VHE / ahu Study

Calculation of Contaminant Accumulation in Soil Due to Long Term Compost Application

European Compost Network ECN e.V.

www.compostnetwork.info

Funding

We are grateful to the following organisations for supporting the project:

European Compostnetwork
ECN e.V.
Im Dohlenbruch 11
44795 Bochum
Germany
www.compostnetwork.info

VHE - Verband der Humus– und Erdenwirtschaft e.V.
Kirberichshofer Weg 6
52066 Aachen
Germany
www.vhe.de

Project work by:

ahu AG
Wasser · Boden · Geomatik
Kirberichshofer Weg 6
52066 Aachen
Germany
www.ahu.de

VHE / ahu Study

Calculation of Contaminant Accumulation in Soil Due to Long Term Compost Application

Impressum:

Authored by:
Dr Silvia Lazar
Dr Silke Höke
ahu AG Wasser · Boden · Geomatik, Aachen, Germany

Translated by:
Dr Jane Gilbert,
Carbon Clarity, United Kingdom

Final translation review:
Dr Michael Kastler,
ahu AG Wasser · Boden · Geomatik, Aachen, Germany

Published by:
EUROPEAN COMPOST NETWORK ECN e.V.
Im Dohlenbruch 11
44795 Bochum
Germany

VHE - Verband der Humus– und Erdenwirtschaft e.V.
Kirberichshofer Weg 6
52066 Aachen
Germany

Contact:
Dr Stefanie Siebert
T. +49-234-4389447
F. +49-234-4389448
Email: info@compostnetwork.info

Date: March 2015

Contents

1 Introduction

When fertilising soils with compost, not only are nutrients and organic matter (humus) applied, but also significant quantities of minerals. The mineral fraction (ash residue) in compost amounts to an average of 61.8% dry matter, meaning that only 38.2% (loss on ignition) is made up of organic matter (BGK, 2010), i.e. more than half of the compost is made up of a stable mineral fraction.

Although the organic matter fraction can be mineralised and the nutrients absorbed by plants, the mineral fraction remains in the soil permanently, contributing towards soil structure. This means that any contaminants will be diluted to some extent within the soil, as shown in Figure 1.

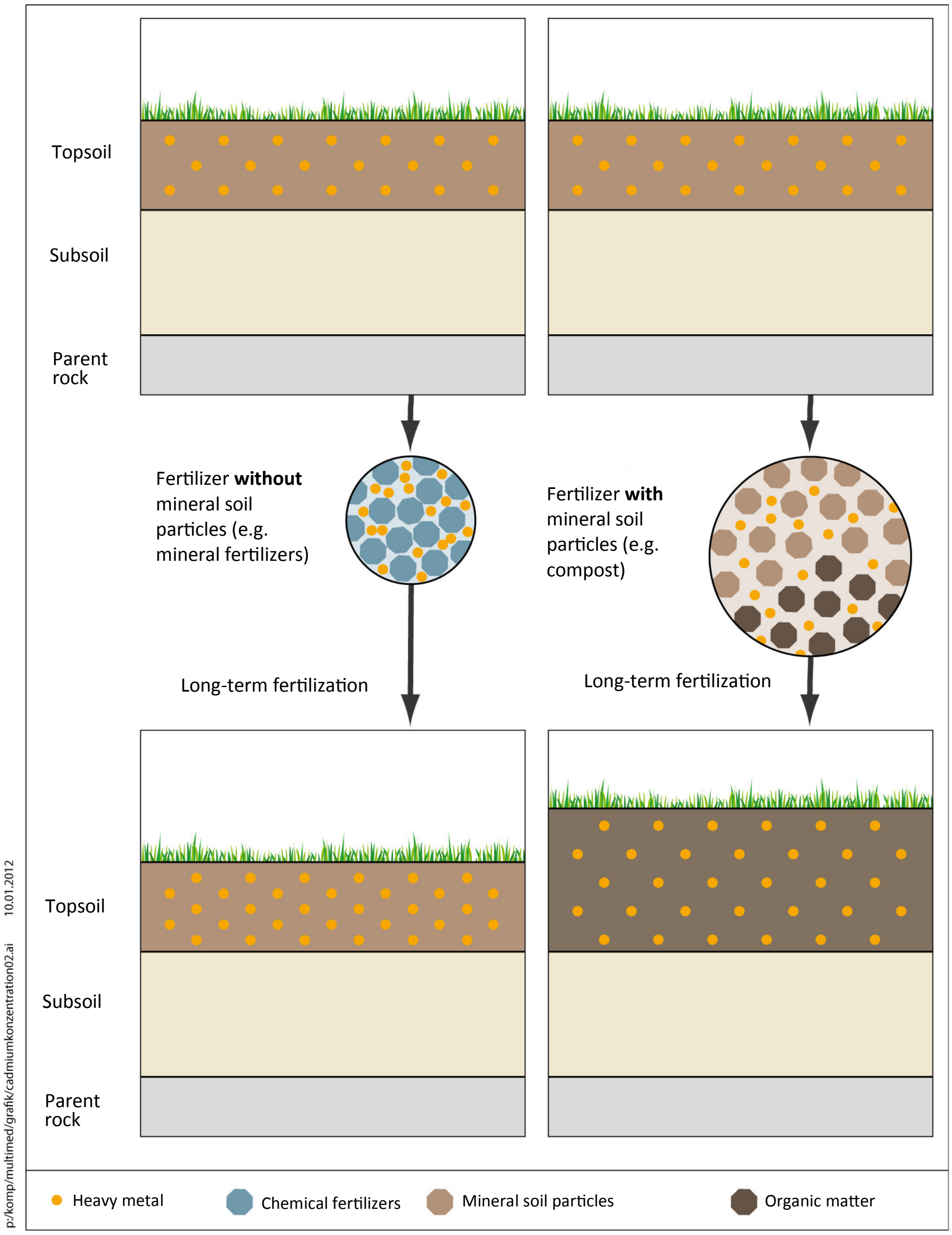


Figure 1 - Soil structure and change in the concentration of heavy metals in the soil through long term fertilization by taking into account mineral soil particles in compost

To date, the influence of this mineral fraction has not been considered when calculating contaminant concentrations in soil. As over 50% of the mass of compost is mineral, this has a significant impact on the actual contaminant levels in the soil. It has been calculated that the upper soil horizon would be increased by 3.6 cm following regular compost use over 100 years (see the calculation in the following section).

Due to increasing the depth of the upper soil horizon (i.e. soil build up) the concentration of contaminants from compost would be significantly lower compared with calculations based solely on the application of contaminants on their own. Similarly, at higher background soil concentrations, reduction in the concentrations of contaminants in the soil are possible due to the application of compost (see examples in Chapter 3).

