NUTRIENT TURNOVER AND LOSSES DURING COMPOSTING OF FARMYARD MANURE - RESULTS OF OUTDOOR EXPERIMENTS OVER 11 YEARS

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Abstract

This paper tries to quantify losses of dry matter and nutrients and to look for parameters relevant to the risk of losses. We used data from 14 outdoor experiments carried out in 11 years with cattle manure. Nitrogen (N) rich manures seem to be predestined to have high dry matter and N losses during composting. In cases of high temperatures in the thermophilic stage we also observed high dry matter losses, but not necessarily high N losses. This may be a hint that an intensive decomposition of organic matter is combined with a strong heat development. However, temperature level was independent from the original N content. K losses were not correlated with any of the investigated parameters, not even with water content. Composted manure was about 60% of the original dry matter (calculated by increase of ash content). However, nutrient losses were much lower. Compared to the original contents, approx. 33% N and 39 or 17% K (based on ash contents) have been lost during the entire period of up to 223 days.

Introduction

The reduction of nutrient losses during composting of farmyard manure or other organic materials to a tolerable, unavoidable extent makes sense for reasons of both agriculture (recycling of nutrients and organic matter) and environment (conservation of natural resources). It is impossible to push losses down to almost zero, as composting is a complex system of biological (mainly microbiological) processes, and each metabolic system, a microbe as well as a manure heap, is an open system which exchanges substances and energy with its environment. To reduce losses requires to know first, in which factors and processes losses originate, and how the relevant parameters can be influenced. This can be studied either in closed systems under controlled laboratory conditions or in outdoor experiments under practical conditions.

In this paper we used data from 11 years of outdoor experiments. We try to quantify losses of dry matter, nitrogen, potassium and phosphorus under such conditions, and we look for relevant parameters to predict the risk of losses. Finally, measures shall be discussed that can be taken against losses.

Methodology

In order to have composted manure for our long-term trials, since 1989 in each year between July and September, cattle manure has been stacked on heaps next to our experimental fields (590 mm precipitation per year, 9.5°C annual mean temperature). The manure was taken from organic or conventional farms with a deep-litter stable or a sloping floor straw yard system. Each heap was at least 2 tons fresh weight. The heaps were covered with straw from the beginning. After the thermophilic stage the heaps were covered with a plastic film to protect the material against precipitation. The composting procedure was basically the same in all years and series. The manure was composted until its application, partly in autumn (September or October) to winter crops, partly in spring (March) to spring crops. In each of the composting series (starting in summer, ending in next spring) at least 2 samples have been taken from the fresh manure and from each of the 1-2 heaps of composted manure in autumn and in spring to analyse dry matter (DM), ash, total nitrogen (N), ammonia ($NH4+$), nitrate ($NO3-$), potassium (K) and phosphorus (P). N, P and K contents have been calculated based on ash content in the material, supposing that this parameter is almost constant over time and therefore reliable to quantify the turnover process. Furthermore, total ash content was regarded as a suitable reference parameter, as the heaps have not been turned during composting (Raupp, 2002). Temperature in the centre of the heaps was measured repeatedly over the entire period.

Results are presented in two groups of composting series, altogether 14 experiments in 11 years between 1989 and 2003. No data could be used from 1991, 1992, 1996, 2001, because either no temperature data had been measured or the composting period was only some weeks long and, thus, not comparable to the other years. In 1998, 2000 and 2003 two series with different fresh manures have been set up. The first group of series consists of the years 1989-98, when the composting series fitted the described two-periods scheme: start in summer, first application in autum, second application in next spring. In 2000 the crop rotation of our long-term trial was changed with the consequence that from 2000 to 2003 only summer crops were cultivated. In these years the composting series built a second group that only comprises one period: starting in autumn and ending with manure application in next spring.

Where appropriate, analyses of variance were calculated using the programme PLABSTAT (H.F. Utz, Univ. of Hohenheim, Germany) setting the factor manure type (sampling date) as fixed and the factors year and heap as random. Dry matter loss has been calculated as amount of composted manure in percent of fresh manure with the term (1 : DM-dec) * 100. In this term DM-dec is the dry matter decrease calculated by its reciprocal phenomenon, i.e. the ash content increase expressed by ash content of compost (% DM) divided by ash content of fresh manure (% DM). Correlation coefficients *r* were calculated between the parameters DM, total N, P, K, temperature, DM loss, K loss, N loss and C:N.

Results and brief discussion

The temperature course in manure heaps usually is regarded as a simple indicator of the currently ongoing processes (Gray & Biddlestone, 1981). In our experiments two different temperature levels in the heaps could be distinguished (for reasons of limited space no figures are presented). We observed years with hot composting at a maximum of 60-70 °C (in 6 series), whereas in other years temperatures remained at a medium level below a maximum of 60, in some years even below 50 °C (in 4 series). The temperature course basically followed the well known pattern with a mesophilic stage at the beginning, a subsequent thermophilic stage and then a second mesophilic, cooling down stage.

