Composting as a Strategy to Reduce Greenhouse Gas Emissions

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Abstract

Composting animal manure has the potential to reduce emissions of nitrous oxide (N_2O) and methane (CH_4) from agriculture. Agriculture has been recognized as a major contributor of greenhouse gases, releasing an estimated 81% and 70% of the anthropogenic emissions of nitrous oxide (N_2O) and methane (CH_4), respectively. A significant amount of methane is emitted during the storage of liquid manure, whereas nitrous oxide is emitted from the storage of manure and from soil following manure or fertilizer application. Composting animal manure can reduce GHG emissions in two ways; by reducing nitrous oxide and methane emissions during manure storage and application, and by reducing the amount of manufactured fertilizers and the GHG associated with their production and use. We will present information of GHG emissions and potentials for reduction based on available data, and on specific composting experiments. Nitrous oxide and methane emissions were monitored on an enclosed composting system processing liquid hog manure. Measurements indicated that total GHG emissions during composting were 24% of the Tier 2 IPCC estimates for traditional liquid hog manure management on that farm. Previous research has also indicated little nitrous oxide emission following application of composted manure to soil. The method of composting has a large impact on GHG emissions, where GHG emissions are higher from outdoor windrow composting systems than from controlled aerated systems. Further research is required to assess the whole manure management system, but composting appears to have great potential to reduce GHG emissions from agriculture. The bonus is that composting also addresses a number of other environmental concerns such as pathogens, surface and groundwater quality and ammonia emissions.

Introduction

Organic waste management contributes a significant amount of the greenhouse gas (GHG) emissions in Canada. Approximately 6% of anthropogenic GHG production results from methane emission from landfills and animal manure storage tanks (Environment Canada, 1999). In some areas, methane emission from landfills is being collected and utilized for energy. There is a negligible amount of methane being collected and utilized from animal manure.

Animal manure management is estimated to be responsible for 1.25% of GHG emissions in Canada (Janzen et al. 1998). This GHG emission is primarily in the form of methane (CH_4) emissions. There are two potential strategies for GHG reduction from animal manure. The first strategy is to capture the methane and use it for energy. Canada spent considerable sums of money on anaerobic digestion and methane production during the 1980s. The research indicated that anaerobic digestion of animal manure was not a cost effective strategy, given the price of energy and the colder climate in Canada. Anaerobic digestion is working effectively in other countries that have warmer climates or that have higher energy prices. Methane production in Canada is now receiving new attention because of the possibility of GHG credits.

An alternate strategy to reduce GHG emissions from animal manure is to eliminate the methane emissions by changing manure management. In this paper, we will demonstrate an effective manure management strategy that can reduce GHG emissions by 90%. This strategy can also be used for municipal organic waste management to reduce methane emissions from new organic waste going to landfills. In order to understand the potential GHG reduction during composting, we must first understand the processes that lead to GHG emissions. We will consider only methane and nitrous oxide emissions because we consider carbon dioxide emissions from plant derived carbonaceous material to be GHG neutral.

Methane is Emitted During Anaerobic Decomposition of Carbon

Methane is a product of anaerobic decomposition of carbonaceous materials. Methane formation involves two steps; an acidification step carried out primarily by facultative anaerobes, and the methanogenic step carried out by strict anaerobic bacteria. The methanogenic step of the composting process is very sensitive to temperature, and other factors such as free ammonia concentration and acid concentrations. During storage of liquid dairy cattle manure, we have observed that up to 25% of the manure carbon was lost as CO_2 and CH_4 during the summer months (manure temperature 20 C) compared with a 2% loss during the winter months (manure temperature of 5 C). Low temperature production and emission of methane does occur as is evidenced by continuous emission of methane from manure storage tanks and from landfills.

Based on the understanding that methane is emitted during anaerobic conditions, it seems reasonable to expect that methane emissions would be minimized during aerobic composting.

