We are IntechOpen,
the world's leading publisher of Open Access books
Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Nitratation Promotion Process for Reducing Nitrogen Losses by N$_2$O/NO Emissions in the Composting of Livestock Manure

Yasuyuki Fukumoto
Institute of Livestock and Grassland Science,
National Agriculture and Food Research Organization (NARO)
Japan

1. Introduction

The livestock industry already has a large impact on the environment by contributing to desertification, eutrophication, global warming, acidic rain, and so on (Dodd, 1994; Isermann, 1990; Pearson and Stewart, 1993; Steinfeld and Wassenaar, 2007). However, it has been predicted that the global demand for livestock products, such as milk, meat and eggs, will increase because of the growing human population and urbanization. Therefore, for having a sustainable livestock production, it is important to remove environmentally harmful factors from the livestock industry's activities as much as possible.

Animal manure is one of the important contributing factors affecting environmental issues that are caused by livestock activity. Livestock animals excrete huge amounts of manure. For example, a milk cow 600 kg in body weight excretes approximately 18,000 kg of manure, while she produces 7,600 kg of milk during one lactation period. Therefore, livestock production is regarded as an industry with more waste than product. In Japan, approximately 90 Tg of livestock manure is generated annually, which accounts for one-quarter of the nation's total organic waste (Ministry of Agriculture, Forestry and Fisheries 2008). Modern livestock production systems integrate numerous livestock animals in a limited area to take advantage of the efficiency of a small scale operation, and to utilize scientific nutrition and management techniques. However, in such a production system, a huge amount of manure is concentrated in the same area, which leads to serious environmental problems such as diffusion of offensive odor and contamination of underground water if the manure is handled in improper ways (Criado, 1996; Rappert and Muller, 2005). Therefore, proper treatment or handling of manure is important for an environmentally sound livestock production system.

Composting is one of the principal treatment methods of organic waste such as livestock manure. The objectives of composting are to stabilize the biodegradable organic matter in raw wastes, to reduce offensive odors, to kill weed seeds and pathogenic organisms, and finally, to produce a uniform organic fertilizer suitable for land application (Haga et al. 1998). Controlled conditions are important for composting, so as to distinguish it from other natural biological decomposition processes such as rotting and putrefaction (Haga, 1990). After composting, the handling of livestock manure is improved, making it possible to

distribute the manure from a limited to a wider area. Therefore, local pollution by livestock manure can be avoided. Moreover, the construction of a sustainable agricultural system is expected to be achieved by enhancing the circulation between the livestock industry and field husbandry via compost of livestock manure.

It is important to improve composting techniques because substantial amounts of harmful gaseous compounds are emitted during the composting process (Fukumoto et al. 2003; Kuroda et al. 1996; Smet et al. 1999). Because of its high nitrogen contents, nitrogenous emission is substantial in livestock manure composting. Those nitrogenous emissions cause not only serious environmental risks, but also a decline in the compost's value as a fertilizer. Ammonia (NH_3) is one of the common nitrogenous emissions, which becomes a main cause of odor coming from the livestock industry (McGinn and Janzen, 1998). Moreover, NH_3 can be the cause of more extensive environmental pollution such as acid rain (Pearson and Stewart, 1993). Due to its high impact on the regional environment, there have been numerous attempts to reduce NH_3 emission from the composting process (Burrows, 2006; Kuroda et al. 2004; la Pagans et al. 2005; Lin, 2008; Yasuda et al. 2009).

Nitrous oxide (N_2O) is also one of the nitrogenous emissions arising from livestock manure composting (Beck-Friis et al. 2001; Czepiel et al. 1996; Osada et al. 2000; Sommer, 2001; Zeman et al. 2002). N_2O is an important greenhouse gas, having a 296-fold stronger effect than carbon dioxide (IPCC, 2007). Additionally, a recent study disclosed that N_2O has now become the largest ozone-depleting substance, surpassing chlorofluorocarbons (Ravishankara et al. 2009). Agriculture is the largest source of anthropogenic N_2O emission (Oenema et al. 2005). Livestock activities in particular contribute to almost two-thirds of all anthropogenic N_2O emissions, and 75-80 percent of agricultural emissions, which are mainly caused by manure (FAO, 2006). However, as of now, the numbers of countermeasures to reduce N_2O emissions from composting are quite few compared with those established for NH_3 emission.

This chapter presents recent knowledge of N_2O reduction from the composting process. The technique developed for reducing N_2O emission is termed the nitratation promotion process. The author will explain effects of the nitratation promotion process on N_2O/NO emissions and nitrogen conservation during swine manure composting. Moreover, the collaboration effect of nitrogen conservation with another countermeasure for reducing NH_3 emission, and the possibility of an adaptation of the nitratation promotion process to other kinds of livestock manure (cattle and poultry) will also be discussed.

2. Abreviations

AOB: Ammonia-oxidizing bacteria
NOB: Nitrite-oxidizing bacteria
AOA: Ammonia-oxidizing archaea
TN: Total nitrogen
DM: Dry matter
WM: Wet matter
OM: Organic matter
NH_3: Ammonia
N_2O: Nitrous oxide
NO: Nitric oxide
NIPRO: Nitratation promotion

MAP: Magnesium ammonium phosphate (struvite)
AGP: Ammonium generation potential

3. N$_2$O emission from composting

Nitrous oxide is generated via both nitrification and denitrification processes as intermediate products or by-products during the composting process (Fig. 1).
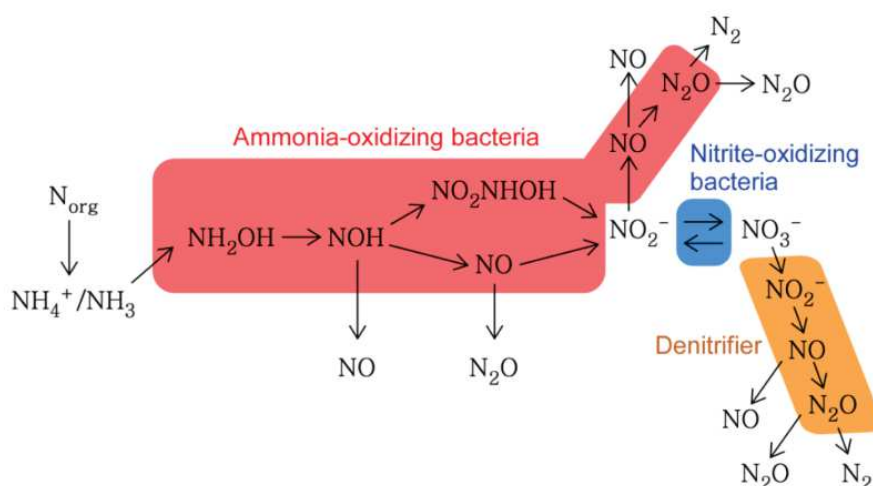

Fig. 1. Transformation of inorganic nitrogen compounds in the composting process

Nitrification is performed by different groups of microbes. Ammonia-oxidizing bacteria (AOB) converts NH$_3$ into nitrite (NO$_2^-$) (this reaction is called nitritation), and nitrite-oxidizing bacteria (NOB) converts NO$_2^-$ into nitrate (NO$_3^-$) (this reaction is called nitratation). Additionally, ammonia-oxidizing archaea (AOA) is thought to have important role in the oxidization of ammonia under various conditions, such as soil, sediments, and seawater (Francis et al. 2005; He et al. 2007; Leininger et al. 2006; Tourna et al. 2011; Wuchter et al. 2006). However, the evidence that AOA activity takes place in the composting process has not yet been confirmed (Maeda et al. 2010b). Nitrification is a prerequisite for N$_2$O generation from stored manure because little nitrate nitrogen is contained in the manure immediately after excretion. Nitrate produced by nitrification has an opportunity to transfer to an anaerobic portion by disturbance of compost pile (turning). The nitrate is then reduced into dinitrogen gas (N$_2$) via N$_2$O by denitrifiers. Inside the compost pile, both aerobic/anaerobic portions coexist, which makes it difficult to estimate the respective contributions of nitrification and denitrification in actual N$_2$O emissions from composting (Maeda et al. 2011).

It is known that there are several factors affecting N$_2$O emission from composting, such as moisture content, amount of mixed bedding material, frequency of pile turning, compost pile scale, and so on (Beck-Friis et al. 2001; Fukumoto et al. 2003; Parkinson et al. 2004; Szanto et al. 2007). It is thought that these factors influence the N$_2$O generation pathway directly or indirectly. As a result, the amount of N$_2$O emitted from the composting would be decided by a synthetic influence of those factors. Therefore, reduction of gas emission by control of these factors is thought possible if there is a factor largely responsible for gas generation. The relative contributions of nitrification and denitrification to N$_2$O emission do not become an important issue in the development of countermeasures, because N$_2$O can be

reduced by controlling such factors, whether the factor induces N_2O generation via nitrification or denitrification. The more important issue is to find such a factor during the treatment process. However, when considering how to magnify the adaptable range of a countermeasure, clarifying the mechanism of the N_2O generation would be an important issue that also has large scientific interest.

