

Klimatgaser och luktemissioner från kompostering.

Greenhouse gases and odour emissions from composting.

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Abstract

Composting is the most widely used biological treatment method for recovering the plant nutrients of organic waste. Composting is an aerobic process and it is well known that mismanagement, e.g. insufficient ventilation, can seriously affect the turnover and performance of the process. The turnover is also strongly inhibited if the operation temperature rises above 40°C before the pH has increased above 6. Such a combination of high temperature and low pH also seriously increases the odour emission potential of the compost operation as the initial high odorous stage is prolonged until the pH increases. When the pH increases beyond 6.5, the odour potential rapidly decreases. The pH development can be accelerated by good cooling and ventilation, and/or by addition of alkaline amendment, e.g. recycling of alkaline compost or addition of wood ash. When the compost is turned, the structure of the compost matrix, and thus the aeration, is improved which decreases odour generation and also the proportion of anaerobic processes and thus the emissions of methane.

Studies of food waste home composts show that these have a much higher moisture content (70-80%) compared to what is normally recommended for composting (40-65%). The common assumption has therefore been that methane emissions from home composts are greater than from large scale municipal composts. However, recent studies in both Sweden and Denmark show that the methane emissions from home composts usually are smaller than from large municipal composts. Furthermore, both studies indicate that the emissions seem to increase if the composts are frequently turned, quite contrary to what was expected. The emissions also seem to increase if the feeding is too high. This means that the capacity of the home compost should not be exceeded and that the efforts for its operation can be kept low, as turning does not seem to be an advantage, at least from the point of view of greenhouse gas emissions.

Key words

Compost, home compost, emissions, odour, greenhouse gas, methane, nitrous oxide

Introduction

Composting is one of the most widely used treatment methods for biological wastes, which also allows recovery of plant nutrients. Composting is an aerobic process that requires good aeration, and if it is mismanaged, the emissions of greenhouse gases (GHG) and of odorous substances can be high. When the ventilation is insufficient, both turnover and performance can be affected to a large extent as shown e.g. by Jiang et al. (2011) for in-vessel composting of pig faeces mixed with chopped corn-stalks. They showed that increased aeration reduced methane (CH₄) emissions, but increased ammonia (NH₃) and nitrous oxide (N₂O) emissions. They propose a moisture content of 65%, aeration rate of 0.48 L/(kg dm·min) and C:N ratio of 21 as optimal from GHG emission point of view. Karnchanawong et al. (2011) compared 6 different 200 L-bin designs with passive aeration observing decomposition rates and the quality of finished compost. The bin designs with holes around the bottom of container provided the highest decomposition rates, demonstrating the importance of aeration. Sundberg et al. (2011) demonstrated that the temperature, pH and aeration affect the production of volatile organic compounds (VOCs) and thus the odour potential, which is especially relevant during the initial stage of composting.

The objective of this paper is to describe how GHG emissions and odour of food and garden waste are affected by different process parameters, such as aeration, temperature, moisture, pH and the scale of the process (home compost or large scale facility). The data presented in this article are from both literature and our own experiments.

Influence of start-up process and pH on odour emissions

Problems with odour are often caused by the initial high rate stage of the composting process, which produces substances with high odour emission potential. The odour emission can be considerably increased if the process is non-optimal. A very common example of non-optimal process during the initial stage is when the temperature reaches high levels (above 40°C) while the pH still is low (below 6). During the initial high-intensity composting phase, large amounts of volatile organic compounds (VOCs) are produced (Komilis et al., 2004), mainly due to incomplete oxidation of the substrate due to oxygen deficiency (D'Imporzano et al., 2008). High concentrations of volatile organic acids and low pH of the compost substrate is one of the most common factors causing and prolonging the initial high odorous phase (Sundberg et al., 2009). When the temperature increases above 40°C before the pH increases above 6, the initial high odorous stage is prolonged for as long as the low pH condition maintained, which can be very long (Smårs et al., 2002, Sundberg et al., 2004, Sundberg et al., 2009). This has been shown to be common also for large scale composting (Sundberg and Jonsson, 2008, Sundberg et al., 2009). When the pH of the compost material increases beyond 6.5, a rapid decrease of the odour emission can be observed. The strong connection between pH and odour during the initial stage of the compost process is clearly shown by the data presented by Sundberg et al. (2011, 2009). The average odour concentration of the compost gas in composts with pH below 6.0 (mean pH 5.0) was 50-70 times higher than that of composts with pH above 6.5 (mean pH 8.0).