The mineral components of various fertilisers have been studied in the R & D project "Comparative evaluation of substance emissions in soils via different routes of entry" (Knappe et al., 2008). In it, they determined nationwide contaminant inputs and losses and their accumulation in the soil.

The mineral fraction of compost were also taken into account in the enrichment scenarios described by Amlinger et al., (2006). They came to the conclusion that “mixing compost into the topsoil layer, the metal concentration is increased asymptotically with a non-linear function towards the metal concentration of the compost respecting the increasing mineral fraction in the soil."

2 Framework for the consideration of the mineral fraction

The influence of the mineral fraction is wholly dependent on a number of basic assumptions, which are shown below. The following assumptions were made for the example calculations shown in Chapter 3. These parameters are also used in other databases.

- **Soil depth:** The depth of the topsoil has a particular effect on contaminant concentration calculations. According to various calculations and scenarios used to determine concentration effects in the topsoil (see Knappe et al., 2008; Amlinger et al., 2006), the Ap horizon (i.e. the upper 30 cm of arable soil) is considered to be the most representative. This horizon depth allows the use of ground-based data from existing studies that relate generally to the Ap horizon from 0 to 30 cm as the sampling horizon.

- **Dry bulk density (d):** A dry bulk density of 1.4 g / cm has been assumed for arable topsoil. This is located in the middle of variations noted by Scheffer & Schachtschabel (2002). However, high intensity farmed arable soils will tend to have higher dry bulk densities.

- **Background contaminant concentrations:** Typical background contaminant concentration values for topsoils quoted by LABO (2003) were used. These include soil use and area-specific values for different parent rocks. The 50th percentile has been used for agriculture in the defined area type III (ubiquitous levels in rural areas), however, it has also been compared with the 90th percentile for agriculture in the defined area type I (areas of urban conglomeration).

- **Inputs and outputs:** The data quoted by Knappe et al. (2008) (Comparative evaluation of chemical inputs in soils through different pathways) considered other sources of inputs through mineral fertilisation, as well as losses through crops and leachate. This data has not been taken into account, in order to distinguish compost-related effects from other contributing factors.

- **Solids content:** Composition and solids content of compost (without digestate) were taken from data supplied by the Bundesgütegemeinschaft Kompost e.V. (BGK, 2010). Median values of fresh and mature composts without digestate were used (see Table 1).

- **Long term mineral fraction (soil build up):** The mineral components (determined by loss on ignition) in the compost is on average 61.8% dry matter, with the organic matter fraction comprising 38.2% dry matter (DM). Part of the mineral fraction in compost is in the form of nutrients (nitrogen 1.4% DM, phosphate 0.7% DM, potassium 1.1% DM; see BGK, 2010) as well as carbonate[1] (7.6% identified as DM as CaO multiplied by the factor of 1.78, see BGK 2010 and MLR 2010). This is shown in Figure 2.
  Nutrients and carbonates can theoretically be mineralised over the long term and washed out or taken up by plants. In terms of a worst case scenario, therefore, nutrients and carbonates were not attributed to the long-term mineral fraction in the soil.
  Even under these conditions, composts will supply an average of 51% of stable minerals that contribute to long-term soil structure.

Table 1: Components in fresh compost (source: median values BGK 2010)	
Unit	**Compost (dry matter)**
Mineral substance in the compost in % DM	61.8%
Organic matter in the compost (loss on ignition) in % DM	38.2%
C_{org} % DM	22.1%
Nitrogen (N % DM) Phosphate (P_2O_5% DM) Potassium (K_2O in % DM)	1.4% 0.5 g 1.1%
Carbonate ($CaCO_3$% DM, determined from CaO % DM)	7.6%
Long-term input of mineral components (in % DM)	51.0%
Long-term fate of mineral components in an application set of 10 t DM / ha per year [mineral substance less nutrients and carbonate]	5.1 t DM / (ha * a)
Increase of the soil horizon 10 t DM/ ha per year	0.36 mm
Cadmium content in the compost (in mg/kg DM)	0.42

What is also not taken into account is that a proportion of the organic fraction of compost also remains in the soil over the long term, contributing towards soil structure. This means that the total supply of substances remaining in the soil (i.e. a combination of both the stable organic and mineral fractions) over the long term is greater than the mineral soil particles, which are only considered in these calculations.
In order to determine the proportion of 'stable organic matter', different approaches and models have been discussed (see Wessolek et al., 2008; Kluge et al., 2008). A simplified way is use of the so-called 'recovery rate method' which assumes that between 26% and 59% of the organic matter originating from the compost, remains in the soil over the long term (cf. Reinhold, 2008 and IFEU / ahu, 2011). When using the lowest recovery rate of 26%, stable substances accounted for 60.9% (51% and an additional 9.9% by organic matter) in the compost. The proportion of stable substances in the compost would be at the highest recovery rate of 59%, 73.5% (51% and an additional 22.5% by organic matter).

- **Soil type:** In the literature there are no data available on the composition and texture of mineral substances in composts. It is assumed that the grain size and composition is regionally specific, since these mineral substances will be derived from adhering soil in garden waste (e.g. weeds) or sod. Mineral components in the compost can also be from potting soils and materials (sand, clays, topsoils) used for gardening and landscaping purposes.

[1] The liming value of compost is usually indicated on the basic active ingredients in the form of CaO (calcium oxide). The lime is mainly present in compost and soils as carbonates (CaCO3) (cf. DLG / LLFG, 2009.). In the present study, the amount of CaO is calculated with the factor of 1.78 (MLR 2010) based on the measured amount of calcium carbonates (CaCO3).

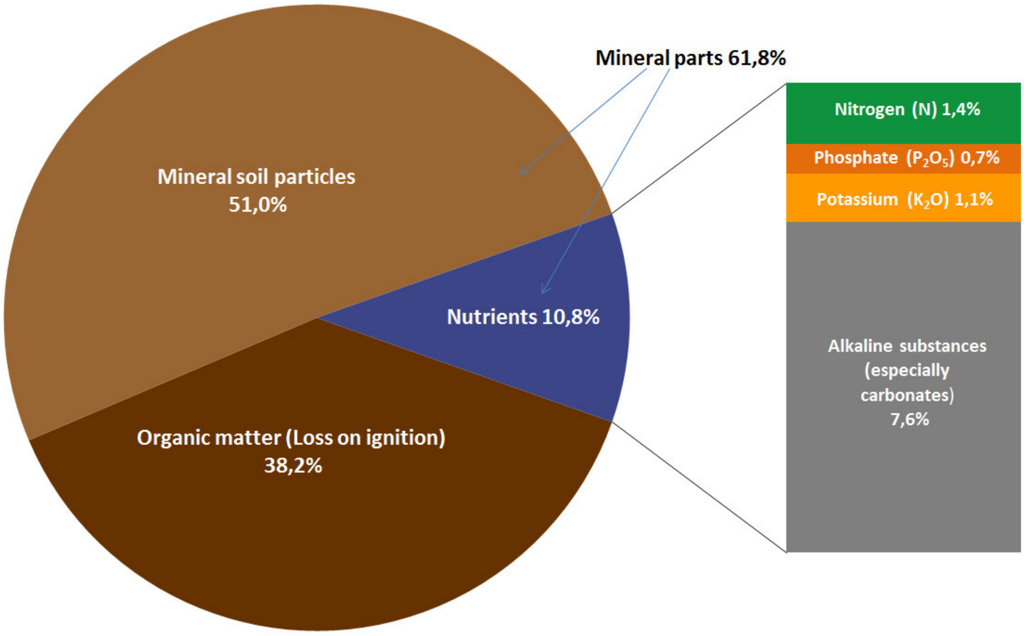


Figure 2 - Typical composition of compost (Source: VHE, 2011)

The precautionary contaminant limit levels of the German Federal Soil Conservation Act (BBodSchV) were used as a benchmark, which relate to clay / silt soils.