4. Effect of nitrite accumulation on N_2O emission

One important factor for N_2O emission from the composting is that NO_2^- can be easily found. He et al. (2001) showed that the amount of N_2O emission from food waste composting had increased when NO_2^- was accumulated. Moreover, a good NO_2^- − N_2O correlation has been confirmed under various environmental conditions. Nitrite is an intermediate product of the nitrification process. Generally, NO_2^- is scarcely observed in the natural environment because nitrite oxidizers, such as *Nitrobacter* and *Nitrospira*, oxidize NO_2^- to NO_3^- immediately. However, it is also a fact that NO_2^- accumulation is observed under several environmental conditions (Burns et al. 1996; Corriveau et al. 2010; Silva et al. 2011).

In swine manure composting, notable N_2O emission begins after the thermophilic phase, because nitrifying bacteria cannot be active under thermophilic conditions, such as high temperature, high free ammonia and high organic matter content. After N_2O emission starts, it tends to continue for a long time during the maturation phase of swine manure composting. It has been confirmed that NO_2^- accumulates in the composting material during this period of N_2O emission. Because of the long duration of N_2O emission in the maturation phase, the amount of N_2O emission induced by NO_2^- accumulation accounts for a large portion of the total N_2O emission in swine manure composting. Nitrite accumulation in swine manure composting is due to an inadequate nitrification process, i.e., the growth of indigenous NOB is inhibited while indigenous AOB is active immediately after the thermophlic phase, leading to a lower oxidization rate of NO_2^-. In this case, NO_2^- can be regarded as a critical factor of N_2O generation. Therefore, it is possible to develop a countermeasure for reducing N_2O emission by the regulation of NO_2^- during the composting process.

Two ways of avoiding NO_2^- accumulation can be considered. One method is to use a reagent of nitrification inhibitor, such as nitrapyrin. Its effect as a nitrification inhibitor that reduces N_2O emission from soil has been confirmed in numerous studies (Bhatia et al. 2010; Dittert et al. 2001; Zaman and Blennerhassett, 2010). However, to our knowledge, there have been no studies investigating the effect of nitrification inhibitors on N_2O emission during the composting process. Probably, disadvantages, such as ammonia accumulation and increasing treatment cost, would make it difficult to use in actual practice.

Another way to reduce NO_2^- is to enhance NO_2^- oxidization, i.e., nitratation promotion. It is thought that the nitratation function is hurt or reduced when NO_2^- accumulates during nitrification. Therefore, for nitratation promotion, recovery of the nitratation function is necessary. In swine manure composting, the growth of NOB is inhibited, causing NO_2^- accumulation. There are two ways to recover the NOB growth. One way is to control the environment so that the composting material is suitable for NOB growth, e.g., decreasing the level of free ammonia. On the other hand, a bioremediational technique of adding NOB is also an effective candidate for the recovery of NOB growth. In fact, controlling the compost to be suitable for NOB growth is difficult. Therefore, the authors tried to develop a

countermeasure reducing N$_2$O emission by the addition of a NOB source during composting.

5. Nitratation promotion process

In the first study conducted for reducing N$_2$O emission from swine manure composting, effects from the addition of a NOB source on NO$_2^-$ accumulation, and the state of nitrifying bacteria and N$_2$O emission have been investigated using a laboratory-scale apparatus (Fukumoto et al. 2006).

5.1 Materials and methods

Two kinds of NOB sources were used. One was incubated mature swine compost, in which NOB had been concentrated at a high density by an incubation process (NOB density: 10^{11} cell/g). The other NOB source was normal mature swine compost (NOB density: 10^6 cell/g). These materials were added to the composting swine manure after the thermophilic phase because NOB activity is strongly restricted under high temperature conditions. Gas emission was monitored continuously using an infrared photoacoustic detector.

5.2 Results and discussion

After the addition of an NOB source to the composting swine manure, the establishment of an NOB population at the cell density of 10^5-10^7 cell/g in the composting material was confirmed, while the absence of NOB continued for 5-6 weeks after the start of AOB growth in the composting bin without the addition of NOB (control) (Fig. 2).
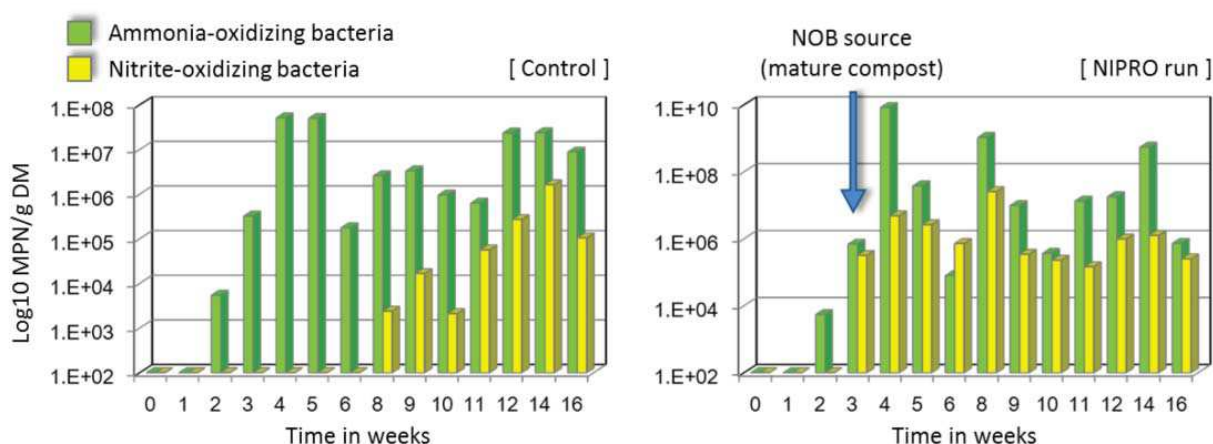

Fig. 2. Changes in the cell number of nitrifying bacteria during swine manure composting. Arrow indicates addition of NOB source of mature swine compost

Because NOB was absent, NO$_2^-$ accumulated for a long duration in the control (precisely, the absence of NOB resulted in the cell number of NOB being under the detection limit of 10^2 cell/g). On the other hand, a prolonged NO$_2^-$ accumulation was not observed in the composting with an NOB source addition (Fig. 3).

Moreover, the effect on NO$_2^-$ avoidance was also obtained by the addition of normal mature compost, which meant that no specific treatment, such as incubation of NOB, was necessary

for preparation of the NOB source. The required cell number of NOB for the oxidation of NO_2^- to NO_3^- seems to be more than 10^5 cell/g compost. Blouin et al. (1990) showed a similar result regarding the required cell number for complete NO_2^- oxidization in swine manure. However, because the population size of NOB grows after a source addition, it is not always necessary for NOB to exceed 10^5 cells per gram compost at the time of the NOB source addition. The pattern of N_2O emission from swine manure composting agreed well with changes in the NO_2^- concentration (Fig. 4).
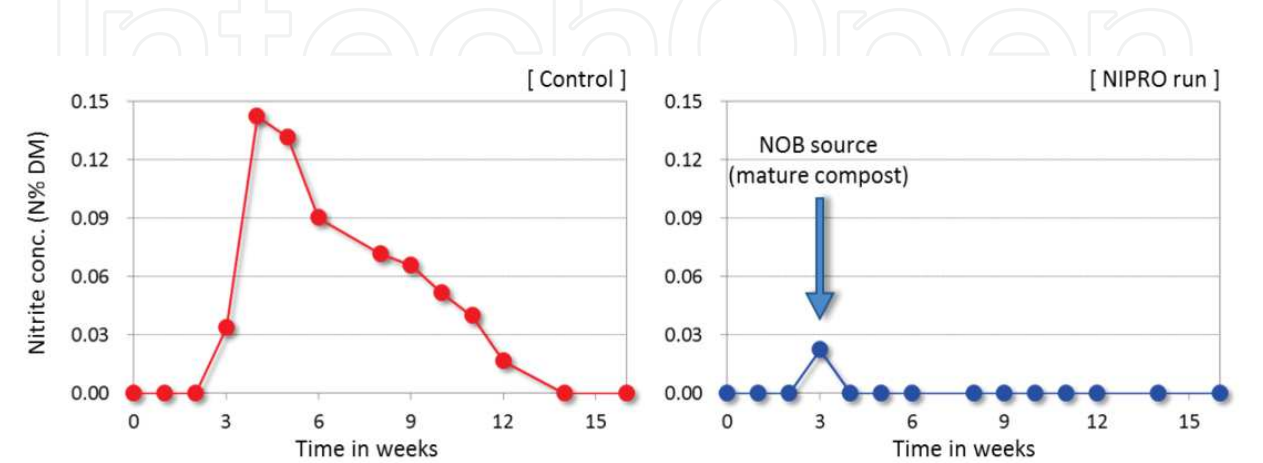