Methane Emission During Composting is Low

There are mixed reports of methane emission during composting, however increased aeration appears to decrease methane emissions. Hellebrand (1998) reported elevated methane emissions during passively aerated composting of grass and greenwaste. Helleman et al. (1997) also observed elevated methane emissions for 30 days during windrow composting of municipal and yard waste. Lopez-Real and Baptista (1996) measured methane emissions for the first 20 days during composting of cattle manure. They observed that methane emissions were drastically reduced by both windrow turning and forced aeration. Hao et al. (2001) calculated 28% higher methane emissions during passively aerated composting than during turned windrow composting. Sommer and Moller (2000) also observed methane emissions during the first 25 days of composting swine manure and straw when the density of the material was high (440 kg m^3) compared with no emissions when the density was low (230 kg m^3). Beck-Friis et al. (2000) also measured significant methane emissions during large windrow composting of organic waste from households. Derikx et al. (1989) isolated large numbers of methanogenic bacteria during the early stages of mushroom compost production (windrow composting).

Kuroda et al. (1996) observed elevated methane emissions for one day during composting of swine manure in forced aerated chambers. They also observed that methane emissions were considerably increased when the aeration was stopped. They concluded that methane would be easy to generate in practical windrow composting with a large amount of material and insufficient aeration. Observations from full scale enclosed composting facilities also confirm the risk of explosions from methane accumulation when aeration systems fail. Proponents of methane production by anaerobic digestion also suggest that a preconditioning step involving aeration can result in increased methane yields during subsequent anaerobic treatment (Mata-Alvarez et al. (2000).

The total emissions of methane in the above studies ranged from 0.2 to 2% of the carbon in the waste. Gronauer et al. (1996) concluded that open windrow composting of all household and municipal organic waste in Germany would increase methane emissions from agriculture by 0.5%, which is hardly significant. Although the total methane emission potential during composting is low, a composting technology that allows increased aeration may further decrease this emission potential.

Nitrous Oxide is Emitted During Decomposition of Organic Waste

Nitrous oxide is emitted as by-products of microbial metabolism during nitrification and denitrification. Nitrification involves the oxidation of ammonium to nitrate. It is not clearly understood whether the N_2O is produced by the nitrifying bacteria themselves, or whether there is a nitrification/denitrification step. Paul et al. (1993) observed that N_2O emission from an aerobically incubated soil was much higher when ammonium and carbon were added than when nitrate and carbon were added. They suspected that perhaps heterotrophic nitrification was occurring, which contributed to the N_2O emission.

Denitrification involves the reduction of nitrate/nitrite to dinitrogen gas, where facultative anaerobic bacteria utilize nitrate or nitrite as an electon acceptor when there is no oxygen present. Nitrous oxide is an intermediate product in the process. It appears that nitrous oxide production increases when there is increased denitrification activity.

The denitrification process is very important in nature because it is the only process whereby nitrogen that is fixed from the air through leguminous plants, or by fertilizer manufacture, can be returned to the air as dinitrogen gas. This means that every molecule of nitrogen in plants will eventually undergo the denitrification step, either in the soil, in the groundwater, or in the rivers, lakes and oceans.

Nitrous Oxide is Emitted During Composting

It appears that the composting process results in significant production and emission of nitrous oxide. This must be taken into consideration when estimating GHG emissions during composting. The method of composting appears to have a significant effect on N_2O emission. Nitrous oxide emission is generally higher during thermophilic composting when the air supply is limited as observed with heaped manure (Martins & Dewes 1992). This is consistent with the theory of increased N_2O emission under a combination of aerobic/anaerobic decomposition.

Table 1. Estimates of nitrous oxide emissions from various research studies.