The pH increase is accelerated by good ventilation, addition of recycled alkaline compost and/or by other alkaline additives, e.g. wood ash (Sundberg and Jonsson, 2008, Sundberg et al., 2009). The importance of good aeration was demonstrated in a well controlled reactor compost trials (Smårs et al., 2001) where we compared the process development in food waste composting under similar conditions, except that the compost gas contained 16% oxygen in one treatment and 1% in the other. For both treatments the temperature was kept under 40°C during low pH phase. The pH in the condensate was used as indicator of the low pH stage. When this increased above 6, the temperature was allowed to increase to 55°C. For the 16% oxygen treatment, this condition was met after 2 days, while for the 1% oxygen treatment, it took 7 days. During this period, the odour concentration of the compost gas was 30-60 times higher than after the pH increase.

Turning the compost is important for improving the structure and thus the aeration, for breaking up anaerobic pockets and for reducing the generation of odorous substances. On the other hand, during the turning operation itself large volumes of trapped gases are released. This especially applies to the gas from the previously mentioned anaerobic pockets of the compost, which contains both odorous substances and greenhouse gases, which means that during the turning the odour emission can be high (Haug, 1993).

Influence of moisture, structure/mixing and aeration on process and GHG emissions

Moisture content can affect the process in many ways. First of all moisture provides the environment for microbial activity and low moisture can become a limiting factor for the aerobic degradation. On the other hand too high moisture can affect the aeration by filling up the available pores, thus creating pockets of oxygen deprived substrate and inducing production of methane. The upper limit of moisture content for a good process varies between different substrates, as it depends on structure of the compost mixture (Haug, 1993) and on its concentration of easily degradable organics. For a substrate consisting of source separated faeces, wood ash, food waste and sawdust, Niwagaba et al. (2009) found that when the initial moisture content was above 65% no good aerobic degradation process developed, which was shown e.g. by the process temperature reaching at the most 43°C. For a good process right from the start, the initial moisture content needed to be below 60%.

Beck-Friis et al. (2000) found that the methane emission from large (2-2.5 m high and 5-6 m wide) extensively managed (turning interval two to four weeks) compost windrows were much larger than from small (1.2 m high and 2 m wide) windrows managed more intensively (turning interval one to two weeks). The moisture of the large windrows was 48-63% and of the small 16-50%. While the methane concentration in the pore gas in the small heaps often was below the detection limit (0.0001% by volume), and the maximum level measured was 0.2% by volume. In the large windrows, all concentrations were above detection limit and, 30% of the measured concentrations were above 1% methane and 10% were above 10% methane (by volume). However, it is hard to establish which portion

of the methane production was due to high moisture and which portion was due to large windrows size and that they were turned seldom .

While the results by Niwagaba et al. (2009) indicate that the moisture is very important for the performance of the compost process, it is relevant to note that they worked with naturally ventilated compost reactors. While using 60 L-compost reactors, Jiang et al. (2011) found that increased aeration significantly decreased the emissions of methane, but at the same time significantly increased the emissions nitrous oxide and ammonia. Higher moisture concentration (75%) seemed to somewhat increase the methane emission as compared to lower moisture concentrations (65% and 70%), but the effect was not significant in this experiment where the reactors were ventilated by force. The fact that the type of aeration is important is supported by Brown et al. (2008), who compared different composting systems. In addition to the aeration system they also suggested that moisture in cooperation with bulk density may affect the emissions by promoting anaerobic processes.