Table 1: Contents of fresh and composted farmyard manure depending on time; mean values of 8 composting series in 7 years between 1989 and 1998; K = potassium, P = phosphorus; values with different letters are statistically different; p < 0.05)

	Fresh manure (in summer)	Composted manure in autumn (66days)	Composted manure in next spring (223 days)
Dry matter (% fresh matter)	23.8 b	25.2 c	21.6 a
Ash (% dry matter)	23.1 a	33.8 b	38.8 c
Compost in % fresh manure	100	67.2	58.8
Total N (% ash)	113.5 c	86.4 b	76.6 a
NH_4-N (mg g^{-1} ash)	20.00 b	1.94 a	1.05 a
NO_3-N (mg 100 g^{-1} ash)	11.8 a	66.6 b	300.6 c
K (mg g^{-1} ash)	138 c	112 b	84 a
P (mg g^{-1} ash)	25.8 a	37.5 b	25.3 a

Whereas dry matter content of the manures showed no clear reaction to composting, the ash content of the materials increased definitely over time, because of organic matter decay (Table 1 and 2). The first group of series showed that a large reduction to 67% of the original material already happened during the first period from summer to autumn (66 days on average of all series; Table 1). In spring after 223 days (on average) the rotted manure was 59% of the original material. We also observed a similar size of mass reduction in the second group of series (Table 2), where 60% of the fresh manure was left after 173 days. Comparing dry matter decomposition and temperature levels it can be stated that the period with the more intense decay also showed the higher temperature. N and K losses (based on ash contents) during the entire period were 32% and 39%, respectively, of the original contents. In the second group of series 33% of N, but only 17% of K have been lost (Table 2). A similar order of magnitude, even higher N losses in many cases, is reported from other investigations. For example, in controlled experiments with sheep manure N losses of 46% were found (Thomsen, 2000). P content remained fairly constant all the time. This proves that phosphorus (like ash content) can be considered as a suitable reference parameter for turnover rates and nutrient losses, as e.g. Petersen *et al.* (1998) recommended.

As expected NH_4-N decreased and NO_3-N increased during composting. In many cases nitrate was not at all detectable in fresh manure. As no ^{15}N-labelled materials were used, the fate of NH_4-N and NO_3-N during composting (nitrification, NH_3 losses, assimilation in biomass) is unclear.

Table 2: Contents of fresh and composted farmyard manure; mean values of 6 composting series in 4 years between 1999 and 2003; K = potassium, P = phosphorus; values with different letters are statistically different; $p < 0.05$)

	Fresh manure (in autumn)	Composted manure (in next spring, 173 days)
Dry matter (% fresh matter)	25.0 a	30.2 b
Ash (% dry matter)	16.5 a	27.9 b
Compost in % fresh manure	100	60.2
Total N (% ash)	128.1 b	85.5 a
NH_4-N (mg g^{-1} ash)	1526 b	111 a
NO_3-N (mg 100 g^{-1} ash)	6.8 a	118.7 b
K (mg g^{-1} ash)	118 b	98 a
P (mg g^{-1} ash)	29.3	27.6

Correlation coefficients have been calculated for selected parameters (Table 3), in order to evaluate possible relations, although it has to be taken into account that a correlation coefficient may give a hint that two facts occur at the same time, but it is no simple indication of a causal connection. In most cases N rich manures had also high P contents, whereas K content was independent from N and P. The N or P rich fresh manures had also high dry matter losses during composting. In cases of high N contents in the fresh manure high N losses have also been observed. No other parameter correlated with N losses. High dry matter losses also occurred in cases of high temperature in the thermophilic stage. This may be a hint that an intensive decomposition of organic matter is combined with an intensive heat development. However, temperature level was independent from the original N content. Hot composting seems to not necessarily be the consequence of a high N supply in the original material. High temperatures were also not correlated with the original humidity (dry matter content), and the original P and K contents. This is surprising, as soil microorganisms react markedly to P availability in soils. Correlation coefficients of C:N ratio give no further information that has not already be gained from the parameter total N.

K losses were not correlated with any of the investigated parameters, not even with water content. It could be assumed that a wet fresh manure will lead to more seepage combined with K losses. However, in our experiments the range of water content in the fresh manures probably was not large enough to play a role.

Table 3: Correlation coefficients *r* between parameters of fresh manure (total nitrogen = N_t, dry matter = DM, phosphorus = P, potassium = K), the maximum temperature in the thermophilic stage (T-max), dry matter losses (DM-l), potassium and nitrogen losses (K-l and N-l) at the end of the composting period and C:N ratio at the beginning; $n = 13$, $p < 0.05$*, $p < 0.01$**

	N_t	DM	P	K	T-max	DM-l	K-l	N-l
DM	-0.467							
P	0.688**	-0.412						
K	0.137	0.42	0.226					
T-max	-0.216	0.219	0.399	0.519				
DM-l	0.730**	-0.351	0.681*	0.319	0.778**			
K-l	0.195	-0.322	-0.113	-0.093	0.177	0.313		
N-l	0.646*	-0.353	0.055	-0.107	-0.615	0.31	0.215	
C:N	-0.946**	0.422	-0.588*	-0.295	0.215	-0.823**	-0.254	-0.624*

Conclusions

Among all investigated parameters, only the original N content was correlated with N losses. This parameter, if any, seems to be suitable to predict the risk of N losses. Therefore, to balance the C:N ratio is sometimes recommended. Gray and Biddlestone (1981) consider a C:N ratio of 30:1 to 35:1 to be optimal. However, these values may only be used as a rough target, as N losses depend upon further circumstances. Moreover, the type of C-rich material used as bedding has an influence on the amount of N losses (Kirchmann, 1985).

The relatively low K losses achieved in our experiments are probably due to the rainproof covering on the heaps by plastic film after the thermophilic stage.

Further experiments should aim at clarifying which factors and interactions are responsible for the temperature level. Although not being significant in our experiments, temperature level seems to have an influence on N turnover.

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