- **Application rates:** In the following examples the legally permissible maximum application rates according to the German Biowaste Ordinance (BioAbfV, 2012) have been assumed.
  According to the Biowaste Ordinance not more than 20 t (treated) organic waste dry matter (DM) can be applied per hectare within three years; additional limits for heavy metals also need to be observed. The application rate can be up to 30 t DM / (ha * 3a) if the more stringent limit values for heavy metals in the compost according to § 4 paragraph 3 sentence 2 are complied with. In the example calculations it is assumed that every three years the maximum amount of 30 t DM / ha compost is applied. When converted to annual applications, this corresponds to an annual application rate of 10 t DM / (ha * a).
  The calculation is performed using maximum application rates to demonstrate the effects following theoretical long term compost applications. To demonstrate these effects, application over 500 years is shown, although, in practice, compost application over such a long period of time would not be expected. An example is also shown of the effect of a lower application rate, which assumes 4 t DM / ha per year (cf. Chapter 3.1).

- **Mass supply:** Regular compost application of an application rate of 10 t DM / ha per year results in 5.1 t DM mineral fraction / ha per year. After 100 years, the mass supply is therefore 510 t DM / ha, over 500 years it is 2,715 t DM / ha (cf. Table 1).

- **Increase in soil horizon:** Following regular compost application and assuming that the fraction of the compost that remains in the soil over the long term is 51% (see above), the surface soil horizon would increase in height by 0.36 mm every year, i.e. in 100 years, the topsoil horizon would increase with regular use of compost by 3.6 cm, at 500 years of use, this would correspond to 18 cm (cf. Table 1).

Formula 1: Increase in the thickness of the horizon

Calculation: h_t = $$\frac{(M \bullet A\_long \bullet ha)}{d\_comp \bullet 10} \bullet t$$

h_t	Increase of the thickness of the horizon	in mm
t	Period of application	in years
M	Applied compost quantity (DM)	in t/(ha*a)
A_{long}	Share remaining in the soil over the long term	in %
d_{comp}	Dry bulk density of the compost (here 1.4 g / cm³)	in g / cm³
ha	Plot size	in hectares (ha)

3 Example contaminant concentration calculations

With the use of compost, as shown in Chapter 1, not only are heavy metals applied, but the topsoil is also built up over the long term. The standard contaminant concentration calculations (see below) consider only the supply of contaminants and neglect the considerable mass supply and associated benefits for building up soil structure with compost use.

The presence of mineral components (which remain in the soil over the long term), is essential in calculating soil contaminant levels, as the following examples show. The conditions and assumptions for the calculation are summarised in Chapter 2.

Example load calculations, taking into account soil build up, is shown for cadmium in compost:

- Influence of the application rate
- Influence of the concentration of contaminants in compost
- Influence of the initial content in the soil
- Influence of the thickness of the soil horizon
- Influence of the proportion of long-term stable constituents in the compost

Formula 2: Excluding mineral components

Function C_{Bo_t} =

$$\frac{(C\_Comp \bullet M \bullet 0{,}1 \bullet ha \bullet t) + (C\_Bo \bullet d \bullet 1000 \bullet h \bullet ha)}{d \bullet 1000 \bullet h \bullet ha}$$

Formula 3: Taking into account the build-up in soil structure through the application of long term residual mineral fractions

Function C_{Bo_t} =

$$\frac{(C\_Comp \bullet M \bullet 0{,}1 \bullet ha \bullet t) + (C\_Bo \bullet d \bullet 1000 \bullet h \bullet ha)}{(d \bullet 1000 \bullet h \bullet ha) + (M \bullet A\_long \bullet 0{,}1 \bullet ha \bullet t)}$$

t	Period of application	in years
C_{Bo}	Concentration in relevant soil horizon at the beginning of the calculation (using the background value according to LABO 2003)	in mg/kg DM
C_{Bo_t}	Concentration in relevant soil horizon after t years	in mg/kg DM
C_{Comp}	Solids concentration in the compost	in mg/kg DM
ha	Surface area	in hectares (ha)
h	Soil horizon thickness	in m
M	Compost application rate (DM)	in t/(ha*a)
A_{long}	Fraction remaining in the soil over the long term (insert into formula: 50% = 0.50)	in %
d	Dry bulk density of soil	in g / cm^3

3.1 Impact of different application rates

The change in the concentration of heavy metals in the soil is dependent not only on its concentration in the compost and in the soil, but also on the compost application rate. The example calculation assumes that the Cadmium (Cd) concentration in typical compost is 0.42 mg / kg DM, based on the database from BGK (2010). The concentration of cadmium in the soil, was based on the background value of 0.36 mg / kg DM (50th percentile) according to LABO (2003) of topsoil under arable use on loess in rural areas of Germany.

The application rates were varied as follows:

- Firstly, the maximum application rate was used according BioAbfV (2012), which limits application rates to 30 t DM / ha every three years in order to comply with heavy metal limit application rates. This was converted to an annual application rate of 10 t DM / (ha * a) (marked in blue in Figure 3).
- On the other hand, a lower application rate of 4 t DM/ha per year was also calculated (marked in green in Figure 3).