Compost	**Method**	**N2O-N Loss % of total N**	**Reference**
Yard waste	turned windrow	0.5	Hellebrand, 1998
Food & yard waste (80:20)	windrow and agitated bed	0.2-0.4	Schenk et al. 1997
Wastewater sludge	aerated static pile	0.7	Czepiel et al. 1996
Cattle & horse manure	turned windrow	0.5	Czepiel et al. 1996
Yard waste	turned windrow	1.2	Ballestero et al. 1996
Horse manure & bedding	turned windrow (> 60 days)	2.2	Ballestero et al. 1996
Swine manure & cardboard	aerated & turned in-vessel	0.1	Kuroda et al. 1996
Animal manure	heaps in containers	5	Martins & Dewes 1992
Cattle manure	passively aerated windrows	0.11	Hao et al. 2001
Cattle manure	turned windrow	0.19	Hao et al. 2001
Swine manure & straw	passively aerated pile	0.8	Sommer & Moller 2000

Most of the N_2O emission appears to occur during the curing and storage phase, when the ammonium nitrogen is being converted to nitrate. This was also observed by Schenk et al. (1997), where they measured N_2O emissions during the thermophilic composting phase, during curing, and during storage. They estimated that N_2O emissions were highest during storage.

The total contribution of N_2O emissions was estimated to be very small. Schenk et al. (1997) estimated that composting of all organic waste in Germany would contribute 0.15 to 1.2% of the total manmade N_2O emissions.

Composting As a Waste Management Strategy for Hog Manure

We would expect that composting would decrease GHG emissions during manure management, but we would also expect further GHG reduction benefits. These include reduced N_2O emission following land application of manure, and reduced GHG emissions from fertilizer production.

Liquid hog manure management contributes approximately 30% (2484 kt CO_2 equivalent) of the total GHG from manure management in Canada (8900 kt CO_2 equivalent) (IPCC 1996). This GHG occurs in the form of methane emission. Liquid swine manure management emits 3.9% of the total agricultural emissions. We would expect that this GHG emission would be dramatically reduced by composting.

Composting the hog manure would also reduce GHG emissions following application to the field. Liquid manure management results in significant N_2O emission following land application of the manure. Paul et al (1993) measured high rates of N_2O emission from soil during the first six days following liquid beef, swine and dairy cattle manure applications. In contrast, they measured negligible N_2O emissions following application of composted beef manure. Composted manure is also more concentrated which means that the manure can be transported further from the sites of manure production. Paul et al. (1993) observed logarithmic increases in N_2O emission with increasing rates of manure application.

Composting hog manure would allow manure to be transported further from the sites of manure production, which means a significantly greater offset of fertilizer requirements. Currently, the economics of liquid manure management restrict the movement of the manure with a 95% moisture content over a long distance. Consequently, most of the liquid manure is applied to land that is close to the site of manure production. With an increasing intensity of livestock production, where more animals are housed in one building, it is becoming difficult to bring the manure back to the land on which the feed was grown.

Minicomposter Trials with Composting Liquid Swine Manure and Straw

The University of Guelph and the Environment Canada, Climate Change Action Fund supported small and large scale research trials to determine whether composting was an effective strategy for reducing GHG emissions during composting.

Small scale trials included four computer controlled mini-composters (0.5 m^3) that simulated a turned and aerated composting system. These composters were fully enclosed and allowed full capture and analysis of all of the exhaust gases. Methane and nitrous oxide concentrations were measured using two Tunable Diode Laser Trace Gas Analysers (Model 100, Campbell Scientific, Logan, Utah).

Liquid hog manure from the University of Guelph swine facility was combined with chopped barley straw and added to the composters. The composting material was aerated to maintain > 50 C temperatures for at least five days. Results from the mini-composters indicated that both CH_4 and N_2O were emitted during the thermophilic aerobic composting phase. The rate of methane emission was significantly lower when the liquid manure was added to the straw sequentially over a number of days compared with liquid manure application at one time.

