GHG Savings from Biological Treatment and Application of Compost

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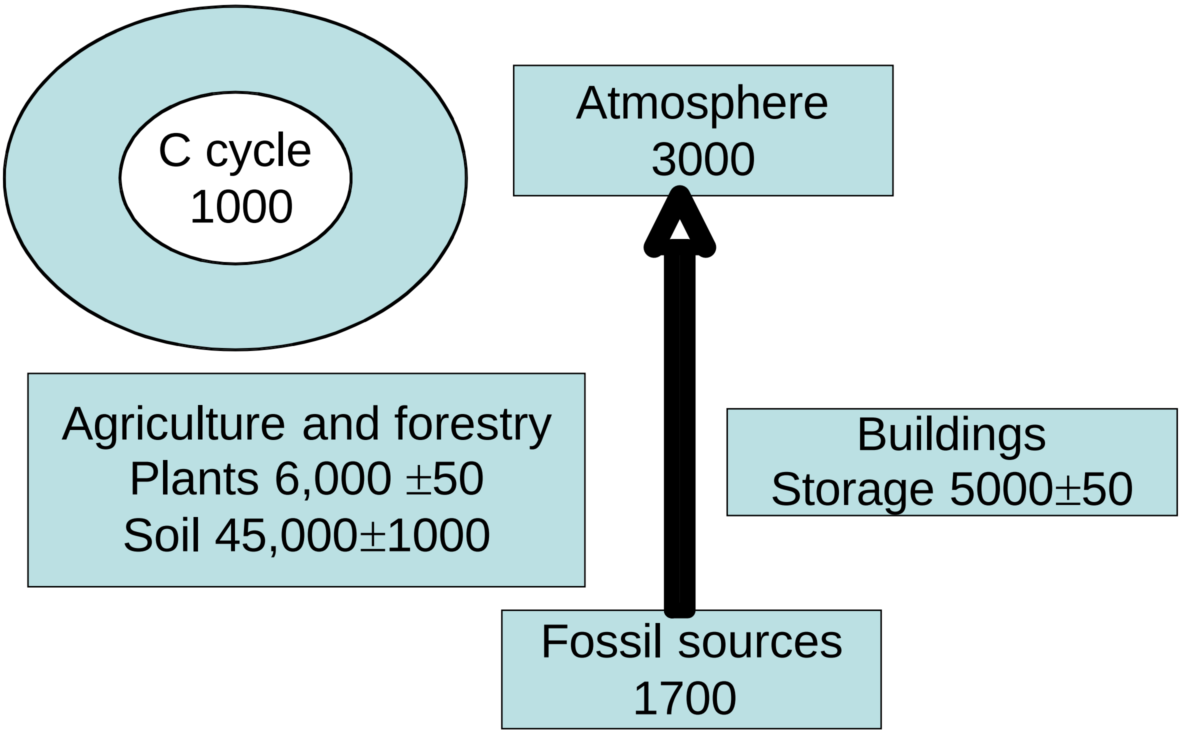
key words: biowaste, GHG, AD, compost, savings.

Abstract

Biological treatment of waste and compost utilisation are two elements of waste management that can influence GHG emissions. Although waste management in general, and more specifically biowaste and the related compost production only involve a rather marginal amount of C, LCAs may tell us which is the best combination of options in order to contribute to general GHG savings. In this respect, biological treatment and the use of the soil improvers thus produced, may have various effects that have been rather overlooked so far, but should be taken into account in LCAs, in decision-making and then in waste policy. The biggest GHG savings (around 135 kg CO_2-eq / tonne of treated biowaste) from biological treatment occur with anaerobic digestion (AD), where renewable energy is produced from biowaste; about 80 kg may derive from the C sink is the soil, 10 kg from replacement of mineral fertilisers; more than 200 kg CO_2 eq. may be saved through compost replacing peat in horticulture, gardening and potted plants. In an optimised strategy for the management of biowaste, combining AD and the application of compost in farmlands and potted plants, total GHG savings may amount to about 500 kg CO_2 per tonne of treated biowaste. This may correspond to about 0.5% the total CO_2 emissions, but it is much more relevant for optimisation of the C budget within waste management itself. It is also worth noting that this calculation, though significant in itself, does not take into account wider benefits of using compost such as reduction of erosion, improved water retention, biodiversity, plant health, because these effects are difficult to quantify in concrete figures given they are site specific and usually also crop specific. Nevertheless, they also contribute to the total of the strategies aiming at reducing the GWP, not to mention the wider benefits for soils and the environment

C-flux (kg/a) per capita in CH



C cycle
1000

Atmosphere
3000

Agriculture and forestry
Plants 6,000 ±50
Soil 45,000±1000

Buildings
Storage 5000±50

Fossil sources
1700

Fig. 1 Estimation of C-fluxes in Switzerland for the year 2005 (after Müller & Bacchini EAWAG).