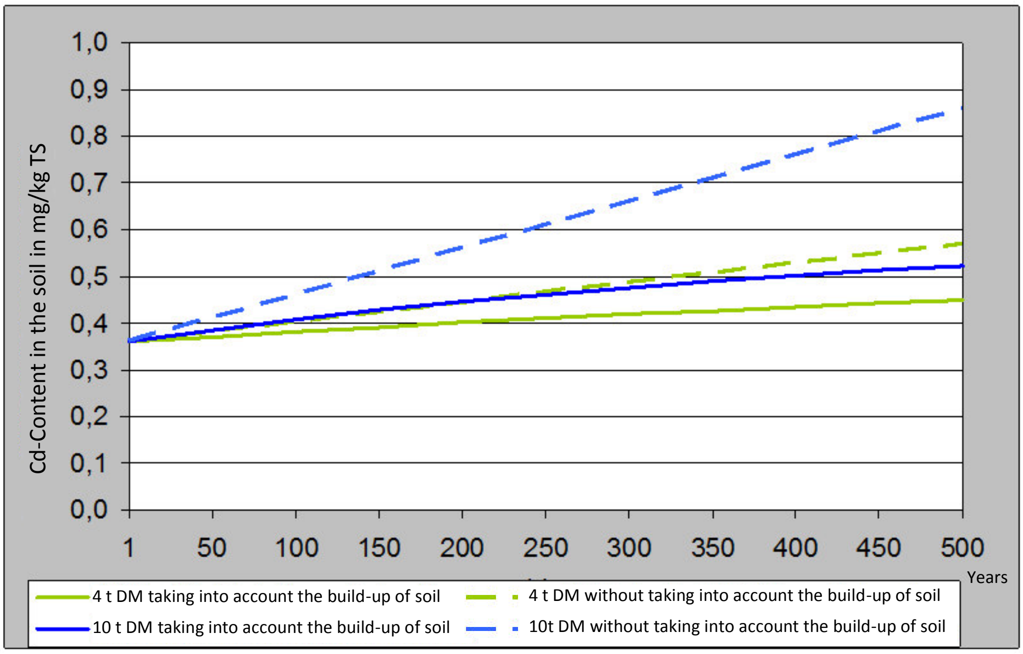


Figure 3 - Enrichment scenarios for cadmium with different compost application rates taking into account and without taking into account build-up of soil structure by mineral soil particles. The initial content of the surface soil is 0.36 mg / kg DM Cd and corresponds to the background value (50th percentile) by LABO 2003 in topsoil for use on arable loess in rural areas. The Cd content in the compost is 0.42 mg / kg DM

As can be seen in Figure 3, by taking into account the mineral component in the compost, the accumulation rate of cadmium in soil was significantly lower, as follows:

- Without taking into account the mineral components, the concentration of contaminants in the soil is determined by the amount of compost applied as the total contaminant load that is applied to an assumed constant amount of soil. At an application rate of 10 t DM / (ha * a) the concentration of cadmium in the soil would increase from an initial concentration of 0.36 mg / kg DM to 0.56 mg / kg dry matter after 200 years (an increase of 0.2 mg / kg DM) and to 0.86 mg / kg DM after 500 years.

- By taking into account the increase in the soil horizon due to the addition of mineral components in the compost, at 10 t DM / (ha * a) the original cadmium content in the soil of 0.36 mg / kg dry matter would only increase to 0.45 mg / kg dry matter after 200 years (an increase of 0.09 mg / kg DM) and to 0.54 mg / kg DM after 500 years.

The more compost is applied, the more significant the difference whether the long term in the soil remaining shares are taken into account or not. At lower application rates (e.g. 4 t DM / (ha * a) marked in green in Fig. 3), the difference is less pronounced.

In general, the figure shows that instead of a continuous, linear increase in the soils cadmium concentration, by taking into account the mineral fraction, the accumulation of contaminants follows a non-linear, asymptotically approach towards the contamination concentration in compost (approximately double amount)[2] . Please refer to the mathematical proof (pp. 16-17).

3.2 Effect of different contaminant concentrations in compost

The contaminant concentration in the compost has a significant influence on its accumulation in the soil. This is shown in Figure 4, which shows how calculated Cd concentrations in soil based on both average concentrations of 0.42 mg / kg DM (shown in blue in Fig. 4) (based on BGK, 2010), and an assumed concentration of 1 mg / kg DM Cd (shown in orange in Figure 4) can increase when the mineral fraction is both taken into account and left out of the equation. In all cases an application rate of 10 t of DM (ha * a) was assumed (based on the BioAbfV maximum application rate of 30 t DM/hectares every three years).

In the example, the calculation shows that at higher concentrations of contaminants in compost, the influence of the mineral components due to accumulation in the soil is particularly clear. According to the current loading rate calculation, long-term compost application at Cd concentrations of 1 mg / kg DM, would reach the precautionary soil limit value set by the BbodSchV (1999) for clay / silt soils at 270 years (1 mg / kg DM; shown in Figure 4 in yellow). When the change in soil structure due to the mineral component in the compost is taken into account, due to the asymptotic curve, this limit value would not be reached until after 500 years (see Figure 4 and Section 3.3).

[2] An asymptotic approximation of the concentration in the soil towards the concentration in the compost is caused by the mineral stable fraction of 51% which is applied with the compost on a long term basis; see additional mathematical section (pp. 14-15).

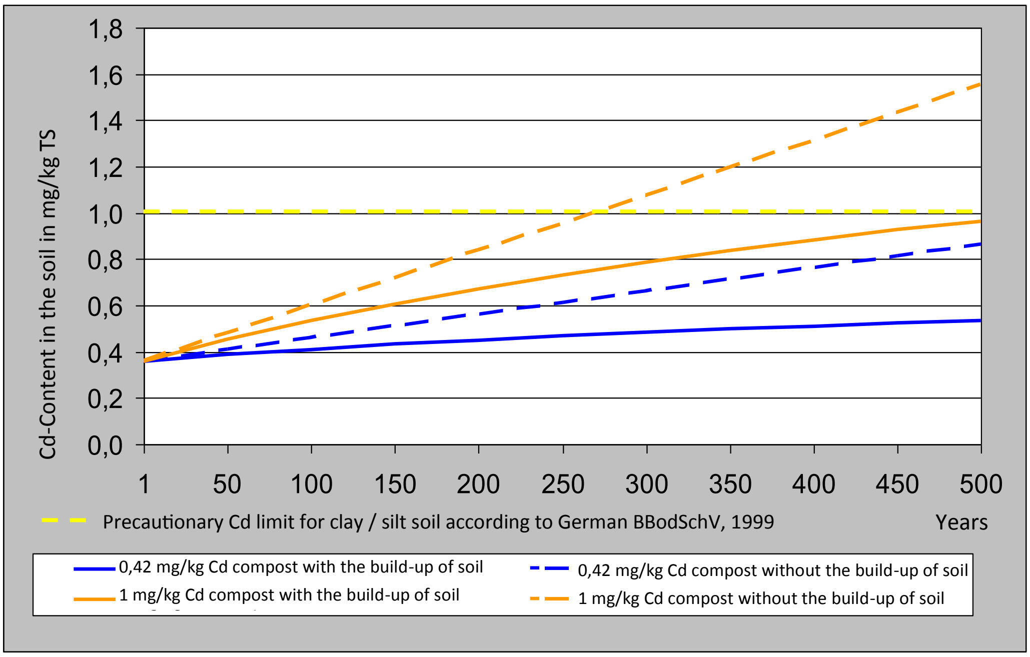


Figure 4 - Enrichment scenarios for cadmium in soil where compost with Cd contents of 0.42 and 1 mg / kg DM were applied.
The initial content of the surface soil is 0.36 mg / kg DM Cd and corresponds to the background value (50th percentile) by LABO (2003) of topsoil for use on arable loess in rural areas.