Fig. 3. Changes in concentration of nitrite nitrogen during swine manure composting. Arrow indicates addition of NOB source of mature swine compost
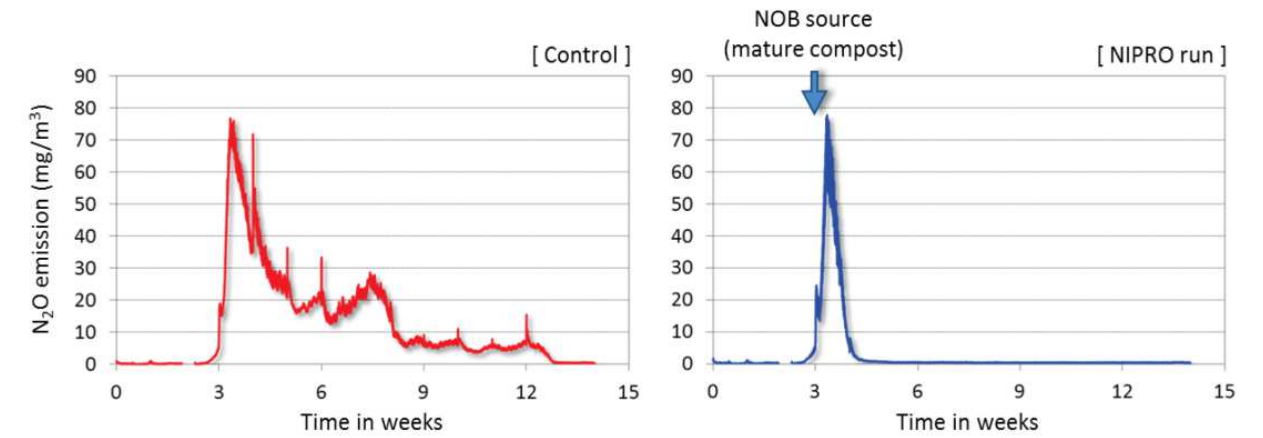

Fig. 4. Emission patterns of N_2O during swine manure composting. Arrow indicates addition of NOB source of mature swine compost

Therefore, the duration of NO_2^- accumulation affects the amount of N_2O emission. In the normal composting (control), the N_2O emission continued until NO_2^- disappeared. As a consequence, the amount of N_2O emission throughout the composting became large (N_2O emission rate: 88.5 g N_2O-N/kg $TN_{initial}$). On the other hand, because of its shortened duration of NO_2^- accumulation, the amount of N_2O emission was reduced in the compost with an NOB source addition (N_2O emission rate: 17.5-20.2 g N_2O-N/kg $TN_{initial}$). The rate of N_2O emission decrease by the addition of an NOB source was calculated as 77-80% in this study (Table 1).

	Total emission, mg N	Emission rate, g N/kg $TN_{initial}$
Control	**10,351**	**88.5**
MSC addition	**2,046**	**17.5**
***cul*-MSC addition**	**2,362**	**20.2**

$TN_{initial}$, initial total nitrogen; MSC, mature swine compost; *cul*-MSC, cultured MSC.

Table 1. Total N_2O emission and its emission rate during swine manure composting

Summarizing our published and unpublished data from the laboratory-scale composting experiments, the average decrease in the rate of N_2O emission by the addition of an NOB source during swine manure composting was calculated to be 60%, and, therefore, this technique appeared to allow a quantitative reduction of N_2O emission in the composting process. The schematic of this technique (nitratation promotion (NIPRO) process) is shown in Fig. 5.
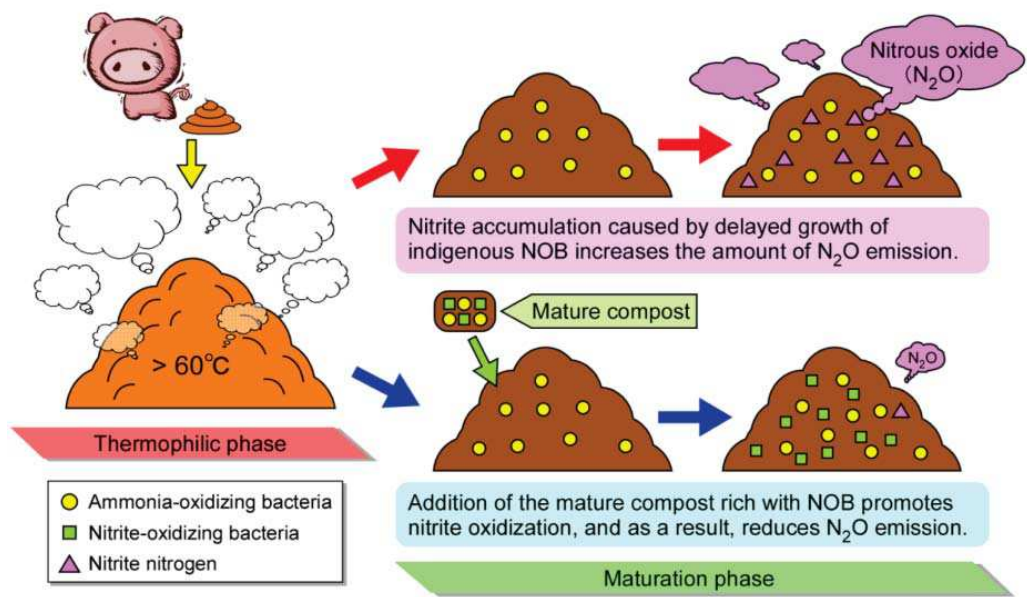

Fig. 5. Schematic of nitratation promotion process for reducing N_2O emission during composting

6. Nitrogen conservation

The nitrogen that had avoided being lost as an N_2O emission by applying the NIPRO process seemed to be preserved in the form of nitrate nitrogen in the compost product. Fig. 6 shows the changes in the NH_4^+, NO_2^- and NO_3^- contents during swine manure composting. During the thermophilic phase (0-3 week), NH_4^+ accounted for most of the inorganic nitrogen. After the start of nitrification, NO_2^-/NO_3^- nitrogen began to increase, while NH_4^+ declined. However, a remarkable difference in NO_3^- increase between the two treatments was observed. In the composting without an NOB addition (control), NO_3^- content increased slowly. In particular, the rate of NO_3^- increase became slower during NO_2^- accumulation. On

the other hand, NO_3^- in the composting with the NIPRO process increased quickly after the addition of an NOB source, and then it reached a concentration in the final product higher than that of the control. Therefore, it was hypothesized that the NIPRO process contributes to nitrogen conservation.
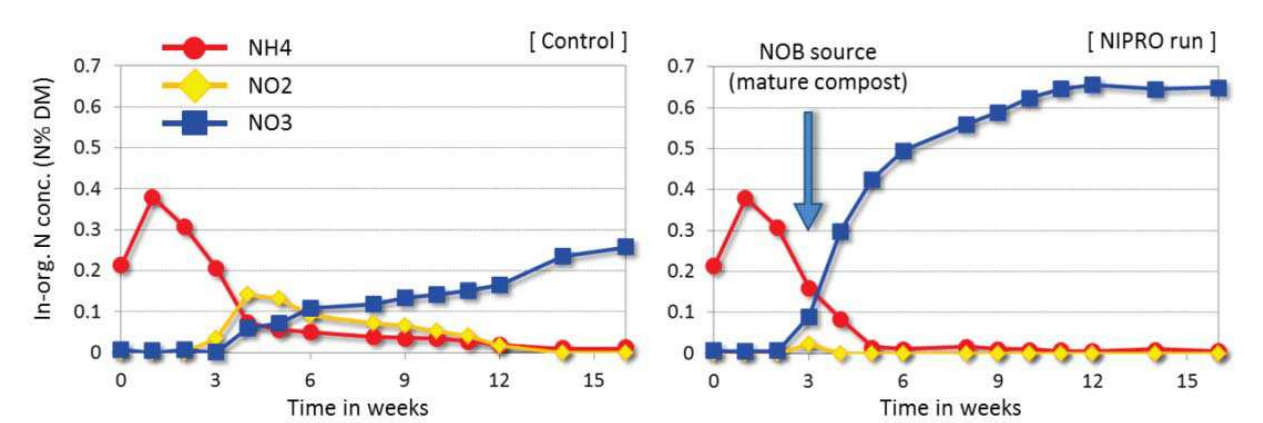

Fig. 6. Changes in concentration of inorganic nitrogen compounds during swine manure composting. Arrow indicates addition of NOB source of mature swine compost

To quantify the effect of the NIPRO process on nitrogen conservation, a nitrogen balance in swine manure composting was investigated (Fukumoto and Inubushi, 2009).