We also observed that the methane emission was higher with increasing aeration rate, however the total methane emission was very small. The increased methane emission when the aeration rate was increased indicates that methane producing bacteria are present in the manure and are active in anaerobic microsites in the composting material (Derikx et al. 1989). Some of this methane is being oxidized by aerobic bacteria in the compost. When the aeration rate is increased, some of this methane is emitted from the composters before the methane oxiders can utilize it for energy.

The overall N_2O emission rates were low from the mini-composter trials. We did observe an order of magnitude higher N_2O emission rates when the liquid manure was added to the straw sequentially over a number of days compared to when the liquid manure was mixed in with the straw at one time. It is not clear yet if there is a significant difference in overall GHG emission when the manure is added sequentially or when it is added all at one time. In one case the methane emission is higher, and in the other case, the nitrous oxide emission is higher.

Large Scale Trials with Composting Liquid Swine Manure and Straw

The large scale research on GHG emissions during composting occurred at the Ridgetown College (University of Guelph) compost facility. This facility is a composting building (12.2 m wide and 24.4 m long) that encloses three aerated concrete channels measuring 15.2 m long, 2.2 m wide and 1.6 m deep. Aeration is provided in the floor of the channels by centrifugal blowers. The composting material is turned with a compost turner that rides along the concrete walls (Global Earth Products, Barrie, ON).

Baled straw was added to the channels, then wetted with liquid hog manure on days 1, 4 and 8 of the composting period. The composting material was mixed with the turner only at the times of the manure application. Emissions of CH_4 and N_2O were measured from the enclosed building using the same analysers used for the small scale experiments.

Fluxes of CH_4 and N_2O were variable over the composting period, showing a pattern of low emissions initially, followed by a period of increasing emissions, followed by a dramatic decrease during the last few days. The addition of manure caused an initial decrease in N_2O emission, followed by gradually increasing emissions. Manure addition resulted in a sharp spike of methane emissions followed by decreasing emissions.

Magnitude of GHG Emissions During Composting

Results from the small scale and large scale composting trials indicated a similar magnitude of N_2O and CH_4 emission. This indicates to us that results from the small scale units accurately represent what is happening in full scale systems. These preliminary results have been reported by Thompson et al. (2001).

In the large scale experiment, the average N_2O-N emission during the 12.8 day composting period was 1056 ng m^{-2} s^{-1}. The average CH_4 emission was 59 ug m^{-2} s^{-1}. Converting this to a per L of liquid manure results in emissions of 4.7 ng N_2O-N L^{-1}, and 262 ng of CH_4 L^{-1}. Expressed as CO_2 equivalents, the results are 7000 ng CO_2 L^{-1} of manure.

To evaluate the effect of composting on GHG emissions, the values obtained were extrapolated for one year and compared with emissions during liquid manure storage. Assuming that all of the manure on the farm was composted, the annual emissions from composting were calculated to be 8402 kg of CO_2. When the emissions from the 12 m^2 holding tank were included, the total emissions for this farm was 13,706 kg CO_2 equivalent.

In comparison, the IPCC (1996) Tier 1 and Tier 2 annual estimates for liquid manure storage in cold climates on this farm are 89,250 and 57,250 kg CO_2, respectively. This means that composting reduced emissions of CH_4 and N_2O to 15 and 24% of Tier 1 and Tier 2 estimates, respectively.

Aerated Composting in an Enclosed Structure is An Excellent Strategy for Manure Management and GHG Reduction

Some of the present concerns with liquid hog manure management in addition to GHG emissions include excess loading of nutrients on land close to the animal production units, ammonia emission, and odor. Ammonia is lost in the barn, during lagoon storage of liquid hog manure, and following field application. Ammonia is difficult to capture from storage lagoons because of their size, and impossible to capture following land application of the manure. Odor from liquid hog manure occurs during lagoon storage, but primarily following field application of the manure.

Composting the manure results in reduced GHG emissions, elimination of odor, capability to capture any ammonia emission, and production of an easily transportable fertilizer product. Table 2 compares some of the present and proposed manure management strategies in relation to present concerns.