3.3 Influences of different soil background levels

The change in heavy metal concentrations in the soil also depends upon the initial soil metal concentration, as well as the loading rates due to compost application. At higher initial soil contaminant levels, the calculated concentration was shown to decrease due to a dilution effect of the compost (see Figure 5).

- An initial content of 0.15 mg / kg DM Cd in topsoil (blue in Fig. 5) was modelled. This value corresponds to the background value (50th percentile) quoted by LABO (2003) of boulder clay / loam in rural areas in Germany.

- Secondly, an initial content of the surface soil of 1.0 mg / kg DM Cd (pink in Fig. 5) was modelled. This level corresponds to the background value (90th percentile) quoted by LABO (2003) for arable loess topsoil in urban conglomeration areas in North Rhine-Westphalia (area type I).

The change in contaminant concentration in the soil due to compost application is therefore dependent upon its initial soil concentration. If the initial soil background concentration is low (e.g. as in those boulder clay / loams suggested by LABO 2003), the rate of accumulation will be higher than in those soils with higher initial background concentrations, when the mineral fraction is taken into account. The enrichment effect due to the increase in soil mass when the mineral fraction is taken into account, shows a marked difference between the Cd concentrations in the two soil types.

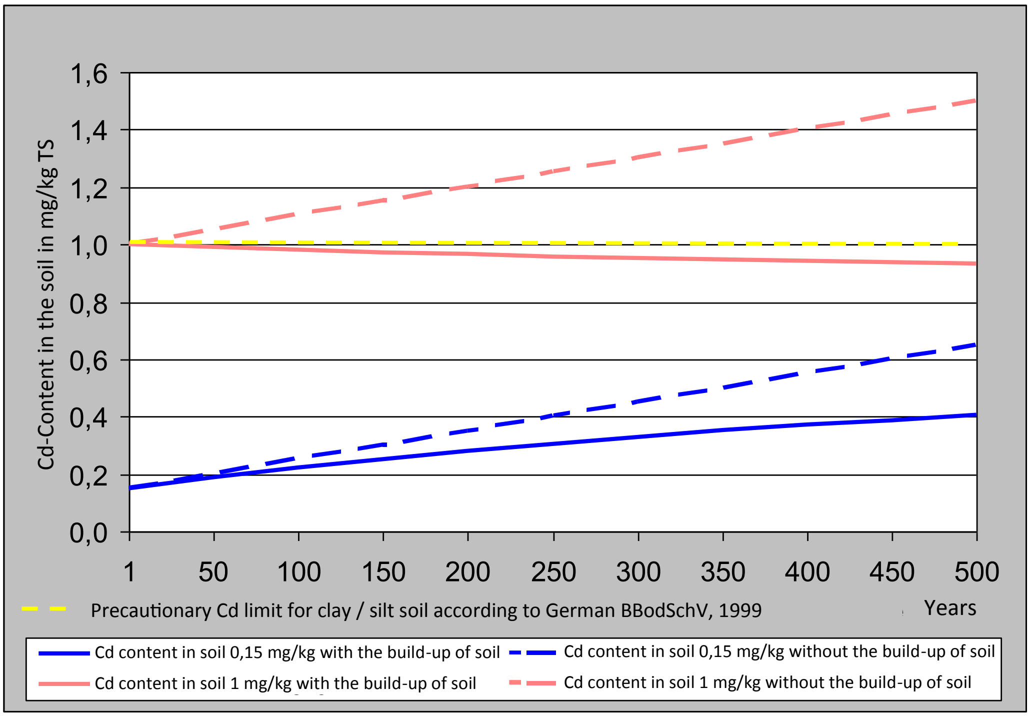


Figure 5: Enrichment scenarios for cadmium, depending on the initial soil concentration. The initial content of the surface soil is 0.15 mg / kg DM Cd (blue) and 1.0 mg / kg DM Cd (yellow). The Cd content in the compost is 0.42 mg / kg DM. The application rate is 10 t DM / (ha * a).

Where there are high background concentrations of heavy metals in the soil, compost application can actually reduce their levels (e.g. as shown in the calculations for background values of agricultural loess soil in urban areas in North Rhine-Westphalia; see Fig 5). The contaminant accumulation rate calculation that doesn't take into account the effects of the mineral fraction would, by contrast, lead to an apparent increase in metal concentration in the soil.

Excursus: Mathematical proof of long-term enrichment

By taking into account the soil mineral fraction, long term fertilization contributes towards a build-up of soil structure. The processes outlined in Chapter 3 illustrate how enrichment or depletion can be mathematically represented by the function (CBo_t), which describes an asymptotic approximation.
Convergence of the function value of CBo_t on a horizontal asymptote, can be computed for t → ∞.

Formula 3: Taking into account the build-up of soil structure by long term residual mineral fractions

Function C_{Bo_t} = $$\frac{(C\_Comp \bullet M \bullet 0{,}1 \bullet ha \bullet t)+(C\_Bo \bullet d \bullet 1000 \bullet h \bullet ha)}{(d \bullet 1000 \bullet h \bullet ha)+(M \bullet A\_long \bullet 0{,}1 \bullet ha \bullet t)}$$

t	Period of application	in years
C_{Bo}	Concentration in relevant soil horizon at the beginning of the calculation (using the background value by LABO 2003)	in mg/kg DM
C_{Bo_t}	Concentration in relevant soil horizon after t years	in mg/kg DM
C_{Comp}	Concentration in compost	in mg/kg DM
ha	area size	in Hektar (ha)
h	Horizon thickness	in m
M	Applied compost quantity (DM)	in t/(ha*a)
A_{long}	long term in the soil remaining interest (paste formula: 50% = 0.50)	in %
d	Dry density of the soil	in g/cm³

Determination of the asymptote and consideration of the function value for t → ∞

(1) functional equation is reformulated into two quotients whose development is considered for each t → ∞:

$$C_{Bo\_t} = \frac{(C\_Bo \bullet d \bullet 1000 \bullet h)}{(d \bullet 1000 \bullet h)+(M \bullet A\_lang \bullet 0{,}1 \bullet t)} + \frac{(C\_Komp \bullet M \bullet 0{,}1 \bullet t)}{(d \bullet 1000 \bullet h)+(M \bullet A\_lang \bullet 0{,}1 \bullet t)}$$

(2) For t → ∞ $$\frac{(C\_Bo \bullet d \bullet 1000 \bullet h)}{(d \bullet 1000 \bullet h)+(M \bullet A\_lang \bullet 0{,}1 \bullet t)}$$

(first quotient) tends towards to 0.

