOOM decree. It is also known that animal manure and artificial fertilisers contribute significantly to the heavy metal content of the soil (Kabata-Pendias and Pendias, 1985). However, the dosage of animal manure is limited only with respect to the total phosphate content, as laid down in the BGDM decree (law concerning the use of animal manures; SDU, 1987).

To preserve optimal soil conditions for agricultural use, the organic carbon content of the topsoil should be kept at a constant level. The addition of a soil conditioner is more effective when it contains more stable organic matter, which is expressed by the effective organic carbon content: the higher the effective organic carbon content, the less organic matter is degraded in the soil (Janssen, 1984). The effective organic-matter content is substantially higher for biowaste-compost than for animal manures (Anonymous, 1997). van Erp and Evers (1995) showed that for the same amount of effective organic carbon dosed (in kg ha⁻¹), the heavy metal and phosphate dosage to
the soil is much lower for biowaste-composts than for various types of animal manures. To guarantee optimal soil quality, all types of fertilisers and soil conditioners have to be treated equally with respect to the supply of macro nutrients (P, K), organic carbon and heavy metals.

5. Conclusions

The physical fractionation of biowaste by wet-sieving and water-elutriation on a laboratory scale gave a clear separation of the biowaste into its physical entities. The size fractions obtained after classification can be assigned to the following biowaste constituents: (1) fraction >1 mm composed of fresh plant material and food remains; (2) organic fraction 0.05–1 mm composed of partly decayed and humified organic matter; (3) inorganic fraction 0.05–1 mm composed of sand; and (4) fraction <0.05 mm composed of silt, clay and humus.

A large amount of biowaste is not organic, but is made up of soil minerals; this is because approximately 80% of biowaste is collected outdoors, i.e. in gardens, which introduces a substantial amount of soil components into the biowaste. For biowaste collected in villages, soil minerals make up more than 50% of the total. The amount of soil minerals is very low when the biowaste comes from indoor-collected organic waste.

The heavy metal content in the fractionated physical entities of biowaste corresponds with the natural background concentration of heavy metals of the biowaste constituents. This shows that biowaste is not contaminated by other unknown sources. However, the biowaste-compost cannot meet the legal criteria of BOOM, and this indicates a conflict between the two government policies of (1) protecting soil systems and (2) promoting the recycling and reuse of solid organic-waste streams. It is postulated that the protection of soil systems could be better guaranteed if the input of stable organic matter, phosphate and heavy metals were to be evaluated for all fertiliser inputs, i.e. animal manure, various types of compost and artificial fertilisers.

References