6.1 Materials and methods
Fresh swine manure was mixed with sawdust to make it suitable for aerobic decomposition. Sixteen kilograms of mixture as wet matter (WM) was piled inside a laboratory-scale apparatus. In the NIPRO run, 500 g WM of mature swine compost was added at turning on day 18 to avoid decreasing the number of NOB added at high temperature.

6.2 Results and discussion
In this composting experiment, the amount of N_2O emission was reduced by 70% by applying the NIPRO process, while there was little difference in NH_3 emission (Fig. 7).
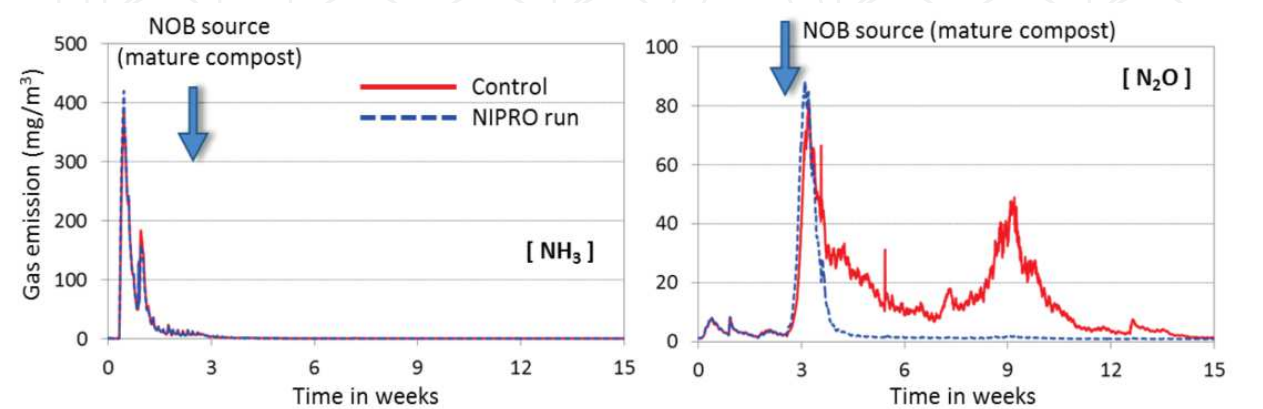

Fig. 7. Emission patterns of NH_3 and N_2O during swine manure composting. Arrow indicates addition of NOB source of mature swine compost

At the start of this composting experiment, approximately 130 g of nitrogen was contained in the initial compost pile of 16 kg (WM). The total mass of nitrogen emitted as N_2O in the control and the NIPRO run were 12.3 g and 4.0 g, respectively, and the amount of NH_3-N emission, which occurred mostly in the thermophilic phase, was 13.0 g in both runs. Therefore, the amounts of nitrogen loss by NH_3 and N_2O emission in the control and the NIPRO run were calculated as 25.2 g and 16.9 g, respectively. However, total nitrogen loss in the control and the NIPRO run were 36.8 g and 17.6 g, respectively (Fig. 8). Nitrogen loss mainly occurred after the thermophilic phase, with the exception of NH_3 and N_2O, and its magnitude became very small in the NIPRO run process that prevented prolonged NO_2^- accumulation. Therefore, it is considered that the unexplained nitrogen loss is expanded by NO_2^- accumulation during the composting, and that the effect of the NIPRO process on nitrogen conservation has a possibility to become larger than expected.

When the composition of nitrogen components in the final compost product between the control and the NIPRO run was compared, the organic nitrogen content made little difference between the runs, but NO_3^- nitrogen, which is a fast release fertilizer, increased greatly in the NIPRO run (Table 2).

Run	Elapsed time (d)	FW (kg)	MC (%)	Nitrogen compounds (gN/kg DM)			
				TN	NH_4^+	NO_2^-	NO_3^-
Control	0	16.00	64.6	23.4	2.0	0.0	0.1
	110	7.77	53.2	24.0	0.1	0.0	1.5
NIPRO	0	16.00	64.6	23.4	2.0	0.0	0.1
	110	8.04	51.3	28.6	0.1	0.0	4.3

FW, fresh weight; MC, moisture content; DM, dry matter; TN, total nitrogen.

Table 2. Properties of initial/final compost material in the swine manure composting

Kester et al. (1997) reported that higher NO_2^- concentrations enhanced both N_2O and nitric oxide (NO) emissions in the continuous cultures of nitrifiers and denitrifiers. Therefore, the emission of NO was measured during swine manure composting to clarify the components of the unknown nitrogen emissions. As a result of the measurement, it was revealed that significant NO emission begins after the thermophilic phase and is enhanced by NO_2^- accumulation during the composting, as with N_2O. Therefore, NO emission will also be reduced by applying the NIPRO (Fig. 9). However, the portion of NO emission from the total nitrogen loss tended to be small compared with NH_3 and N_2O emissions, even in the control, especially when the moisture content of the composting material was high. In one example, the level of nitrogen loss as an NO emission was only one-tenth the magnitude of the N_2O emission in our composting experiment. However, there was also a case in which the amount of NO emission had become half of the N_2O emission under comparatively dry conditions (Fukumoto et al. 2011a). It is known that moisture content is an important factor related to NO emission (del Prado et al. 2006), and these results seemed to have reflected it. Information concerning NO emissions from composting is limited (Hao and Chang, 2001), though it exerts a strong impact on chemical and physical processes in the atmosphere.

Therefore, further research is warranted to assess the environmental risk caused by NO emission from livestock activity.
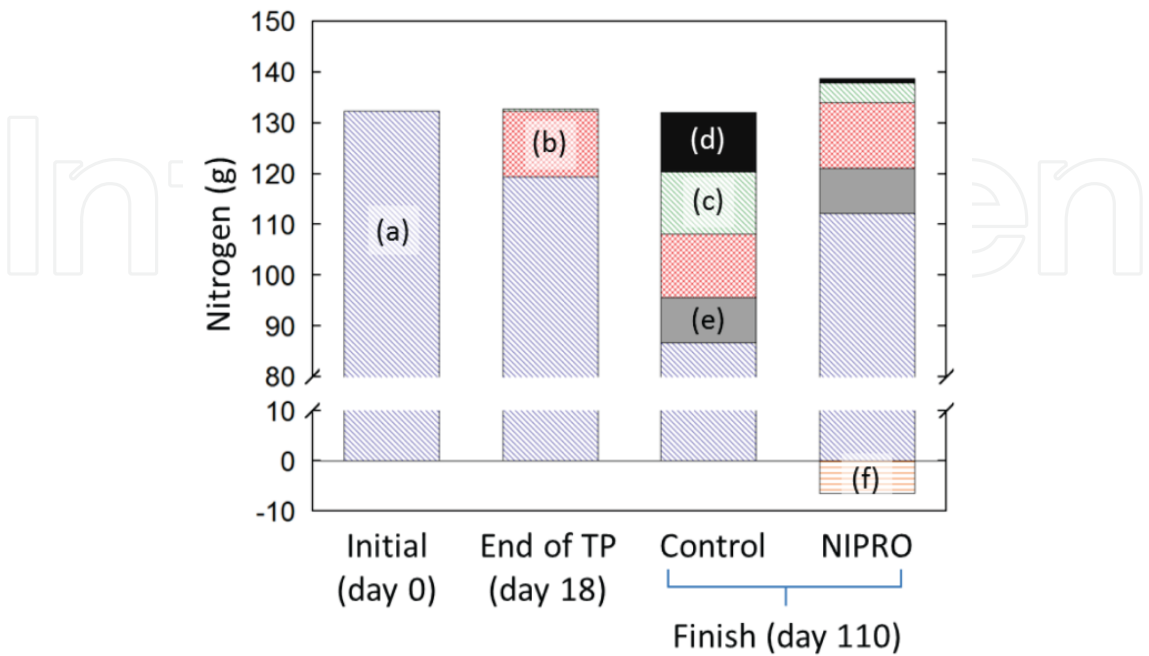