(3) For t → ∞ $$\frac{(C\_Komp \bullet M \bullet 0{,}1 \bullet t)}{(d \bullet 1000 \bullet h)+(M \bullet A\_lang \bullet 0{,}1 \bullet t)}$$

(second Quotient) tends towards $$\frac{C\_Komp}{A\_lang}$$

Justification for (3) - Development of second quotient:

$$\frac{(C\_Komp \bullet M \bullet 0{,}1 \bullet t)}{(d \bullet 1000 \bullet h) + (M \bullet A\_lang \bullet 0{,}1 \bullet t)}$$

(4) Expanding the equation with $\frac{1}{t}$

this results in = $$\frac{\frac{C\_Komp \bullet M \bullet 0{,}1 \bullet t}{t}}{\left(\frac{d \bullet 1000 \bullet h}{t}\right) + \left(\frac{M \bullet A\_lang \bullet 0{,}1 \bullet t}{t}\right)}$$

(5) equation is reduced, [simplified]

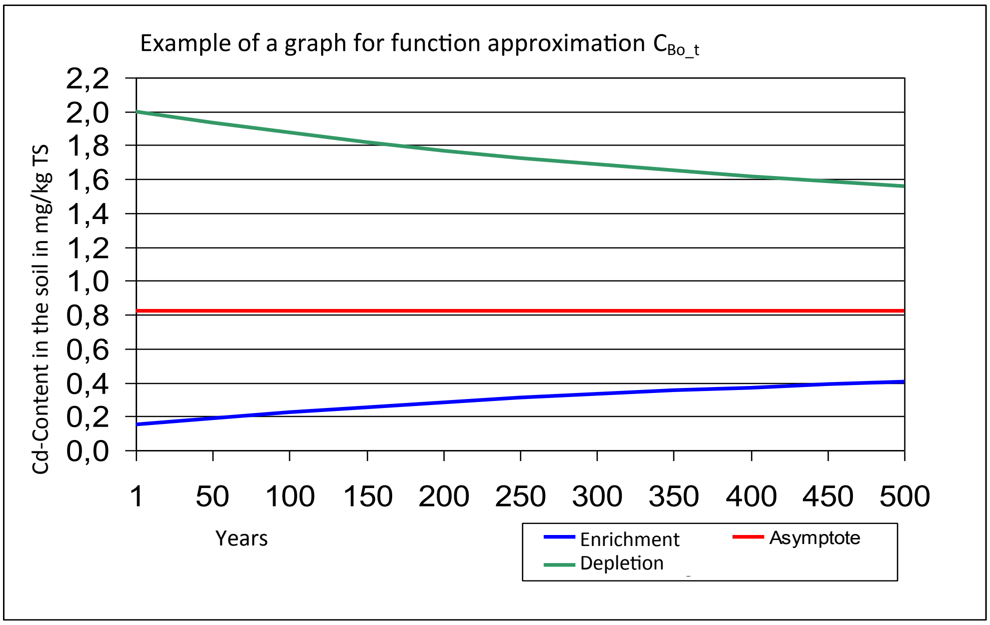
thus remains = $$\frac{C\_Komp \bullet M \bullet 0{,}1}{\left(\frac{d \bullet 1000 \bullet h}{t}\right) + M \bullet A\_lang \bullet 0{,}1}$$

(6) For t → ∞ $\frac{d \bullet 1000 \bullet h}{t}$ tends towards 0.

(7) thus remains $\frac{C\_Komp \bullet M \bullet 0{,}1}{M \bullet A\_lang \bullet 0{,}1}$ = $\frac{C\_Komp}{A\_lang}$

It follows that:

For t → ∞ the value of the function C_{Bo_t} always approximates to : $\frac{C\_Komp}{A\_lang}$



3.4 Influence of the soil horizon thickness

The calculated change in the concentration of heavy metals in the soil due to the supply of compost is highly dependent on the thickness of the soil horizon. The example shown in Figure 6 assumes compost having a Cd content of 0.42 mg / kg DM (BGK, 2010) and a proportion of long-term stable mineral fraction of 51% (as in the preceding examples) is applied to a soil with a Cd background concentration of 0.36 mg / kg DM (50th percentile of loess topsoils under arable use in rural areas in Germany; LABO, 2003).

The horizon thickness was varied as follows:

- A horizon depth of 10 cm (light blue line in Fig. 6), and
- A horizon depth of 40 cm (dark green line in Fig. 6).

Figure 6 shows that the horizon thickness of conventional loading rate calculations that exclude the effects of the mineral fraction significantly affect the soil Cd concentrations after 500 years (i.e. they were calculated to be 0.74 mg / kg DM Cd at 40 cm depth horizon and 1.86 mg / kg dry matter at 10 cm horizon depth). By contrast, the differences after 500 years between the two soil depths when the mineral fraction of the compost was taken into account was nowhere near as marked: the calculated Cd soil concentrations after 500 years were 0.51 mg / kg dry matter at 40 cm depth horizon and 0.66 mg / kg dry matter at 10 cm depth horizon. The approach to the asymptote of about 0.82 mg / kg DM Cd was shown to be independent of the horizon thickness, as shown mathematically. The enrichment and approach is, however, slowed again in larger soil horizons.

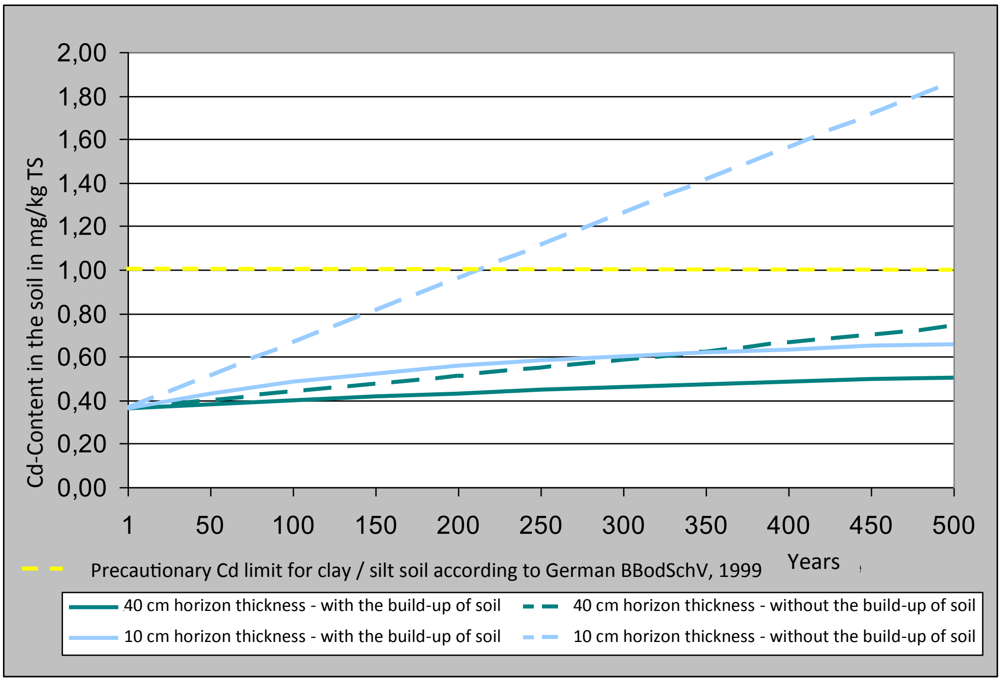


Figure 6 - Enrichment scenarios for cadmium in a Cd content in the compost of 0.42 mg Cd/ kg and different thickness horizon.
The initial content of the surface soil is 0.36 mg / kg Cd and corresponds to the background value (50th percentile) by LABO (2003) of loess topsoil under arable use in rural areas