Evidence that the emissions of methane normally are higher under conditions with low oxygen supply has been given by many, e.g. Zeman et al. (2002), Szanto et al. (2007) and Jiang et al. (Jiang et al., 2011). Zeman et al. (2002) reported the normal range of methane emissions to be between 1-4% of initial C. However, when the aeration is poor, emissions can be much higher. Szanto et al. (2007) reported 12.6% of initial VS degrading to methane in static piles and Beck-Friis et al. (2000) measured methane concentrations of up to 47% in the pore gas. Beck-Friis et al. (2003) and Jiang et al. (2011) have shown that the methane emissions decrease rapidly with increasing ventilation and oxygen supply. This supports the common recommendation that frequent, or at least regular, turning is important for keeping the methane emissions from large scale composts low (e.g. Beck-Friis et al., 2000). There are however some studies pointing in the other direction, e.g. the study of pilot scale manure composting by Ahn et al. (2011), which shows that the GHG emissions increased by 20% when the compost was turned as compared to when it was static.

Nitrous oxide is a potent GHG, with the global warming potential of 298 over 100 years (IPCC, 2007). Even though many authors agree that compost management is decisive to determinate the amount of emission (Hao, 2007, Szanto et al., 2007, de Guardia et al., 2010, Hellebrand and Kalk, 2000, Christensen et al., 2009), there is a difficulty to establish the variables that will be influencing the emissions the most. For instance during the initial phase of composting, Jarvis et al. (2009) suggests that oxygen limitation plays a big role. In their compost experiment they observed nitrous oxide peaks after 9 and 21 days of composting and they attributed those peaks to nitrification and denitrification processes respectively. Beck-Friis et al. (2003) establish that the mesophilic temperature during the initial phase of composting is beneficial for nitrous oxide formation and when thermophilic conditions are reached, the production decreases. In denitrification process, nitrous oxide is an intermediate product, which can be transformed to N_2 if the N_2O reductase is present in the microbial community and the pH levels are beneficial (pH 6.5 - 7) for its assembly and functioning (Bergaust et al., 2010). Jiang et al. (2011) suggest that a substantial release of N_2O happens after the turning operations due to the transfer of NO_2^-/NO_3^- from aerobic portion into the anoxic portion. They also suggest that higher aeration rates can increase the nitrification rate, producing both N_2O and higher concentrations of NO_2^-/NO_3^- in the material.

Nitrous oxide in maturation phase of composting can be expected due to both nitrification and denitrification processes, which is especially relevant for larger composts as oxygen gradient is formed within the material (Beck-Friis et al., 2000), temperatures are in mesophilic range and natural aeration is reducing. These conditions allow both nitrification and denitrification activities to continue.

Home composting - Influence of scale on methane emissions

The scale of the composting operations, when home composting is compared to centralized municipal composting, affects both the management and the emissions from the process. In large scale composting the outgoing compost gas is often treated by a biofilter, and sometimes by a more sophisticated type of filter, which should decrease the resulting emissions from the compost process. On the other hand, the smaller scale home composting means that the emissions from waste transport are eliminated and that the chance of the compost being put to good use are increased. Good use means that the finished compost actually replaces the use of mineral fertilizers and/or peat based soil improvers, which greatly improves composting with respect to its influence on the green-house effect.

Our recent study of food waste home composting (Ermolaev et al., 2011a) shows, just as a recent Danish study (Andersen et al., 2011), that the moisture content of the home composts in general is much higher (70-80%) than what is normally recommended for composting (40-65% moisture). The common assumption has therefore been that the methane emissions from home composts are greater than from large municipal composts. However, both our study of 18 home composts over a full year in Sweden (Ermolaev et al., 2011a) and the study in Denmark (Andersen et al., 2010a), show that the methane emissions from most home composts are smaller than from large, well-managed municipal composts (Ermolaev et al., 2011b, Andersen et al., 2010b). In this comparison it should be noted that the windrow compost measured by Andersen et al. (2010b) was a garden-waste compost, which due to better structure and lower concentration of easily degradable substrate, normally would be expected to emit less methane than a compost with food waste.