1. Introduction

Apart from the oceans, soil constitutes the largest C sink for carbon storage (about 2/3 agricultural soils and 1/3 forest) (ref). The mass of C stored in plants (mainly forest) is equal to that stored in buildings. A typical accounting of C stocks for Switzerland is shown in Figure 1.
Each year, some 2500 to 3000 kg of C are mineralised per capita, about two thirds of which are of fossil origin (oil, natural gas and their derivates, including peat) (ref). Compost from biowaste accounts for about 1% of the renewable C in circulation; and if its use in an integrated waste management strategy is optimised, it may contribute through sectoral savings. In order to assess the potential contribution of biological waste treatment to greenhouse gas inventories, the following has been assumed:

- CO_2 from biowaste processing is climate neutral, since it forms part of the short-term C cycle. Other gases emitted from biowaste processing, such as CH_4 and N_2O, can have negative impacts on the climate (ref the other article)
- Energy savings include the replacement of fossil fuel as energy source by that from the incineration of biowaste or from biogas production, as well as reduction of atmospheric CO_2 by regular application of organic matter (OM) on soils, which increases their humus content reduces, thus transferring C to the soil sink. CO_2 emissions are also reduced by recycling nutrients instead of producing new fertilisers. Other factors that may contribute to reducing CO_2 emissions are improved water retention, reduced erosion and disease suppression, improved workability of soils (that requires less consumption of fuels), etc.

2. Savings related to the production of renewable energy from anaerobic digestion:

Table 1: Avoided emissions when electricity and heat are generated from AD instead of from fossil fuels

Parameter	Value	Unit
Biogas yield	100	$m^3/ton_{sep.\ coll.\ waste}$
Calorific value of biogas (60% CH_4)	600	kWh/t_{waste}
Electricity generated (30% efficiency)	180	kWh/t_{waste}
Net electricity produced (70% of total generated)	120	kWh/t_{waste}
Avoided emissions from electricity production	54	kg_{CO2}/t_{waste}
Heat recovered for the CHP option (80%)	336	kWh/t_{waste}
Net heat exported for the CHP option (80%)	286	kWh/t_{waste}
Avoided emissions from CHP heat export	81	kg_{CO2}/t_{waste}

Source: AEA Technology, 2001 Waste Management Options and Climate Change, Report to the European Commission