3.5 Influence of the mineral fraction

According to the mathematical proof for determining the asymptote (see Excursus on pp. 16-17), the development of the function value is dependent upon the proportion of stable mineral fraction. As shown in Chapter 2, a worst-case scenario was used which assumed that the stable mineral soil content in the compost was 51%. However, this does not take into account that a proportion of the organic matter in compost can also be stable and remain in the soil for a long time. This can be anywhere between 9.9% and 22.5% (see Section 2), meaning that the stable fraction in compost can be up to 73.5%.

The example calculation shown in Figure 6 illustrates how the contaminant concentration in soil varies depending upon the assumed percentage of the stable fraction in the compost. A compost with an assumed Cd concentration of 0.42 mg / kg DM (BGK, 2010) was applied to a soil having a background Cd concentration of 0.36 mg / kg DM Cd (50th percentile) after LABO (2003) of loess topsoils under arable use in German rural areas. The proportion of stable substances in the compost was varied as follows:

- Proportion of stable fractions in compost of 20% (asymptote: 2.1),
- Proportion of stable fractions in compost of 51% (asymptote 0.82)
- Proportion of stable fractions in compost of 70% (asymptote: 0.6).

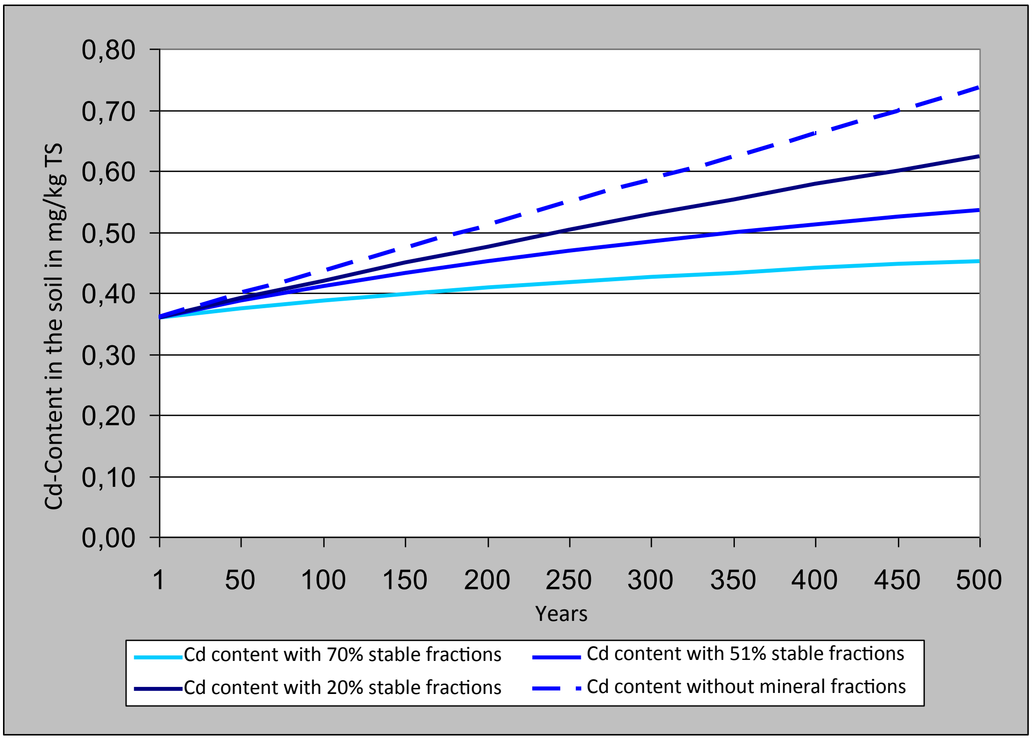


Figure 7 - Enrichment scenarios for cadmium in a Cd content in the compost of 0.42 mg / kg DM and different stable fractions.
The initial content of the surface soil is 0.36 mg / kg DM Cd and corresponds to the background value (50th percentile) by LABO (2003) of topsoil for use on arable loess in rural areas.

The curve clearly shows how the proportion of mineral components in the compost determines the accumulation rates of contaminant levels in the soil.

The calculations and the following Figure 7 show that over a period of 500 years, the calculated levels of cadmium from the original 0.36 mg / kg DM Cd increased to:

- 0.62 mg / kg DM Cd, assuming a stable fraction of 20% of the compost,
- 0.54 mg / kg DM, assuming a stable fraction of 51% of the compost,
- 0.45 mg / kg DM, assuming a stable fraction of 70% of the compost, and
- 0.74 mg / kg DM, assuming a stable fraction of 0% of the compost.

If longer periods of time are considered (over 500 years), the difference is increasingly evident that the modelled concentrations approach the asymptote. Thus, for a compost applied on a regular basis having a stable mineral fraction of 51%, the soil cadmium concentration does not exceed the asymptote of 0.82 mg / kg DM ($t \rightarrow \infty$). With a stable fraction of 70%, a maximum concentration of 0.6 mg / kg DM Cd in the soil (asymptote) is not exceeded. In contrast, a compost having only 20% as its stable fraction, a soil Cd concentration of 2.1 mg / kg DM is possible.

4 Conclusions

The example loading rate calculations show that by taking into account the stable fraction of compost, this fundamentally affects the resulting concentrations of contaminants in the soil over time.
The mathematical evidence shows that taking into account the Data by BGK (2010), that is, at a mean Cd content in the compost of 0.42 mg / kg DM and a long-term stable mineral soil accounted for 51%, the concentration of
0.82 mg /kg dry soil is exceeded in any case, as this is the asymptote (Approximate straight line).

The asymptote was calculated from $\frac{C\_Comp}{A\_long}$,

i.e., the maximum concentration (C_{Bo}) arises from the ratio of the concentration in the fertilizer (here compost: C_{comp}) and the stable fraction ($A_{\_long}$).