Both the Danish and the Swedish studies of home composts show that the methane emissions significantly increase with the frequency of turning and methane emissions were lowest from the units which were not turned at all (Andersen et al., 2010a, Ermolaev et al., 2011a). In the experiment by Andersen et al. (2010a) the feed to one of the home compost was tripled. This resulted not only in significantly increased direct emissions of both methane and nitrous oxide, but also when calculated as emissions per kilogram of substrate added. In the study by Ermolaev et al. (Ermolaev et al., 2011a), the increase of the methane emission with increased feeding was a tendency, but it was not statistically significant at the 5% level. However, in this study both increased temperature in the compost and increased moisture resulted in statistically significant increases in the methane emission. Also Chan et al. (2011) has shown that increasing temperature increases the emission of methane from home composts, but in their study the effect of moisture was not significant.

Total greenhouse effect of composting - influence of use

The total greenhouse effect of composting is very much influenced by how the compost is used. If the compost is used to substitute peat and/or mineral fertilizers, then this means that the greenhouse gas emissions from the production and use of the peat and mineral fertilizer products will be saved and these savings can be much larger than the direct emissions of greenhouse gases. Boldrin et al. (2009) have calculated that the direct greenhouse effect of composting is 3-242 kg CO₂-eq per ton wet weight (ww) of organic waste for open composting technologies and that the corresponding range is 5-81 and 77-220 kg CO₂-eq per ton ww for enclosed composting and home composting, respectively. The potential saving in greenhouse gas emissions by using the compost to replace mineral fertilizer or peat are ranging from saving emissions of 146 kg CO₂-eq per ton of ww organic waste composted, to an added emission of 17 kg CO₂-eq per ton ww, and from saving 880 kg CO₂-eq per ton ww, to an added emission of 44 kg CO₂-eq per ton ww, respectively. The large range for the substitutions is due to different types of waste yielding different amount of compost and that the peat substitution was assumed to be done on volume basis and the density of peat varies by a factor of five. These calculations show that, while it is important to have a good composting process, and good off-gas treatment to minimize greenhouse gas emissions, for the minimization of the total greenhouse gas effect it is even more important to use the compost in the best way. If the compost is used in soil mixtures, where it substitutes both peat and mineral fertilizers, more than 1000 kg CO₂-eq per ton ww of organic waste can be saved. On the other hand, if open composting is done and the compost is just disposed in such a way that neither its nutrients nor its organic matter is utilized, then the net greenhouse gas emission can be as high as 240 kg CO₂-eq per ton ww of organic waste.

Conclusions and recommendations

To minimize odour, it is important to quickly reach good composting conditions, which means a pH above 6.5. In food waste composting the incoming waste often has a pH of 5 and below. Under these conditions, it is important either to A) cool the compost sufficiently so that the temperature does not exceed 40°C until the pH has increased above 6.5, B) mix the substrate with ample amounts of alkaline compost recycle or C) mix with sufficient amounts of alkaline additive e.g. wood ash, so that proper composting conditions will be reached as quickly as possible. This will simultaneously minimize the odour.

To minimize methane emissions, in large scale composts it is important to ensure good aeration. This means that the compost should have a good structure and it is an advantage if it is force aer-

ated. It is also important that the compost substrate is not too wet, and in large scale composts it should preferably be below 60% moisture. Keeping below this moisture seems more important if the compost is naturally aerated than if it is force aerated.

The nitrous oxide emissions often increase after the initial high rate period, but they do not seem to have any clear relationship with the different process variables. To minimize the nitrous oxide emissions, the compost should not be allowed to mature more than necessary.

In home composts, the methane emissions increase with the frequency of turning and are lowest if the compost is not turned at all. Also for home composts, methane emissions will slightly decrease if the moisture decreases and it is an advantage if the compost is not allowed to mature more than necessary.