Fig. 8. Nitrogen mass balance over 110 days of swine manure composting. TP, thermophilic phase of composting; (a), N in the compost material; (b), N loss as NH$_3$ emission; (c), N loss as N$_2$O emission; (d), N loss as other emissions; (e), N loss as sample; (f), N in the added MSC for NIPRO process
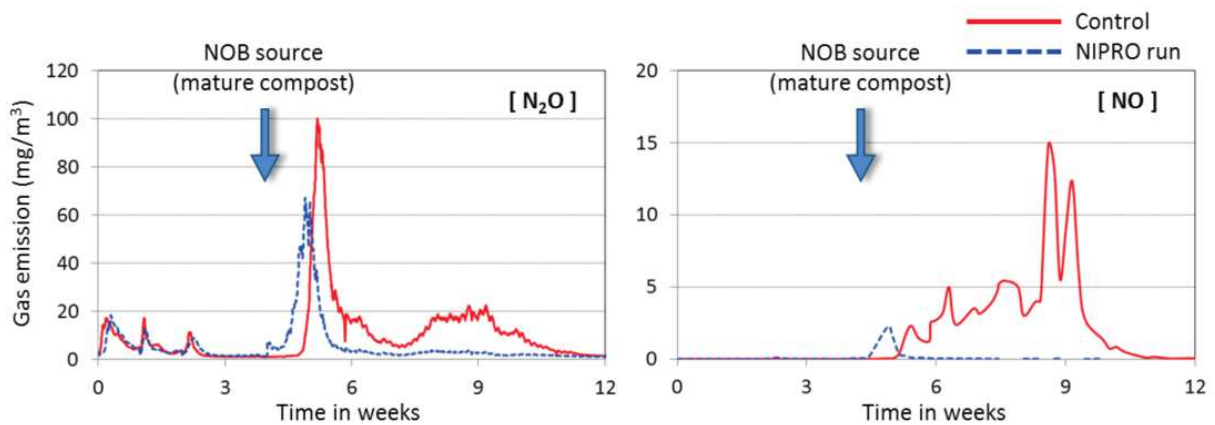

Fig. 9. Emission patterns of N$_2$O and NO during swine manure composting. Arrow indicates addition of NOB source of mature swine compost

7. Collaboration with struvite crystallization

Ammonia emission during the thermophilic phase is thought to be a principal cause of nitrogen loss during composting, though N$_2$O, NO, and other emissions during the maturation phase have an important role in nitrogen loss. Therefore, reducing NH$_3$ emission

is necessary for nitrogen conservation in composting. Recently, struvite crystallization has been considered to be one effective countermeasure for reducing NH_3 emission (Jeong and Kim, 2001). Struvite is crystallized magnesium ammonium phosphate (MAP, $MgNH_4PO_4 \bullet 6H_2O$), which is formed according to the following equation:

$$HPO_4^{2-} + NH_4^+ + Mg^{2+} + OH^- + 6H_2O \rightarrow MgNH_4PO_4 \bullet 6H_2O \text{ (Struvite)} + H_2O$$
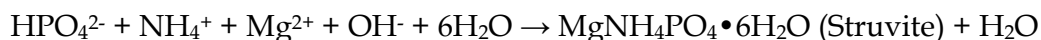
In the composting process, struvite crystallization used for reducing NH_3 emission is prompted by the addition of magnesium (Mg) and phosphate (PO_4) salts. The struvite crystallization reaction is accelerated when the pH is between 8 and 9. During the thermophilic phase, the pH of composting material generally rises to over 8 by the increase of NH_4^+ nitrogen, which is generated by the decomposition of organic nitrogen. Therefore, the adjustment of pH is not necessary. The effect of struvite crystallization on reducing NH_3 emission has been confirmed in the composting of food waste, and of poultry and swine manure. Struvite is a valuable slow-release fertilizer. The ingredients of struvite are released under acidic conditions. Nitrate nitrogen that is generally contained in mature compost is a fast-release type fertilizer; therefore, the struvite crystallization is thought to add a new and different value to the compost product, as well as reducing environmental risks. As reported in several papers, the reagent addition of struvite crystallization has a negative effect on the composting microorganisms decomposing in organic matter. Therefore, there is a possibility that nitratation promotion would be affected by the reagent addition of struvite crystallization in the case that these two countermeasures are applied simultaneously.

7.1 Materials and methods

To quantify the combined effect of struvite crystallization (MAP) and the NIPRO process on the reduction of nitrogenous emissions, laboratory- and mid-scale composting experiments of swine manure were conducted (Fukumoto et al. 2011a). The dose of Mg and PO_4 sources is an important issue related to struvite crystallization in composting (Jeong and Hwang, 2005; Lee et al. 2009). A higher dose of Mg and PO_4 could reduce the amount of nitrogen loss; however, there would be adverse effects on the decomposing organic matter and treatment costs would be increased. In our study, the respective doses of Mg and P placed into 0.045 and 0.030 mol/kg of raw feces was decided according to our past study, considering the balance of three factors (N conservation, degradation of organic matter and cost). The reagents for struvite crystallization were added at the start of composting, and then the mature swine compost (NOB source) was added after the thermophilic phase for nitratation promotion.

7.2 Results and discussion

By the addition of Mg and PO_4 salts, the amount of NH_3 emission could be reduced by 25-43% compared with the control. To confirm the struvite formation, the amount of nitrogen fixed in struvite crystals was measured according to the procedure of Tanahashi et al. (2010). As the result of these analyses, the amount of struvite nitrogen contents in the final product of sole struvite crystallization treatment became larger than those in the control. Therefore, it was confirmed that struvite crystallization had been enhanced by the addition of reagents during swine manure composting. However, in the treatment of two combined

countermeasures (MAP and NIPRO), the struvite nitrogen content had become lower than those in the control despite the addition of Mg and PO_4 salts. To evaluate the effect reagent addition has on struvite crystallization, changes in the struvite nitrogen content were investigated. During the thermophilic phase (0-28 days), the struvite nitrogen content in the treatment of two combined countermeasures had changed more than those in the control, which indicated that the struvite crystallization was enhanced by the addition of reagents. However, after the addition of mature swine compost for nitratation promotion, the struvite nitrogen content was suddenly decreased, and became lower than that of the control. During the thermophilic phase, the material pH rose to over 8 due to the high NH_4^+ contents. However, the material pH generally declined due to the start of nitrification. Particularly, because more NO_3^- nitrogen is accumulated in the compost product by the NIPRO process, the material pH tended to become lower than what was found in normal composting. Due to the lower pH, the struvite crystals formed during the thermophilic phase are considered to have been dissolved again during the maturation phase (Fig. 10).
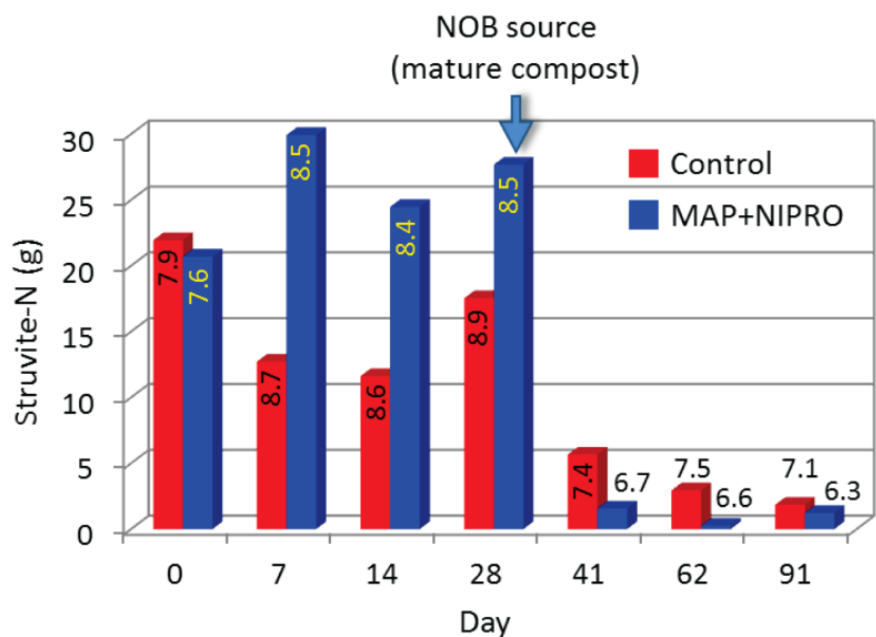

Fig. 10. Changes in the struvite nitrogen content during swine manure composting. Arrow indicates addition of NOB source of mature swine compost. Numbers on bars show the material pH

On the other hand, the effect of struvite crystallization on reducing N_2O emission was small (decreasing rate of N_2O was 10%). When the NIPRO process was applied simultaneously, the amount of N_2O emission could be reduced by 52-80%. However, the struvite crystallization showed a reducing effect on NO and other nitrogenous emissions during the maturation phase, as well as the NIPRO process. Conserving nitrogen in the form of struvite crystals has a benefit for stable nitrogen conservation because microbes cannot use the nitrogen in the struvite before it is dissolved. Therefore, it is considered that the struvite crystallization had a reduction effect on nitrogen losses during the maturation phase (Fig. 11).

