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Potential of Compost-Nitrogen to Improve Environmental Quality

I. Körner
Institute of Waste Resource Management, TUHH – Hamburg University of Technology, Hamburg, Germany

Abstract
The potential of a sensible N management during composting to improve environmental quality was investigated. The evaluation was based on results from 53 composting series, which covered a wide range of input materials and process regulation options. The amounts of N lost as ammonia in the experiments ranged from 0.0 to 1.3 % of the dry substrate. N-losses due to N_2 generation fell within the same range. N-emissions via leachate were of less importance. These N compounds including the N organically-bound in the compost are not or insufficiently used as a fertilizer today. Readily plant available nutrients are only in the inorganic N compounds. Ammonium/ammonia-N was contained in significant amounts almost in all samples. The content reached up to 1.8 % of the dry substance. Nitrate- and nitrite-N was detected more rarely and reached up to 0.75 % of the dry substance for nitrate-N and up to 0.18 % of the dry substance for nitrite-N. A calculation of the used and unused fertilizer potential will be presented for the German situation. The application of an N-optimized process regulation provides the potential of the additional use of up to 2/3 of the N contained in the waste.

1 Background
The global nitrogen (N) cycle is very labile. Additionally, the situation has worsened due to anthropogenic impacts. N compounds may be emitted from agriculture, animal husbandry and industry into the atmosphere, lithosphere and hydrosphere. For instance overfertilization may lead to ground water pollution; ammonia emissions from animal husbandry lead to atmospheric pollutions.

The main compounds of the global N-cycle are N_2, organic N, NH_3, NO_3^-, NO_2^- and N_2O. Transformations between these compounds appear in the different spheres.

The main pools of nitrogen can be found in the lithosphere, where they are contained mostly in rocks and stones, but also in soils and in sediments. In the atmosphere N is mostly contained as N_2. Quantitatively of less importance is the hydrospheric N, where it occurs in dissolved and particulate form (see Figure 1).

The biosphere belongs to all of the three spheres and covers living and dead organisms. Although the biospheric N pool is by far the smallest, it has the major

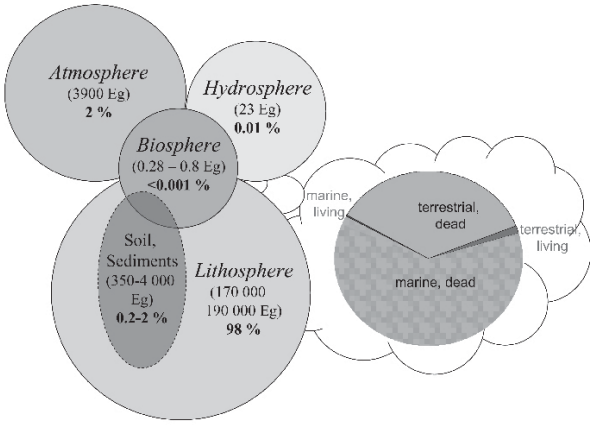


Fig. 1: Global N-Pools (Data from Tamm, 1991; Winstanley et al. 2007; diagram not to scale; 1 Eg = 10^{18} g)

impact on the global N cycle. The N in organic waste contributes significantly to the biospheric N. Therefore, the potential of a sensible N management during composting to improve environmental quality was investigated.

2 Material and Methods

In total, 53 composting series were carried out. The test set-up of the pilot plant with its 100 l-bioreactors as well as the measurement techniques used and the chemical analysis were described in detail in Körner et al. (2003). The treatment time of the composting series varied between 3 and 60 weeks, but mostly was in the range of 3 to 6 months. Real waste (biowaste, digestion residues, MSW, chicken manure, vegetable waste, sewage sludge; partly mixed with structural materials) and well defined model waste (consisting of 7-10 of the following components: apples, potatoes, turnips, wheat, peas, meat and bone meal, wood, bark, straw, leaves, grass, sand) was applied. The process control varied as far as aeration rates, temperature profiles, water contents, portions of structural material and pH values are concerned.