At higher background soil concentrations, the concentration in the soil also approximates to this same value, i.e. there is a reduction in the concentration of the contaminant. For example, in soils containing concentrations greater than 0.82 mg / kg DM Cd, long-term improvements in the soil contaminant concentrations can be achieved.

The example calculations show that considering the stable (invariant) fraction in compost to calculate the resulting soil heavy metal concentration following its long term application is both technically meaningful and plausible. The loading rate calculations commonly used in which only the heavy metal concentrations in the product as well as in the receiving soil are taken into account, are not realistic and over calculate resultant soil heavy metal concentrations. This is particularly true if organic fertilizers with high levels of mineral soil particles are used.

5 References

Ad-hoc-AG Boden (2005): Bodenkundliche Kartieranleitung (KA5). 5. Aufl., Hannover.

Amlinger, F.; Peyr, S.; Geszti, J.; Dreher, P.; Weinfurtner, K.; Nortcliff, S. (2006): Evaluierung der nachhaltig positiven Wirkung von Kompost auf die Fruchtbarkeit und Produktivität von Böden. Literaturstudie. Herausgegeben vom österreichischen Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien.

BBodSchG (1998): Gesetz zum Schutz vor schädlichen Bodenveränderungen und zur Sanierung von Altlasten (Bundes-Bodenschutzgesetz- BBodSchG), in: BGBl I 1998, Teil I, 502.
http://www.gesetze-im-internet.de/bundesrecht/bbodschg/gesamt.pdf

BBodSchV (1999): Bundes-Bodenschutz- und Altlastenverordnung vom 12. Juli 1999 (BGBl. I S. 1554), die zuletzt durch Artikel 5Absatz 31 des Gesetzes vom 24. Februar 2012 (BGBl. I S. 212) geändert worden ist.
http://www.gesetze-im-internet.de/bundesrecht/bbodschv/gesamt.pdf

BioAbfV (1998): Verordnung über die Verwertung von Bioabfällen auf landwirtschaftlich, forstwirtschaftlich und gärtnerisch genutzten Böden Bioabfallverordnung in der Fassung der Bekanntmachung vom 4. April 2013 (BGBl. I S. 658), die zuletzt durch Artikel 5 der Verordnung vom 5. Dezember 2013 (BGBl. I S. 4043) geändert worden ist" http://www.gesetze-im-internet.de/bundesrecht/bioabfv/gesamt.pdf

Bundesgütegemeinschaft Kompost – BGK (2010): Medianwerte gütegesicherter Komposte und Gärprodukte im Jahr 2010 (zur Verfügung gestellt von der Bundesgütegemeinschaft Kompost e.V., Februar 2011).

DLG / LLFG - Deutsche Landwirtschafts-Gesellschaft e.V. / Landesanstalt für Landwirtschaft, Forsten und Gartenbau Sachsen-Anhalt [Hrsg.] (2009): Hinweise zur Kalkdüngung, DLG-Merkblatt 353, Frankfurt.

DüngeVO (1996): Verordnung über die Grundsätze der guten fachlichen Praxis beim Düngen - Düngeverordnung - vom 26.01.1996, in: BGBl 1996, Teil I, Nr. 6, S. 118-121.

DüV – Düngeverordnung (2007) Verordnung über die Anwendung von Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis beim Düngen (Düngeverordnung - DüV) vom 27. Feb. 2007, BGBl I Nr. 7 vom 5.03.2007 S. 221).

IFEU / ahu (2011): Optimierung der Verwertung organischer Abfälle. Teil 1: Wirkungsanalyse Boden, unveröffentl. Zwischenbericht zum Forschungsvorhaben FKZ 3709 33 340.

Kluge, R. et al. (2008): Nachhaltige Kompostanwendung in der Landwirtschaft. Hg. vom Landwirtschaftlichen Technologiezentrum Augustenberg – LTZ, Karlsruhe. auch veröffentlicht in: BGK/LTZ (2008): Nachhaltige Kompostanwendung in der Landwirtschaft. Thema des Abschlussprojektes

Kompost-Anwendungs-versuche Baden-Württemberg, gefördert durch das Ministerium für Ernährung und Ländlichen Raum BW, BGK und VHE. Nachfolgeprojekt des Verbund-Forschungsprojektes der Deutschen Bundesstiftung Umwelt (Laufzeit 2000-2002). Landwirtschaftliches Technologiezentrum Augustenberg (Hrsg.), August 2008.
Download of English Summary published as ECN INFO PAPER No 02/2010: http://www.compostnetwork.info/wordpress/wp-content/uploads/2011/05/ECN-INFO-02-2010_Sustainable_Use_of_Compost_in_Agriculture_LTZ-Project.pdf

Knappe, F.; Möhler, S.; Ostermayer, A.; Lazar, S.; Kaufmann, C. (2008): Vergleichende Auswertung von Stoffeinträgen in Böden über verschiedene Eintragspfade, UBA-Forschungsbericht 203 74 275, UBA Texte 39/08, Berlin.

LABO – Bund/Länder-Arbeitsgemeinschaft Bodenschutz (2003): Hintergrundwerte für anorganische und organische Stoffe in Böden, 3. überarb. u. erg. Auflage 2003.

MLR – Ministerium für Ernährung, Ländlichen Raum und Verbraucherschutz Baden-Württemberg (2010): Infodienst Landwirtschaft - Ernährung - Ländlicher Raum. Dünger-Umrechnungstabellen, http://www.landwirtschaft-bw.info/servlet/PB/show/1209715/Dnger %20Umrechnungstabelle.xls.

Reinhold, J. (2008): Anhang 2, Teil 1, zu (Kluge et al. 2008): Untersuchungen zu heißwasserlöslichen Bodengehalten an Kohlenstoff und Stickstoff sowie zur Humusreproduktion und Humusqualität. Kompost-Abschlussbericht 2008. Punkte C 2.2.1.2 und C 2.2.1.5, Ausführlicher Ergebnisbericht.

Timmermann, F. et al. (2003): Nachhaltige Kompostverwertung in der Landwirtschaft, DBU-Abschlussbericht zum Verbundforschungsprojekt Praxisbezogene Anwendungsrichtlinien sowie Vermarktungskonzepte für den nachhaltigen Einsatz von gütegesicherten Komposten im landwirtschaftlichen Pflanzenbau, hg. v. der Gütegemeinschaft Kompost Region Süd e.V., Leonberg.

Scheffer, F. & Schachtschabel, P. (2002): Lehrbuch der Bodenkunde, Heidelberg.

Wessolek, G. et al. (2008): Ermittlung von Optimalgehalten an organischer Substanz landwirtschaftlich genutzter Böden nach § 17 (2) Nr. 7 BBodSchG. Forschungsprojekt im Auftrag des Umweltbundesamtes FuE-Vorhaben. FKZ 202 71 264, Berlin.