The amount of total nitrogen loss was reduced by 60% by applying the two combined countermeasures, opposed to 50% by the struvite crystallization alone. No adverse effects from adding reagents to the growth of NOB were observed. However, the NIPRO process dissolved struvite crystals due to a decline in pH. Therefore, the effectiveness of struvite as a slow-release fertilizer cannot be expected when the struvite crystallization is applied with the NIPRO process.
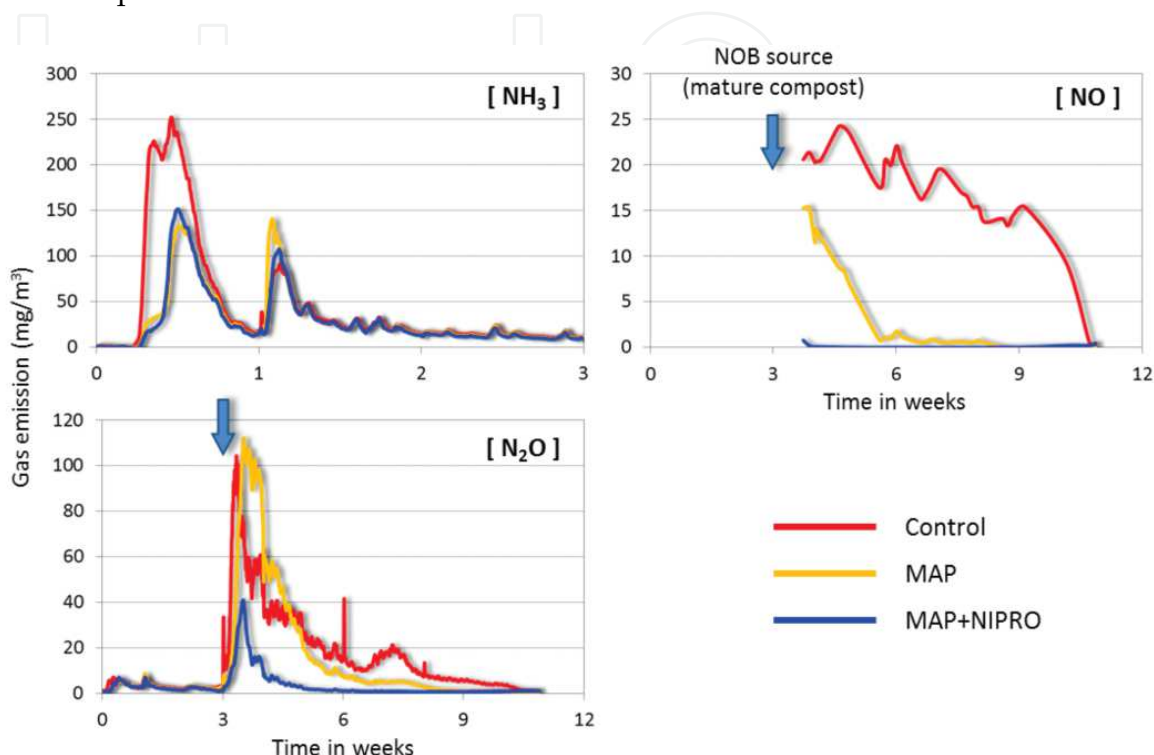
Fig. 11. Patterns of NH$_3$, N$_2$O and NO emissions during swine manure composting. Arrows indicate addition of NOB source of mature swine compost

8. Cattle and poultry manure composting

In the sections above, all composting experiments were conducted using swine manure. This is because swine manure has a natural property that is suitable for applying the NIPRO process. A precondition for showing the maximum effect of the NIPRO process is that N$_2$O induced by NO$_2^-$ accumulation contributes to a large portion of its total emission. In swine manure composting, because the decreasing rate of N$_2$O emission by applying the NIPRO process is comparatively high (average decreasing rate is 60%), the portion of N$_2$O induced by NO$_2^-$ accumulation is considered to be large. However, such information is inapplicable in the composting of cattle and poultry manure. Thereupon, to inspect the adaptability of the NIPRO process, composting experiments of cattle and poultry manure, and incubation tests for the quantification of ammonium generation potential (AGP) in respective animal manure, were conducted (Fukumoto et al. 2011b).

8.1 Materials and methods
In composting experiment of cattle manure, the house-shaped dynamic chamber system, which was constructed in a former study (Fukumoto et al. 2011a), was used. On the other

hand, the laboratory-scale composting apparatus was used for poultry manure composting.

To estimate the maximum ammonium generation potential (AGP), incubation tests of respective livestock manure were conducted. The mixed solution of fresh manure (3-5% w/v) and nitrification inhibitor was agitated continuously at 25°C in the dark, and the concentration of NH_4^+-N in the solution was periodically measured until the rising curve became a plateau. The AGP was calculated as the amount of generated NH_4^+-N per gram of organic matter

8.2 Results and discussion

In cattle manure composting, the trends of nitrogen transition and N_2O emission were different from those of swine manure composting (Fig. 12). Most N_2O in cattle manure composting tends to be generated in the thermophilic phase, whereas it occurs in the maturation phase in swine manure composting. Similar results of N_2O emission in cattle manure composting were also observed in other studies (Maeda et al. 2010a; Maeda et al. 2010b). Moreover, the delayed growth of indigenous NOB, which is a cause of prolonged NO_2^- accumulation in swine manure composting, was not observed in cattle manure composting. Therefore, it is considered that the activity of nitrification, which becomes the starting point of N_2O generation from livestock manure, is high even during the thermophilic phase in cattle manure composting. The level of NH_4^+-N in cattle manure is usually lower than that of swine manure, which also indicates that the inhibitory effect of free ammonia on nitrification is low. A high NH_4^+-N level is thought to be one of the causes of delayed growth of indigenous NOB in swine manure composting. The quick recovery of indigenous NOB, i.e., complete nitrification, in cattle manure composting seems to be due to the lower influence of inhibitors, such as free ammonia. Therefore, the prolonged NO_2^- accumulation after the start of nitrification did not occur in cattle manure composting, which indicates that the NIPRO process may be not suitable for cattle manure composting.
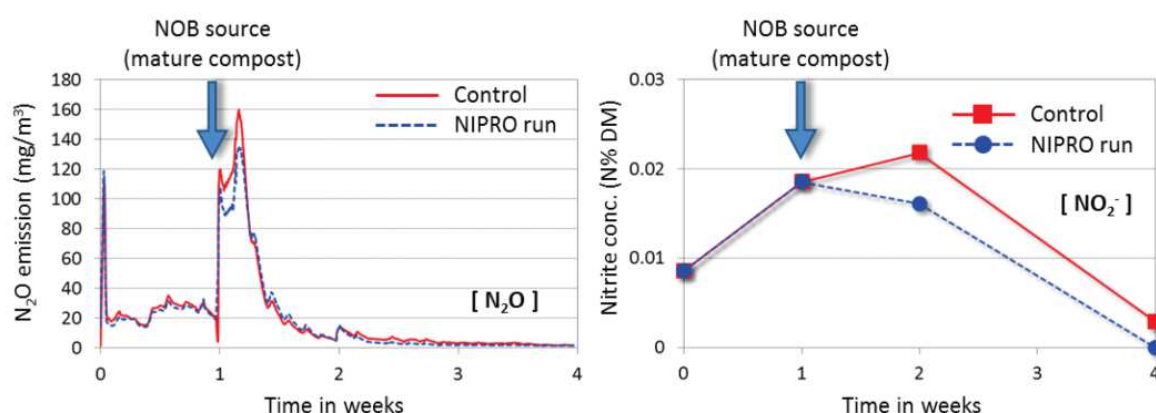

Fig. 12. Emission patterns of N_2O and changes in the concentration of nitrite nitrogen during cattle manure composting. Arrow indicates addition of NOB source of mature bovine compost

With the poultry manure composting, no obvious nitrification activity could be observed even in the long maturation phase (over 300 days). The excretion mechanism of poultry is

different from other livestock animals. The bird excretes urine together with feces in the form of uric acid, making nitrogen content in the manure extremely high. Therefore, it is considered that nitrification was completely inhibited by a high concentration of free ammonia in poultry manure composting. In fact, any growth of nitrifiers was not observed in this study, except for some temporary detections of AOB. Because nitrification could not be initiated, no significant N_2O emissions were confirmed. Therefore, it is considered that the NIPRO process, which reduces the amount of N_2O generated via inadequate nitrification, has no positive effect on poultry manure composting.