Within the experiments liquid, solid and gaseous samples were taken. The NH_3 contained in the exhaust air was collected via the condensed water and via an acidic scrubbing solution. The leachate was collected on demand and gaseous samples were taken 2-5 times a week. Substrate samples were taken during turning. To establish N-balances the following parameters were analysed in the different sample types:

- Organic N in the substrate (determined via the dried and powderized solid sample)
- NH_4^+/NH_3-N in the substrate (determined via the extract of the fresh solid sample)
- NO_3^--N in the substrate (determined via the extract of the fresh solid sample)
- NO_2^-- N in the substrate (determined via the extract of the fresh solid sample)
- NH_3-N in the exhaust air (determined via the condensed water and the acidic solution)
- N_2 and N_2O in the exhaust air (measured directly in the gaseous sample)
- Total N in the leachate (measured directly in the leachate sample)

The N balances were established in accordance with the method indicated in Körner and Stegmann (2002). The balances contained gaseous N-emissions, the N released via leachate, and the organic and inorganic N portion of the substrates. The measured N_2 concentrations in the exhaust gas were not used for balancing since the fresh air already contained 78,1 % by vol. of N_2. With the airflow and the N_2 measurement the relatively low changes could not be determined with sufficient accuracy. Furthermore the production of biogas by anaerobic processes inhibited the direct calculation of the generated N_2 on the base of the aeration rate. Due to these problems the N_2-generation during composting was calculated indirectly via the lack in the balances. N_2O emissions were not considered here since they were very seldom detected and in very low amounts. To evaluate the balances water content, pH value, temperature, organic content, bulk density and gas composition were measured in addition.

3 Results

The organic N-compounds of the initial waste were transformed and released during composting in variable ways. Nevertheless, the organic N still formed the largest N-pool in the compost. Inorganic N in form of NH_4^+/NH_3-N, NO_3^--N NO_2^--N was contained only in relatively small amounts. N-leaching was of minor importance compared to the N-emissions via exhaust gas. All emissions could occur in quantitative significant amounts, but in many of the experiments some of the paths were rather small or not existing (see Figures 2, 3, 4 and 5).

Figure 2 shows the N-contents of the substrates distinguished into the organic N and the different inorganic N compounds. In the graphs the N-content of samples taken at the begining, during and at the end of composting were considered. The boxes in the graphs mark the 25-75 % - quantile of the determined values, the circular marks show extreme values and eventually mavericks. The organic N content was mostly between 1.0 and 2.5 % DS, but ranged from 0.5 to 4.1 % DS. NH_4^+/NH_3-N could be measured in almost all samples. It was most often detected between 0.1 and 0.4 % DS. Commonly, the higher values were detected into

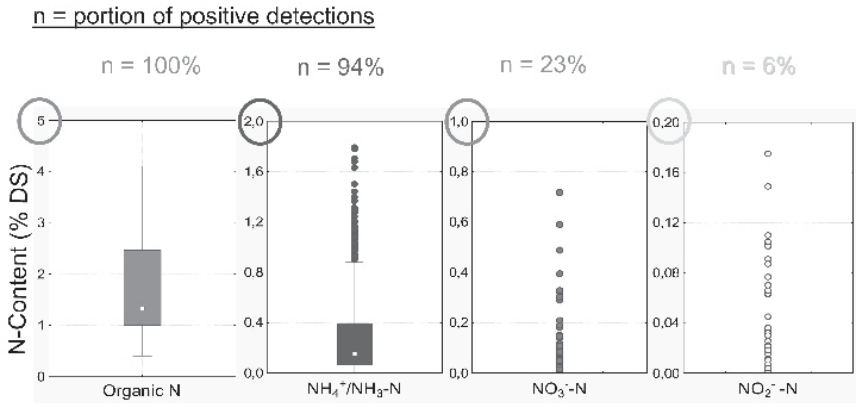


Fig. 2: Content of N compounds in the wastes and composts from 53 composting experiments.

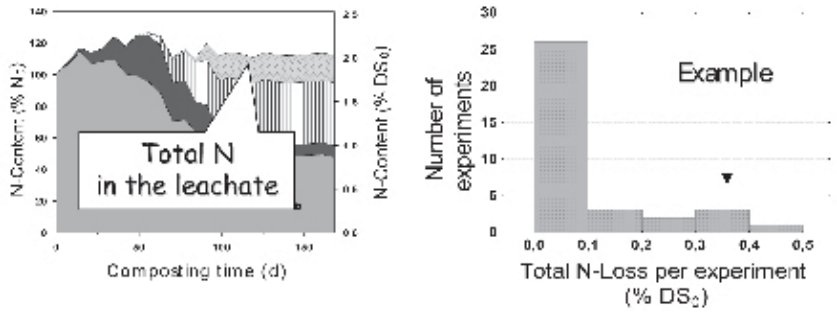


Fig. 3: Total N-losses via leachate: sample N-balance and summary of all experiments.