Table 2. Environmental issues with liquid hog manure processing systems

Environmental Issue	Liquid storage	Aerating Liquid	Anaerobic digestion	Composting
Storage/Processing				
GHG Emission	Medium	High	Lowest	Low
Ammonia Emission	Medium	High	Low	Low to Medium
Odor	Medium	Low	Low	Low
Energy required	None	High	Medium to High	Medium
Energy obtained	None	None	High	None
Field Application				
GHG Emission	High	Low	High	Low
Ammonia Emission	High	Low	High	Low
Odor	High	Medium	Medium	Low
Energy required	High	High	High	Medium
Energy obtained	None	None	None	None

Simple aeration of liquid manure reduces the available carbon (BOD) and the soluble nitrogen. The carbon is oxidized to CO_2 and the nitrogen is lost as ammonia or incorporated into microbial protein. Nitrous oxide emissions are significantly increased (Burton et al. 1993). There is energy required for the aeration, and there is no energy obtained because the available energy in the manure is lost as CO_2. When the product is field applied, there is less odor than anaerobically stored manure. Ammonia emission is lower because ammonia was removed during processing. All of the water remains in the product, hence considerable amount of energy is required to distribute the nutrients in an environmentally sustainable manner.

Anaerobic digestion is a promising alternative because GHG emissions are reduced by capturing methane. This can in turn reduce GHG emissions further by utilizing the energy in the methane for heat or electricity. There is a lot of energy required for this process because of the infrastructure required for capturing and processing the methane. Following processing, the only environmental concern that we have reduced is the odor. All of the liquid and the nutrients remain to be applied in a sustainable manner. There is a high risk of ammonia emission.

Composting reduces greenhouse gas emissions, both during processing and following application to the field. Composting results in relatively little ammonia loss, but is highly dependent on the amount of nitrogen in the waste product and the availability of the carbon in the bulking agent. In previous trials with hog manure composted with straw in the same facility used for the present experiments, the ammonia loss was estimated at 15 to 20% of the total nitrogen in the manure (Fleming and MacAlpine 2001). Because the composting systems are enclosed within a building, it is possible to capture any ammonia using an ammonia scrubber. There is no energy recovered, and there is a medium amount of energy required during the process – for infrastructure, for aeration, and for handling. Additional carbonaceous materials are usually required for the process. Perhaps the most advantageous aspect to composting is that the environmental concerns following field application are eliminated. There is no odor, no ammonia emission, and no GHG emission. Because the nutrients are in a relatively dry, pathogen and odor free form, they can be easily transported further from the site of livestock production. The material is also in a form that is much more marketable than raw manure. This opens up the possibility of exporting nutrients from the farm, a highly desirable option for some farmers.

Benefits of Composting in Enclosed Facilities Applies to All Types of Organic Waste

The above discussion regarding the benefits and environmental concerns regarding liquid manure management apply to all organic wastes. When evaluating various technologies for their GHG reduction potential, we must consider all aspects of the process including the final home for the nutrients after processing. This must include the costs of recycling the nutrients in the organic waste.

There is some difference in GHG emissions with various methods of composting. A well managed forced aerated composting system is expected to have the lowest GHG reduction rates. This process also reduces the risk of odor, worker health and safety, fugitive ammonia emission, and ground and surface water quality. Composting in enclosed buildings also meets the new European Union guidelines for organic waste processing (European Commission 2000).

Conclusions

The overall impact composting on GHG emissions is very small. The method of composting does impact GHG emissions, where GHG emissions are higher from outdoor windrow composting systems than from controlled aerated systems. Further research is required to assess the whole manure management system, but composting appears to have great potential to reduce GHG emissions from agriculture. The additional advantage is that composting also addresses a number of other environmental concerns such as pathogens, surface and groundwater quality and ammonia emissions. The composting process does not require as much capital investment as some of the other organic waste solutions.

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