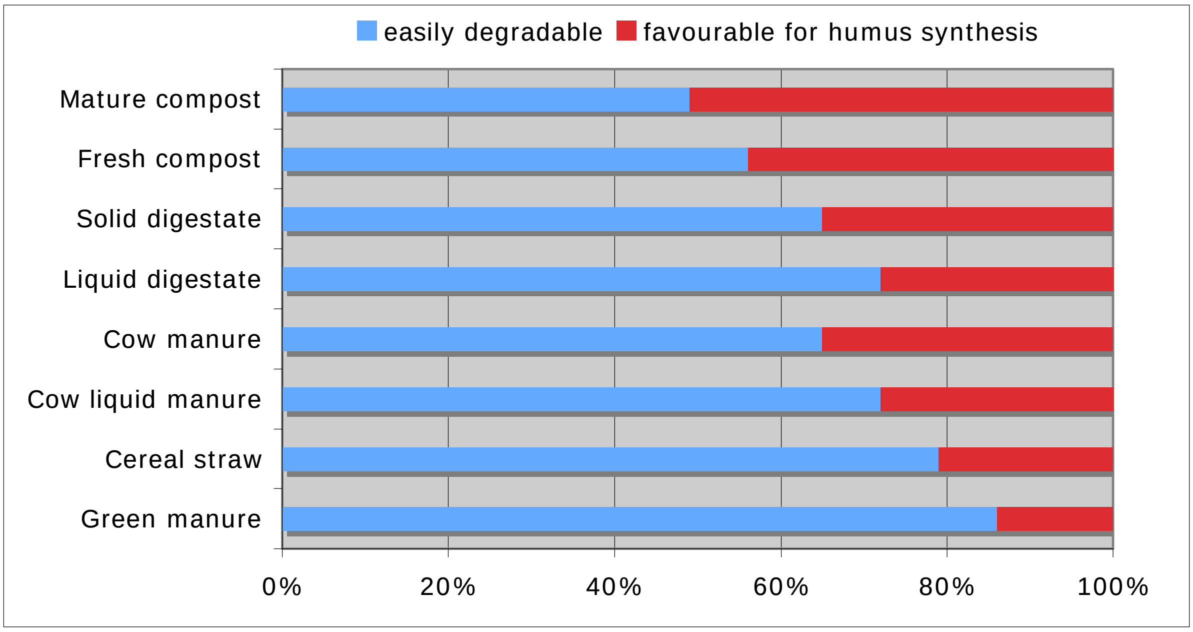
Anaerobic digestion of solid waste yields about 100 m^3 of biogas per ton of biowaste on average, with fatty wastes or food wastes producing higher yields, and fibrous woody wastes lower yields. Data from Zurich, Switzerland, showed a yield of 7,658,183 m^3 biogas from 74,952 tons of biowaste, which is consistent with the typical yield value. A recent EU report cited a similar estimate in 2001, where avoided emissions from electricity and heat production were calculated for one tonne of anaerobically digested biowaste (AEA Technology, 2001) (Table 1). Although the optimal theoretical yield from the conversion of the chemical energy in biogas into electricity and heat would result in CO_2 savings of about 135 kg per ton of biowaste, 100 kg of CO_2 per tonne is considered a reasonable practicable estimate.

3. The soil improving effect: crediting C in compost and digestate

3.1 Improving the C-sink in the soil

Fresh organic matter, such as green manure or animal manure, does not increase the humus content of the soil, although it can provide some short-term nourishment. The degradation and maturation processes during biowaste composting or anaerobic digestion increase the "stable humus" content of the resulting solids. In effect, during composting, while readily degradable organic material is decomposed to CO_2 and water, more resistant compounds, like lignin, are slowly degraded to form a stable humus residue. Also, a significant amount of nitrogen is immobilised and can later be released when the compost is applied to the soil.

Figure 2: Proportions of easily degradable and more persistent organic matter (i.e. more favourable for the synthesis of humus), in various organic fertilisers



Source: J. Reinhold, VHE BBS e.V.

The comparison in figure 2 shows that, depending on the type of fertilizer, between 14 and 51% of the organic carbon (TOC) it contains may be assimilated into the humus matrix of the soil onto which it is applied. The easily degradable organic fraction is not converted into humus and will be mineralised by soil microorganisms in a comparatively short time, so that temporary storage in humus compounds can be considered negligible.

With mature compost, up to 50% of the carbon applied annually to the soil may contribute to raising the humus content of the soil. Since humus is slowly degraded after application, with a half-life of 70 years, the carbon sink effect is limited. Application of compost containing 100 kg of C, would result in only 30 kg C remaining after 100 years, which is the time span generally considered relevant for climate effects in the IPCC methodology. When converted to kg of CO_2, this amount of carbon corresponds to about 80 kg of CO_2 per 100 kg of soil-applied compost.

It should be noted that the use of an arbitrary (but appropriate) 100-year time span does not allow for one important effect of compost, namely the slow degradation that brings C back to the atmosphere at a much lower rate than would occur with other waste management practices, such as incineration. It is not irrelevant that, through compost production and application, some C will stay in the soil for 70 - 90 years, and although this will not reach the 100-year threshold that would allow it to be considered “C sequestration”, it will functionally contribute to the yearly build-up of C and increase the total C stock in soils relative to the atmosphere. This methodological consideration is reviewed in more detail elsewhere.

3.2 Substituting peat: a most promising contribution to GHG savings

Just as with the production of renewable energy, it is quite simple to calculate the GHG savings when replacing fossil materials such as peat. The rationale here is that the more intact the fossil C sources remain, including peat bogs, the less the effect on the climate: intact peat bogs are therefore one protection against climate change, just as is geologically trapped oil.