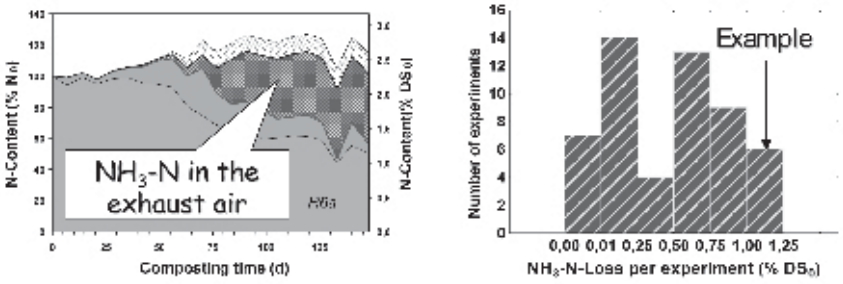


Fig. 4: Losses via NH_3-N: sample N-balance and summary of all experiments.

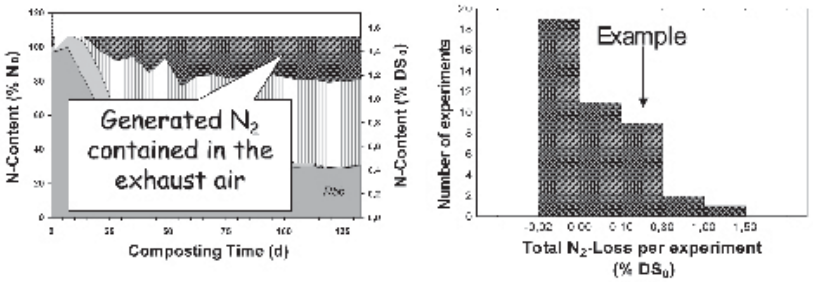


Fig. 5: Losses via generated N_2: exemplarily N-balance and summary of all experiments.

the thermophilic and partly into the cooling phase of the composting process. NO_3^--N and NO_2^--N was mostly not contained in the samples. Only 23 % of the measurement values for NO_3^--N and 6 % of the values for NO_2^--N gave positive detections. If detected, the generation of these compounds started earliest from the cooling phase of the composting process and may have reached up to the end of composting.

Figure 3 (left) shows a sample N-balance which includes a significant portion of N released via leachate. But leachate occurred only in 35 of 53 experiments. Therefore only in these experiments N-emissions via leachate could be detected. All leachates did contain N, but in different concentrations. The cumulative N-loss via leachate per series was given as a portion related to the initial dry substance (see Figure 3, right). Commonly it was not more than 0.1 % DS_0; but in some composting series it reached up to 0.3-0.5 % DS_0. The amount of the leached N was depending on the content of the soluble N compounds in the substrate as well as on the leachate volume. The N-leaching occurred mainly in the earlier phases of composting.

Figure 4 (left) shows a sample N-balance which includes a significant portion of NH_3-N released via the exhaust gas. NH_3-N emissions occurred in all 53 experiments. The cumulative amount of released NH_3-N is documented in Figure 4 (right) as a portion related to the initial dry substance for all experimental series. The range of NH_3-N emissions per experiment was very variable and could reach up to 1.25 % DS_0. Mostly it ranged between 0.01 and 0.75 % DS_0. The amount of emitted NH_3-N was mainly a function on the concentration of NH_4^+/NH_3-N in the substrate, but also depended on the substrate temperature and on the aeration rate. Compared to these influencing factors, pH was of less importance. The NH_3 losses mainly occurred during the thermophilic composting phase, but also low emissions occurred in the maturation phase.

Figure 5 (left) shows a sample N-balance which includes a significant lack. The lack of nitrogen was caused by the generation of N_2 during composting. The indi-

rectly determined total N_2-losses per series were given as a portion related to the initial dry substance too. In the evaluation the analytical error propagation and the inhomogeneous substrates was considered. Significant lacks were detected in 23 of 42 experiments (see Figure 5 , right). Eleven experiments could not be assessed due to the analytical error propagation and the inhomogeneous substrates. Eventually smaller lacks occurred also in some of the experiments belonging to the cluster –0.02 to 0.00 % DS_0. But they were not clearly verifiable in consequence of variations due to analytical error propagation and the inhomogeneous substrates. If a lack was clearly detectable, it occurred mostly in the range up to 0.3% DS_0 and was only seldom larger. The lack due to N_2 generation occurred partly from the cooling up to the curing stage.