Most important for the total greenhouse effect of composting is how the finished compost is used. If the composting is well managed with appropriate technology and the compost substitutes both peat and mineral fertilizers then more than 1000 kg CO₂-eq can be saved by ton of wet organic waste composted. If, on the other hand, the compost is not used at all, then composting results in net emissions of up to about 240 kg CO₂-eq.

References

- AHN, H. K., MULBRY, W., WHITE, J. W. & KONDRAD, S. L. 2011. Pile mixing increases greenhouse gas emissions during composting of dairy manure. *Bioresource Technology*, 102, 2904-2909.
- ANDERSEN, J. K., BOLDRIN, A., CHRISTENSEN, T. H. & SCHEUTZ, C. 2010a. Greenhouse gas emissions from home composting of organic household waste. *Waste Management*, 30, 2475-2482.
- ANDERSEN, J. K., BOLDRIN, A., SAMUELSSON, J., CHRISTENSEN, T. H. & SCHEUTZ, C. 2010b. Quantification of Greenhouse Gas Emissions from Windrow Composting of Garden Waste. *J Environ Qual*, 39, 713-724.
- BECK-FRIIS, B., PELL, M., SONESSON, U., JÖNSSON, H. & KIRCHMANN, H. 2000. Formation and Emission of N₂O and CH₄ from Compost Heaps of Organic Household Waste. *Environmental Monitoring and Assessment*, 62, 317-331.
- BECK-FRIIS, B., SMÅRS, S., JÖNSSON, H., EKLIND, Y. & KIRCHMANN, H. 2003. Composting of source-separated household organics at different oxygen levels: Gaining an understanding of the emission dynamics. *Compost Science & Utilization*, 11, 41-50.
- BERGAUST, L., MAO, Y. J., BAKKEN, L. R. & FROSTEGARD, A. 2010. Denitrification Response Patterns during the Transition to Anoxic Respiration and Posttranscriptional Effects of Suboptimal pH on Nitrogen Oxide Reductase in *Paracoccus denitrificans*. *Applied and Environmental Microbiology*, 76, 6387-6396.
- BOLDRIN, A., ANDERSEN, J. K., MOLLER, J., CHRISTENSEN, T. H. & FAVOINO, E. 2009. Composting and compost utilization: accounting of greenhouse gases and global warming contributions. *Waste Management & Research*, 27, 800-812.
- BROWN, S., KRUGER, C. & SUBLER, S. 2008. Greenhouse Gas Balance for Composting Operations. *Journal of Environmental Quality*, 37, 1396-1410.
- CHAN, Y. C., SINHA, R. K. & WEIJIN, W. 2011. Emission of greenhouse gases from home aerobic composting, anaerobic digestion and vermicomposting of household wastes in Brisbane (Australia). *Waste Management & Research*, 29, 540-548.
- CHRISTENSEN, T. H., SIMION, F., TONINI, D. & MOLLER, J. 2009. Global warming factors modelled for 40 generic municipal waste management scenarios. *Waste Management & Research*, 27, 871-884.
- D'IMPORZANO, G., CRIVELLI, F. & ADANI, F. 2008. Biological compost stability influences odor molecules production measured by electronic nose during food-waste high-rate composting. *Science of The Total Environment*, 402, 278-284.
- DE GUARDIA, A., MALLARD, P., TEGLIA, C., MARIN, A., LE PAPE, C., LAUNAY, M., BENOIST, J. C. & PETIOT, C. 2010. Comparison of five organic wastes regarding their behaviour during composting: Part 2, nitrogen dynamic. *Waste Management*, 30, 415-425.
- ERMOLAEV, E., JOHANSSON, A., KEMPE, B., PELL, M., SUNDBERG, C. & JÖNSSON, H. 2011a. Greenhouse gas emissions from home composting in practice. Manuscript.