Peat is not much used in agriculture, which rather employs manure or straw. Agriculture also uses about 2/3 of the compost produced. Peat substitution by compost can therefore be taken into account for about 1/3 of the compost produced, since this is the part that goes to horticulture and potted plants. Straw is not a fossil resource, in contrast to peat. Digestate is not used in horticulture. The use of compost or digestate in agriculture can however substitute mineral fertilisers. Some GHG savings may be obtained here, as we will show below (see chap. 3.2).

The amount of organic matter in compost and anaerobically digested biowaste solids is about the same (Table 2). One ton of biowaste yields 540 kg of compost.

Table 2: Crediting organic matter in compost and solid digestate as peat substitute

	Amount produced [kg/t biowaste]	**Organic matter [% fresh weight]**	**Potential substitution [kg/t biowaste]**	**Effective substitution [kg/t biowaste]**
Compost	540	22	199.8	66.6
Peat		63		

If we now consider that only 1/3 of the yearly amount of carbon originating from biowaste can actually substitute peat, we come to a figure of just under 70 kg of peat substituted per tonne of biowaste composted (of which 1/3 goes to horticulture) or about 94 kg of CO_2 equivalents.

However, as we saw in figure 2, the proportion of stable humus precursors in compost is roughly double that in peat. This means that each kg of organic matter in peat need only be substituted by 0.5 kg of organic matter from compost to obtain about the same degradation time, since the organic matter in compost is degraded at a much slower rate. This would double our savings to about 140 kg of peat substituted per tonne of biowaste composted (188 kg CO_2 eq.).

Also, since peat is usually imported over long distances, and is a lightweight material (which increases the “burden” of transportation), its replacement by locally produced compost could therefore result in further important GHG savings. Depending on transport distances, one can estimate that 120 to 180 kg of CO_2 per tonne of composted biowaste are saved due to avoided transport.

3.3 Savings due to nutrient replacement

GHG savings due to nutriment replacement amounts to a maximum of 10 kg per tonne of biowaste (Table 3). Only 10% of the nitrogen in compost can be accounted for as fertilizer, the rest goes into humus. Doubling this figure to account for the CO_2 emissions for transporting the fertiliser, one can estimate a maximum saving of 10 kg CO_2 eq. per ton of biowaste, which is rather negligible when compared to other effects.

Table 3: GHG savings due to substitution of mineral fertilisers, per ton of biowaste treated

Nutrient element	**Nutrient content [kg per ton biowaste]**	**Amount accounted for as fertilizer [%]**	**Emissions from mineral fertilisers [kg CO_2 eq./kg element]**	**Avoided CO_2 emissions [kg CO_2 eq./ton biowaste]**
N	4.0	10	5.30	2.12
P	1.5	100	0.52	0.78
K	3.0	100	0.38	1.14

Source: AEA Technology, 2001 Waste Management Options and Climate Change, Report to the European Commission,

4. Total possible GHG savings from biowaste treatment

Table 4 sums up the calculations of the preceding chapters, showing that up to 500 kg of CO_2 savings per tonne of biologically treated biowaste could be obtained, assuming the waste is first anaerobically digested, then that the solid digestate produced is post-composted or used directly in agriculture.

Table 4: Total GHG-savings from AD and compost application per ton biowaste

Step	**GHG-saving by**	**kg CO_2 equivalents**
1	Anaerobic digestion with CHP option	135
2	C-sink in the soil by added humus	80
3	Peat substitution and avoided transport	200 - 300[1]
4	Replaced mineral fertiliser	10
	Total	**400 - 500**

[1] 94 to 188 (substitution) + 120 to 180 (transport)

5. Further beneficial properties of compost and their implications on GHG savings – a review

The followings benefits are considered to be positive effects attributable to organic matter in compost.

All these effects could have implications for GHG emissions that, though they are difficult to calculate or attribute precisely, will certainly increase the overall benefits of a “biologically treated C stock”.

The beneficial effects of OM in compost can be classified as following:

1. physical (soil structure, protection against erosion, water retention);
2. chemical (fertilisation, soil buffer, multiple fertilization);
3. biological (microbial inoculum, nourishment for soil organisms, influence on the soil flora and on plant roots and seeds, etc…).

5.1 Physical effects of compost organic matter

The keyword here is soil improvement.

The most important parameter relating to the physical properties of the soil is its structure, composed of the soil skeleton (the stones), the middle-sized particles and the fine fraction (silt or clay). A good farm soil must contain a reasonable amount of each of these fractions.

This makes for optimal air and water balance. The fine fraction is above all relevant for the chemical properties of the soil, which derive from its ability to bind molecules and ions.