These three kinds of livestock manure each showed characteristic nitrogen transitions and N_2O emission patterns. It is considered that the respective unique nitrogen turnover of each livestock depends on the amount of active nitrogen generated via decomposition of manure. Therefore, as one of the factors affecting nitrogen turnover, the AGP of fresh livestock manure was investigated (Fig. 13).
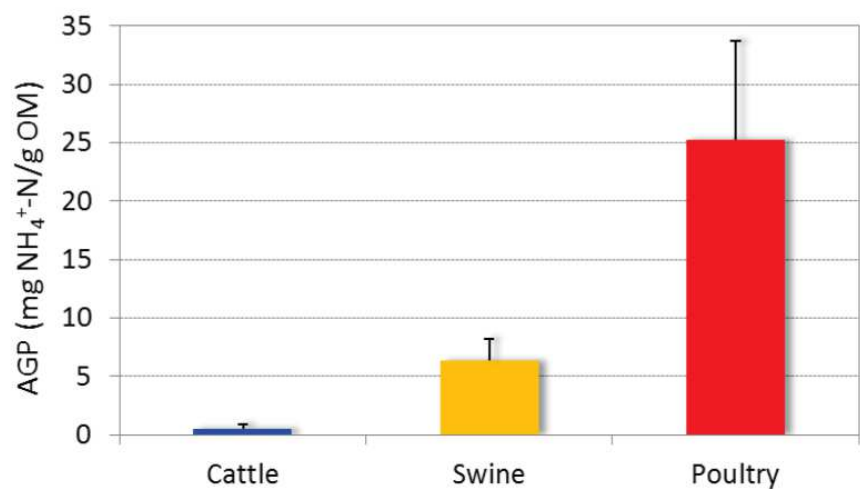

Fig. 13. Ammonium generation potential (AGP) of cattle, swine and poultry manure. OM, organic matter. Error bars indicate standard deviation

From the results of the incubation tests, poultry manure showed the highest AGP value among the three kinds of manure, as expected. On the other hand, the lowest AGP value was observed in cattle manure, which was approximately one-fiftieth the value of poultry manure. Swine manure showed an intermediate value between cattle and poultry manure.

The AGP value is thought to affect nitrification. In poultry manure composting, large amounts of ammonium are generated, which inhibits the activity of nitrification completely (Anthonisen et al. 1976). On the other hand, because of the low AGP, the effect of inhibitory factors, such as free ammonia, would be small in cattle manure composting, which would lead to the quick recovery of complete nitrification. Therefore, in cattle or poultry manure composting, it is thought that prolonged NO_2^- accumulation scarcely occurs, although when it does, it is for completely different reasons. This indicates that the quantity of N_2O emission induced by NO_2^- accumulation is small. Therefore, the effect of the NIPRO process on reducing N_2O emission would be slight in cattle and poultry manure composting. On the other hand, the level of AGP in swine manure might be suitable for NO_2^- accumulation. That is, it is considered that the AGP of this level does not inhibit the activity of the first half of

nitrification (i.e., nitritation), but would have a serious influence on the latter half of nitrification (i.e., nitratation) because the tolerance of NOB on inhibition factors, such as free ammonia, is lower than that of AOB. It is thought that the AGP would become one of the decisive materials when choosing to apply the NIPRO process to the composting of organic wastes.

9. Conclusions

The present report showed the effect of the nitratation promotion (NIPRO) process on nitrogenous emissions during the composting of livestock manure. The NIPRO process can reduce the nitrogenous emissions induced by NO_2^- accumulation by the addition of an NOB source such as mature compost. In swine manure composting, a remarkable reducing effect on N_2O, NO and other nitrogenous emissions (probably N_2) by applying the NIPRO process, was confirmed. As a result, more nitrogen could be preserved in the final compost product in the form of NO_3^- nitrogen, which is expected to improve the compost's value as a fertilizer. Moreover, the NIPRO process can collaborate with the struvite crystallization which reduces NH_3 emission in the thermophilic phase. However, it was revealed that struvite crystals formed during the thermophilic phase have been dissolved during the maturation phase due to a pH decline induced by NO_3^- accumulation in the case applying the NIPRO process. In cattle or poultry manure composting, it seemed to be difficult to apply the NIPRO process for reducing nitrogen losses, because prolonged NO_2^- accumulation would be difficult to maintain in those manure composts. Before putting these findings to practical use, however, some issues still remain. For instance, how to decide the timing of NOB addition, and how to evaluate effects and outcomes in an actual case. Therefore, further study is indeed necessary.

10. Acknowledgement

11. References

Anthonisen, A.C., Loehr, R.C., Prakasam, T.B.S. & Srinath, E.G. (1976). Inhibition of nitrification by ammonia and nitrous-acid. *Journal Water Pollution Control Federation*, 48, 835-852.

Beck-Friis, B., Smårs, S., Jönsson, H. & Kirchmann, H. (2001). Gaseous emissions of carbon dioxide, ammonia and nitrous oxide from organic household waste in a compost reactor under different temperature regimes. *Journal of Agricultural Engineering Research*, 78, 423-430.

Bhatia, A., Sasmal, S., Jain, N., Pathak, H., Kumar, R. & Singh, A. (2010). Mitigating nitrous oxide emission from soil under conventional and no-tillage in wheat using nitrification inhibitors. *Agriculture Ecosystems & Environment*, 136, 247-253.

Blouin, M., Bisaillon, J.-G., Beaudet, R. & Ishaque, M. (1990). Nitrification of swine waste. *Canadian Journal of Microbiology*, 36, 273-278.

Burns, L.C., Stevens, R.J. & Laughlin, R.J. (1996). Production of nitrite in soil by simultaneous nitrification and denitrification. *Soil Biology & Biochemistry*, 28, 609-616.

Burrows, S. (2006). The chemistry of mushroom composts. II.-Nitrogen changes during the composting and cropping processes. *Journal of the Science of Food and Agriculture*, 2, 403-410.

Corriveau, J., van Bochove, E., Savard, M.M., Cluis, D. & Paradis, D. (2010). Occurrence of high in-stream nitrite levels in a temperate region agricultural watershed. *Water Air and Soil Pollution*, 206, 335-347.

Criado, S.R. (1996). Considerations on main factors which take part in nitrate contamination of ground water in Spain with relationship to other EU countries. *Fertilizer Research*, 43, 203-207.

Czepiel, P., Douglas, E., Harriss, R. & Crill, P. (1996). Measurements of N₂O from composted organic wastes. *Environmental Science & Technology*, 30, 2519-2525.

del Prado, A., Merino, P., Estavillo, J.M., Pinto, M. & Gonzalez-Murua, C. (2006). N₂O and NO emissions from different N sources and under a range of soil water contents. *Nutrient Cycling in Agroecosystems*, 74, 229-243.

Dittert, K., Bol, R., King, R., Chadwick, D. & Hatch, D. (2001). Use of a novel nitrification inhibitor to reduce nitrous oxide emission from N-15-labelled dairy slurry injected into soil. *Rapid Communications in Mass Spectrometry*, 15, 1291-1296.

Dodd, J.L. (1994). Desertification and degradation in sub-Saharan Africa - the role of livestock. *Bioscience*, 44, 28-34.

FAO (2006). Livestock's role in climate change and air pollution. in: H. Steinfeld, P. Gerber, T. Wassenaar, V. Castel, M. Rosales & C. de Haan (Eds.), Livestock's long shadow. LEAD Virtual Research and Development Centre, Rome, Italy, pp. 102-123.

Francis, C.A., Roberts, K.J., Beman, J.M., Santoro, A.E. & Oakley, B.B. (2005). Ubiquity and diversity of ammonia-oxidizing archaea in water columns and sediments of the ocean. *Proceedings of the National Academy of Sciences of the United States of America*, 102, 14683-14688.

Fukumoto, Y. & Inubushi, K. (2009). Effect of nitrite accumulation on nitrous oxide emission and total nitrogen loss during swine manure composting. *Soil Science and Plant Nutrition*, 55, 428-434.

Fukumoto, Y., Osada, T., Hanajima, D. & Haga, K. (2003). Patterns and quantities of NH₃, N₂O and CH₄ emissions during swine manure composting without forced aeration−effect of compost pile scale. *Bioresource Technology*, 89, 109-114.

Fukumoto, Y., Suzuki, K., Kuroda, K., Waki, M. & Yasuda, T. (2011a). Effects of struvite formation and nitratation promotion on nitrogenous emissions such as NH₃, N₂O and NO during swine manure composting. *Bioresource Technology*, 102, 1468-1474.

Fukumoto, Y., Suzuki, K., Osada, T., Kuroda, K., Hanajima, D., Yasuda, T. & Haga, K. (2006). Reduction of nitrous oxide emission from pig manure composting by addition of nitrite-oxidizing bacteria. *Environmental Science & Technology*, 40, 6787-6791.

Fukumoto, Y., Waki, M. & Yasuda, T (2011b). Characteristics of nitrogen transition and N₂O generation in the composting of cattle, swine and poultry manure (22IOS4-04), *Proceedings of CIGR International Symposium on "Sustainable Bioproduction – Water, Energy, and Food"*, Tokyo, Japan, 19-23 September 2011.

Haga, K. (1990). Production of compost from organic wastes. *FFTC (Food and Fertilizer Technology Center)/ ASPAC Extension Bulletin*, 311, 1-18.

Haga, K., Osada, T., Harada, Y., Izawa, T. & Nishimura, Y. (1998). Constituents of the anaerobic portion occurring in the pile during composting of cattle wastes. *The Journal of the Society of Agricultural Structures, Japan*, 29, 125-130.