- ERMOLAEV, E., PELL, M., SMÅRS, S., SUNDBERG, C. & JÖNSSON, H. 2011b. Greenhouse gas emission from covered windrow composting with controlled ventilation. *Waste Management & Research*.
- HAO, X. 2007. Nitrate accumulation and greenhouse gas emissions during compost storage. *Nutrient Cycling in Agroecosystems*, 78, 189-195.
- HAUG, R. T. 1993. *The practical handbook of compost engineering*, Boca Raton, Lewis Publishers.
- HELLEBRAND, H. J. & KALK, W.-D. 2000. Emissions caused by manure composting. *Agrartechnische Forschung*, 6, E26-E31-E26-E31.
- IPCC 2007. *Climate change 2007 - the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC*, Cambridge University Press.
- JARVIS, A., SUNDBERG, C., MILENKOVSKI, S., PELL, M., SMARS, S., LINDGREN, P. E. & HALLIN, S. 2009. Activity and composition of ammonia oxidizing bacterial communities and emission dynamics of NH₃ and N₂O in a compost reactor treating organic household waste. *Journal of Applied Microbiology*, 106, 1502-1511.
- JIANG, T., SCHUCHARDT, F., LI, G., GUO, R. & ZHAO, Y. 2011. Effect of C/N ratio, aeration rate and moisture content on ammonia and greenhouse gas emission during the composting. *Journal of Environmental Sciences*, 23, 1754-1760.
- KARNCHANAWONG, S. & SURIYANON, N. 2011. Household organic waste composting using bins with different types of passive aeration. *Resources Conservation and Recycling*, 55, 548-553.
- KOMILIS, D. P., HAM, R. K. & PARK, J. K. 2004. Emission of volatile organic compounds during composting of municipal solid wastes. *Water Research*, 38, 1707-1714.
- NIWAGABA, C., NALUBEGA, M., VINNERAS, B., SUNDBERG, C. & JONSSON, H. 2009. Substrate composition and moisture in composting source-separated human faeces and food waste. *Environmental Technology*, 30, 487-497.
- SMÅRS, S., BECK-FRIIS, B., JÖNSSON, H. & KIRCHMANN, H. 2001. An advanced experimental composting reactor for systematic simulation studies. *Journal of Agricultural Engineering Research*, 78, 415-422.
- SMÅRS, S., GUSTAFSSON, L., BEEK-FRIIS, B. & JÖNSSON, H. 2002. Improvement of the composting time for household waste during an initial low pH phase by mesophilic temperature control. *Bioresource Technology*, 84, 237-241.
- SUNDBERG, C. & JONSSON, H. 2008. Higher pH and faster decomposition in biowaste composting by increased aeration. *Waste Management*, 28, 518-526.
- SUNDBERG, C., JÖNSSON, H., ROMANTSCHUK, M., ARNOLD, M., NORGAARD, E. & SMÅRS, S. 2009. Minimisation of odour from composting of food waste through process optimisation - A Nordic collaboration project. SLU Sveriges lantbruksuniversitet, Department of Energy and Technology.
- SUNDBERG, C., SMARS, S. & JONSSON, H. 2004. Low pH as an inhibiting factor in the transition from mesophilic to thermophilic phase in composting. *Bioresource Technology*, 95, 145-150.
- SUNDBERG, C., YU, D., FRANKE-WHITTLE, I., KAUPPI, S., SMÅRS, S., INSAM, H., ROMANTSHUK, M. & JÖNSSON, H. 2011. Organic acids increase odour from food waste composting. Manuscript.
- SZANTO, G. L., HAMELERS, H. V. M., RULKENS, W. H. & VEEKEN, A. H. M. 2007. NH₃, N₂O and CH₄ emissions during passively aerated composting of straw-rich pig manure. *Bioresource Technology*, 98, 2659-2670.
- ZEMAN, C., DEPKEN, D. & RICH, M. 2002. Research On How The Composting Process Impacts Greenhouse Gas Emissions and Global Warming. *Compost Science & Utilization*, 10, 72-86.