The woody fraction of a compost can also contribute to the soil skeleton, while the middle-sized fraction provides nourishment for the soil organisms and the fine fraction harbours many of these organisms and improves the coherence of sandy soils. The organic matter also helps to buffer unfavourable properties of heavy clayey soils, which are prone to shrinking and swelling and to compacting under pressure. OM buffers all extreme (physical) properties of soils. Stable humus is only found in mature compost. It can contribute durably to the increase of the humus content of a soil.

A first, and remarkable, consequence of improved soil structure is its enhanced workability and lower resistance to ploughing and tilling, with important implications on fuel savings and GHG emissions - though this is difficult to assess in general terms, given that the effects are very site-specific.

The following effects of the compost application to soil are also scientifically recognised:

- increase in the humus content;
- increase of the pore fraction where water and air circulate, with a resulting decrease in the specific gravity;
- increase of the capacity to retain water in a form available to plants, reducing the need for irrigation (lowering the energy consumption of the culture, with ensuing GHG savings) and also decreases the water stress if watering is impossible;
- better percolation of rainfall into the soil and reduced surface runoff, because soils fertilised organically generally contain far more earthworms, some of which tunnel vertically into the soil and improve the percolation of water after heavy rainfall;
- improved crumb stability by the application of OM, which reduces sludging of the upper soil and, consequently, also wind or water erosion.

These effects apply above all to farm soils with a low humus content (up to ca. 3%). Soils with a higher organic content react differently and in general the effect will, quite reasonably, be less remarkable.

5.2 Chemical effects of compost organic matter

Compost is a multiple fertilizer: it contains both main and trace nutriment in good proportions. The feedstock for compost is mainly composed of plant materials, so the mineral profile of the mature product will also be well suited to making new plants. However, the nutriments are generally not present in a soluble form (with the exception of potassium), so the fertilizing effect is limited in the short term, although may be better exploited in the long term, when a steady-state is reached, with nutrients from previous applications being made available as new nutrients are brought to the soil with new compost, that will then in turn be made available in future years.
The alkaline minerals (Ca, Mg, etc.) contribute to the buffering capacity of compost, which is a valuable quality in farm soils. The humus enrichment also increase the cation-exchange capacity, which helps to retain nutriments in the soil in a form available to the plants. The effect of the compost nitrogen is particular: as is consist for more than 95% of organic N, whilst the short-term effect of the nitrogen is very limited.

Besides GHG savings related to reduced production and application of mineral fertilisers, other effects that could also exert an influence on GHG emissions should be investigated, such as the tendency of a slow-release source of N to increase (or decrease) the production of N_2O compared to the quickly available N in mineral fertilisers. This is also discussed in another article in this issue (ref).

5.3 Biological effects of compost organic matter

OM contains energy in different forms, which are each released and utilised differently. Easily degradable OM is attacked immediately by the soil organisms, since enough oxygen and micro-nutriments are generally available. Excess or lack of water can slow down the degradation. The catabolic and anabolic processes in the soil provide large amounts of energy for the organisms, which makes for a living soil. To avoid immobilising too much of the soil nitrogen during the degradation processes, the OM must either contain enough nitrogen itself or degradation should be postponed till a time when nitrogen will be present in excess in the soil (such as summer or fall). OM influences practically all the processes in the soil. Changes induced are site- and crop-specific and cannot be precisely quantified. However, if the soil is easier to cultivate, this is clearly beneficial and could procure GHG savings, in that less energy will be required to ensure a particular production level.

Direct effects on plants should also be considered. The effect of humus compounds on plants is not uniform: there are cases of clear stimulation of plant growth, but also others where no such effect was observed. Increased growth and yields may have beneficial climate-change implications, such as more crop residues being available for incorporation of C into soil, or less energy required for cropping at a same production level.

As for direct effects on microorganisms, compost is extremely rich microbiologically. Microorganisms influence each other, compete with each other, predate on one another or help each other, depending on the situation and the species involved. As they are mainly degradation specialists, compost microorganisms attack anything easily degradable that they find in the soil, including other microorganisms, and namely predate on those which are plant pests. This translates into a direct “suppressive effect” on plant diseases which is well known and has been demonstrated in many experimental trials. This, of course, results in a reduced use of pesticides and – besides other beneficial environmental effects – could reduce the total energy required by farming and the related GHG emissions.

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