Hao, X. & Chang, C. (2001). Gaseous NO, NO_2, and NH_3 loss during cattle feedlot manure composting. *Phyton-Annales Rei Botanicae*, 41, 81-93.

He, J., Shen, J., Zhang, L., Zhu, Y., Zheng, Y., Xu, M. & Di, H.J. (2007). Quantitative analyses of the abundance and composition of ammonia-oxidizing bacteria and ammonia-oxidizing archaea of a Chinese upland red soil under long-term fertilization practices. *Environmental Microbiology*, 9, 2364-2374.

He, Y., Inamori, Y., Mizuochi, M., Kong, H., Iwami, N. & Sun, T. (2001). Nitrous oxide emissions from aerated composting of organic waste. *Environmental Science & Technology*, 35, 2347-2351.

IPCC (2007). Fourth Assessment Report - Climate Change 2007: The Physical Science Basis.

Isermann, K. (1990). Share of agriculture in nitrogen and phosphorus emissions into the surface waters of western-Europe against the background of their eutrophication. *Fertilizer Research*, 26, 253-269.

Jeong, Y.K. & Hwang, S.J. (2005). Optimum doses of Mg and P salts for precipitating ammonia into struvite crystals in aerobic composting. *Bioresource Technology*, 96, 1-6.

Jeong, Y.K. & Kim, J.S. (2001). A new method for conservation of nitrogen in aerobic composting process. *Bioresource Technology*, 79, 129-133.

Kester, R.A., de Boer, W. & Laanbroek, H.J. (1997). Production of NO and N2O by pure cultures of nitrifying and denitrifying bacteria during changes in aeration. *Applied and Environmental Microbiology*, 63, 3872-3877.

Kuroda, K., Hanajima, D., Fukumoto, Y., Suzuki, K., Kawamoto, S., Shima, J. & Haga, K. (2004). Isolation of thermophilic ammonium-tolerant bacterium and its application to reduce ammonia emission during composting of animal wastes. *Bioscience, Biotechnology, and Biochemistry*, 68, 286-292.

Kuroda, K., Osada, T., Yonaga, M., Kanematu, A., Nitta, T., Mouri, S. & Kojima, T. (1996). Emissions of malodorous compounds and greenhouse gases from composting swine feces. *Bioresource Technology*, 56, 265-271.

la Pagans, E., Font, X. & Sanchez, A. (2005). Biofiltration for ammonia removal from composting exhaust gases. *Chemical Engineering Journal*, 113, 105-110.

Lee, J.E., Rahman, M.M. & Ra, C.S. (2009). Dose effects of Mg and PO_4 sources on the composting of swine manure. *Journal of Hazardous Materials*, 169, 801-807.

Leininger, S., Urich, T., Schloter, M., Schwark, L., Qi, J., Nicol, G.W., Prosser, J.I., Schuster, S.C. & Schleper, C. (2006). Archaea predominate among ammonia-oxidizing prokaryotes in soils. *Nature*, 442, 806-809.

Lin, C. (2008). A negative-pressure aeration system for composting food wastes. *Bioresource Technology*, 99, 7651-7656.

Maeda, K., Hanajima, D., Toyoda, S., Yoshida, N., Morioka, R. & Osada, T. (2011). Microbiology of nitrogen cycle in animal manure compost. *Microbial Biotechnology*, DOI: 10.1111/j.1751-7915.2010.00236.x.

Maeda, K., Morioka, R., Hanajima, D. & Osada, T. (2010a). The impact of using mature compost on nitrous oxide emission and the denitrifier community in the cattle manure composting process. *Microbial Ecology*, 59, 25-36.

Maeda, K., Toyoda, S., Shimojima, R., Osada, T., Hanajima, D., Morioka, R. & Yoshida, N. (2010b). Source of nitrous oxide emissions during the cow manure composting process as revealed by isotopomer analysis of and amoA abundance in betaproteobacterial ammonia-oxidizing bacteria. *Applied and Environmental Microbiology*, 76, 1555-1562.

McGinn, S.M. & Janzen, H.H. (1998). Ammonia sources in agriculture and their measurement. *Canadian Journal of Soil Science*, 78, 139-148.

Ministry of Agriculture, Forestry and Fisheries, Japn (2008). Statistics of Livestock Industry in 2008.

Oenema, O., Wrage, N., Velthof, G.L., van Groenigen, J.W., Dolfing, J. & Kuikman, P.J. (2005). Trends in global nitrous oxide emissions from animal production systems. *Nutrient Cycling in Agroecosystems*, 72, 51-65.

Parkinson, R., Gibbs, P., Burchett, S. & Misselbrook, T. (2004). Effect of turning regime and seasonal weather conditions on nitrogen and phosphorus losses during aerobic composting of cattle manure. *Bioresource Technology*, 91, 171-178.

Pearson, J. & Stewart, G.R. (1993). The deposition of atmospheric ammonia and its effects on plants. *New Phytologist* 125, 283-305.

Rappert, S. & Muller, R. (2005). Odor compounds in waste gas emissions from agricultural operations and food industries. *Waste Management*, 25, 887-907.

Ravishankara, A.R., Daniel, J.S. & Portmann, R.W. (2009). Nitrous oxide (N$_2$O): the dominant ozone-depleting substance emitted in the 21st century. *Science* 326, 123-125.

Silva, C.D., Cuervo-Lopez, F.M., Gomez, J. & Texier, A.C. (2011). Nitrite effect on ammonium and nitrite oxidizing processes in a nitrifying sludge. *World Journal of Microbiology & Biotechnology*, 27, 1241-1245.

Smet, E., Van Langenhove, H. & De Bo, I. (1999). The emission of volatile compounds during the aerobic and the combined anaerobic/aerobic composting of biowaste. *Atmospheric Environment*, 33, 1295-1303.

Sommer, S.G. (2001). Effect of composting on nutrient loss and nitrogen availability of cattle deep litter. *European Journal of Agronomy*, 14, 123-133.

Steinfeld, H. & Wassenaar, T. (2007). The role of livestock production in carbon and nitrogen cycles. *Annual Review of Environment and Resources*, 32, 271-294.

Szanto, G.L., Hamelers, H.V.M., Rulkens, W.H. & Veeken, A.H.M. (2007). NH$_3$, N$_2$O and CH$_4$ emissions during passively aerated composting of straw-rich pig manure. *Bioresource Technology*, 98, 2659-2670.

Tanahashi, T., Yano, H., Itou, H. & Oyanagi, W. (2010). Magnesium ammonium phosphate in cattle and swine manure composts and an extraction method for its evaluation. *Japanese Journal of Soil Science and Plant Nutrition*, 81, 329-335.

Tourna, M., Stieglmeier, M., Spang, A., Konneke, M., Schintlmeister, A., Urich, T., Engel, M., Schloter, M., Wagner, M., Richter, A. & Schleper, C. (2011). Nitrososphaera viennensis, an ammonia oxidizing archaeon from soil. *Proceedings of the National Academy of Sciences of the United States of America*, 108, 8420-8425.

Wuchter, C., Abbas, B., Coolen, M.J.L., Herfort, L., van Bleijswijk, J., Timmers, P., Strous, M., Teira, E., Herndl, G.J., Middelburg, J.J., Schouten, S. & Damste, J.S.S. (2006). Archaeal nitrification in the ocean. *Proceedings of the National Academy of Sciences of the United States of America*, 103, 12317-12322.

Yasuda, T., Kuroda, K., Fukumoto, Y., Hanajima, D. & Suzuki, K. (2009). Evaluation of full-scale biofilter with rockwool mixture treating ammonia gas from livestock manure composting. *Bioresource Technology*, 100, 1568-1572.

Zaman, M. & Blennerhassett, J.D. (2010). Effects of the different rates of urease and nitrification inhibitors on gaseous emissions of ammonia and nitrous oxide, nitrate leaching and pasture production from urine patches in an intensive grazed pasture system. *Agriculture Ecosystems & Environment*, 136, 236-246.

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.

Soil Health and Land Use Management

Edited by Dr. Maria C. Hernandez Soriano

Soils play multiple roles in the quality of life throughout the world, not only as the resource for food production, but also as the support for our structures, the environment, the medium for waste disposal, water, and the storage of nutrients. A healthy soil can sustain biological productivity, maintain environmental quality, and promote plant and animal health. Understanding the impact of land management practices on soil properties and processes can provide useful indicators of economic and environmental sustainability. The sixteen chapters of this book orchestrate a multidisciplinary composition of current trends in soil health. Soil Health and Land Use Management provides a broad vision of the fundamental importance of soil health. In addition, the development of feasible management and remediation strategies to preserve and ameliorate the fitness of soils are discussed in this book. Strategies to improve land management and relevant case studies are covered, as well as the importance of characterizing soil properties to develop management and remediation strategies. Moreover, the current management of several environmental scenarios of high concern is presented, while the final chapters propose new methodologies for soil pollution assessment.

INTECH
open science | open minds