4 Conclusions

Based on the N-balances the major processes of the N-cycle during composting could be summarized as shown in Figure 6. Initially N was mainly contained in the proteins in the waste. During composting, the proteins were transformed via ammonification into NH_4^+/ NH_3. NH_4^+ and NH_3 form an equilibrium depending on the pH and the temperature of the substrate. Only NH_3 may be released via the exhaust gas. NH_4^+/ NH_3 can also be leached or immobilized into humic substances or it can be transformed into NO_3^- via NO_2^- by nitrification. All inorganic N-compounds and partly the organic N compounds are water-soluble and therefore may be leached. NO_3^- and NO_2^- can also be transformed via denitrification into N_2, whereas N_2O may be an intermediate product seldom occurring.

The N-compounds shown in Figure 6 may have an impact on local, regional or global level. Local effects are given by the compost application on agricultural land. Only the inorganic compounds are directly usable as fertilizer. Organic N compounds are not directly available to plants and could only realize a limited, long term fertilization effect. The fertilizer value of the organic N is difficult to calculate, because organic N may get lost during application. Mineralisation processes in the soil can transform organic into inorganic N compounds. These can be emitted into the atmosphere or leached into ground water. They become distributed with the air or the water and therefore may have regional impacts.

Another source of regional pollution may be realized due to direct emissions of NH_3 from the composting facilities or from the application of compost on the land. The malodorous smell of NH_3 affects mostly the surrounding of the composting facility. But NH_3 as a gaseous compound may also be transported in the atmosphere. The deposition may occur at far away places and lead to over-fertilization. Forestry systems, for example, are very sensitive regarding N pollution. From global importance is mainly N_2O which contributes to the greenhouse effect and the destruction of the ozone layer. Although quantitatively not so important as direct emission from the composting facility, it may be generated after compost application or eventually may transformed from N-compounds emitted into the atmosphere during composting.

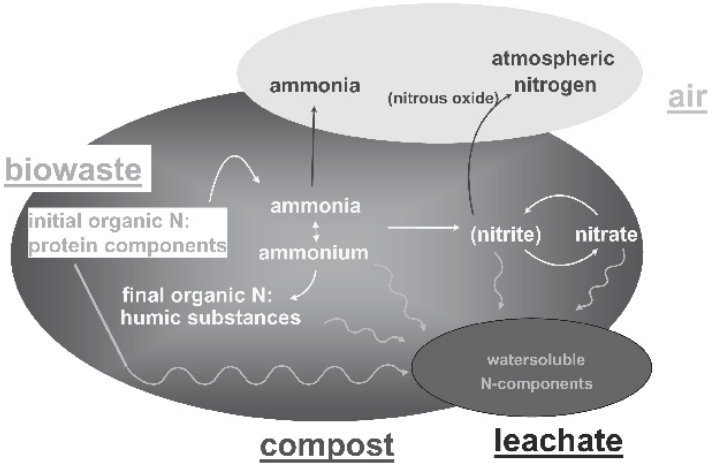


Fig. 6: Major compounds of the composting N-Cycle and their transformation possibilities.

CASE STUDY GERMANY:

Treated in composting facilities - 8 Mio. Mg wet organic waste/a
Estimated Fertilizer Price - 0.84 €/kg N

Calculations with mean values from the experiments

Not optimally used/unused N compounds:		Usable for fertilization:	
0.75 N_{org}	10.7 €/Mg compost	0.25 N_{org}	3.6 €/Mg compost
NH_3-N	4.0 €/Mg compost	NH_4^+/ NH_3-N	2.4 €/Mg compost
N_2	0.9 €/Mg compost	NO_3^--N	0.1 €/Mg compost
	15.6 €/Mg compost		6.1 €/Mg compost
	62 Mio. €/a		24 Mio. €/a

Fig. 7: Calculation of the value of not optimally or unused and the already used compost N

In conclusion, N emissions during composting and compost application may affect the environment negatively. On the other hand N is a valuable fertilizer. In Figure 7 was presented a sample calculation regarding the N value of the compost and the N potential which is still unused. The calculation was based on the German situation. The waste treated in German composting facilities was considered and a mass loss of 50 % during composting assumed. With the mean N-contents and N-emissions of the experiments the calculation presented in Figure 7 was carried out. It was assumed, that the inorganic N-compound can be completely used as fertilizer, the organic N-compounds only to 25 % and that the emitted N-compounds are completely lost. Figure 8 shows, that under today's situation less than a third of the N is used. The lost value was calculated with 62 Mio. €/a for Germany. Under the situation of increasing energy prices it can be expected, that the value of N will also increase in the future, since the mineral fertilizer production by the Haber-Bosch-Process is very energy intensive. But the potential for influencing the N content and composition in composts, as well as the N emissions into the environment, still is untapped. Significant improvements could result from adapting process regulation mechanisms. Tailor-made composts could improve soil quality and reduce atmospheric and hydrospheric pollution.

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