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Greenhouse gas and ammonia emissions from digested and separated dairy manure during storage and after land application

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ABSTRACT

Manure management at dairy production facilities, including anaerobic digestion (AD) and solid-liquid separation (SLS), has shown strong potential for the abatement of greenhouse gas (GHG) and ammonia (NH_3) emissions. However, previous study results are inconsistent and the combined effect of AD + SLS remains to be quantified. This study evaluated the effects of AD, SLS, and AD + SLS on GHG and NH_3 emissions during manure storage through land application over nine months. AD and SLS alone significantly ($P < 0.05$) reduced total GHG emissions for storage and land application compared to untreated manure slurries by 25% and 31%, respectively. The majority of that reduction was from methane during storage. SLS had a greater potential for methane reduction in storage than AD, but the variability in digester performance likely impacts the reduction potential. Digestion with subsequent separation further decreased CH_4 emissions from 3.9 g CO_2-eq to 1.3 g CO_2-eq, but increased emissions of nitrous oxide (N_2O) from 0.6 g CO_2-eq to 2.0 g CO_2-eq during storage eliminating a further reduction of GHG emissions as compared to AD alone. AD resulted in a gas emission tradeoff as it increased NH_3 emissions by 81% during storage, which could be mitigated by subsequent SLS, manure storage covers, or other beneficial management practices.

1. Introduction

In 2013, 7.7% of all U.S. greenhouse gas (GHG) emissions were from agricultural sources. Gaseous losses from ruminant livestock in the form of manure management were responsible for 15.2% of agricultural emissions (USEPA, 2015). In addition, GHG emissions from dairy manure management increased by 53% from 1990 to 2012 and are expected to continue to rise; therefore, it is critical to recommend efficient manure management mitigation strategies to dairy producers to abate overall agricultural GHG emissions (USEPA, 2015). Many different strategies have demonstrated potential to reduce methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3) emissions from manure (Montes et al., 2013; Ndegwa et al., 2008). For example, manure processing using anaerobic digestion (AD) can reduce CH_4 emissions and solid-liquid separation (SLS) can reduce both CH_4 and N_2O emissions (Amon et al., 2006; Chadwick et al., 2011; Clemens et al., 2006; Meyer-Aurich et al., 2012).

AD is a microbial process that degrades organic material, such as cattle manure, in the absence of oxygen, producing biogas, which is primarily composed of CH_4 and carbon dioxide (CO_2). Biogas can be captured and combusted to generate electricity, directly burned for heating applications, or further upgraded for use in higher value applications such as vehicle fuel. These processes reduce the net emissions impact from feedstocks natural decomposition as CH_4 in biogas is converted to CO_2 during combustion. When CH_4 is captured and used as an energy source it can also reduce the life cycle depletion of fossil fuels from manure management at a dairy facility by 43% as grid-based electricity is replaced by biogas-based electricity (Aguirre-Villegas et al., 2014). The effluent leaving the digester, known as digestate, has modified chemical content (e.g. total solids, carbon, ammonium (NH_4), and pH), contains more soluble plant nutrients due to mineralization, and has less degradable biomass than the original substrate resulting in changes in GHG and NH_3 emissions (Clemens et al., 2006). These changes can result in an additional benefit as the effluent from the digester has reduced organic matter, which has

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shown potential to mitigate GHG emissions during storage and after land application (Amon et al., 2006; Clemens et al., 2006; Hafner et al., 2013). Amon et al. (2006) found that digestion reduced total GHG emissions by 60% from the untreated slurry due to the reduction of CH_4 emissions, however the results from this study should be used with caution as there was no replication.

While there exists a potential for GHG emissions reductions, a tradeoff may exist in using digestion to mitigate manure GHG emissions, as some of the changes in the manure composition can promote NH_3 emissions following digestion. During the AD process, methanogens and other microorganisms break down proteins, amino acids, and urea forming NH_4 (Bernet et al., 2000). In addition, mineralization of organic N and volatile fatty acids during AD increases manure pH and available N (Petersen and Sommer, 2011), factors which increase NH_3 emissions. Despite these known mechanisms, studies measuring NH_3 emissions after AD have been inconsistent. Amon et al. (2006) found that NH_3 emissions from digested manure storages were similar to untreated. After application, this same study found that NH_3 emissions for the digested manure were 15% greater than the untreated manure. On the contrary, Neerackal et al. (2015) reported significantly higher NH_3 emissions from manure storage after AD, but a reduction of NH_3 emissions after manure land application. In addition, the variability in results highlights the importance of conducting additional research that explores the effect of AD on NH_3 emissions.

Solid-liquid separation is a process in which manure solids are mechanically separated from manure liquids to reduce storage capacity and increase flexibility of manure management (Christensen et al., 2013). The liquid portion after separation has a lower amount of organic matter and carbon available for methanogenesis resulting in lower CH_4 production potential. In comparison with liquid manure, storage of separated manure solids results in an environment that is predominately aerobic, eliminating the anaerobic conditions necessary for CH_4 production and thus decreasing CH_4 emissions. Fangueiro et al. (2008) found that separate storage of the liquid and solid fraction resulted in a reduction of CH_4 emissions of approximately 35% when compared to the raw manure. Further reductions during storage may be possible if AD is utilized before separation as it can lower carbon in the manure prior to separation, but exploring the effect of combining AD and SLS on GHG and NH_3 emissions has been largely absent from the literature.

Similar to AD, a tradeoff may exist in reduction of gaseous emissions from SLS as it can increase NH_3 and N_2O emissions in the separated solids. Aerobic solid manure storage systems promote the production of NH_4 and without a subsequent anaerobic environment for nitrification some NH_4 is volatilized as NH_3 (Hansen et al., 2006). As with AD, the results have been inconsistent regarding the effects of SLS on emissions. Amon et al. (2006) found that SLS increased total NH_3 and N_2O emissions from storage and application by 77% and 19% respectively, with a majority of emissions from the composting of the solid portion. Conversely, Hou et al. (2015) observed no significant difference in N_2O emissions between separated liquids from unprocessed manure and reported that the separated solids show lower N_2O emissions than unprocessed manure in terms of percentage of N applied. Neerackal et al. (2015) also found no significant difference of NH_3 emissions between raw manure and separated liquids.

Altering the composition of manure though AD and SLS can affect GHG and NH_3 emissions from downstream processes, which highlights the importance of keeping track of the emissions throughout all manure handling steps. Studies have focused on specific processing technologies (e.g. only storage or only land application) or specific emissions (Dinuccio et al., 2011; Koirala et al., 2013; Neerackal et al., 2015) but there is limited literature quantifying both GHG emissions and NH_3 emissions from both manure storage and land application and from the same manure stream. Amon et al. (2006) conducted a more comprehensive assessment of emissions from stored and applied manure, but the study contained no replication and followed emission for only 20 days after application. While the prior work conducted in this area was critical to develop data trends, continued work is needed to provide more comprehensive evaluation of manure processing systems, particularly the combination of processing systems. This study is one of the first to compare the magnitude and direction of GHG and NH_3 emissions from manure storage and land-application after combined AD and SLS from the same manure stream.

Literature on CO_2 emissions from processed manure using AD and SLS is also limited. Researchers generally do not quantify gaseous losses of CO_2 from manure as they have been previously absorbed and metabolized by plants that constitute the dairy ration, thus, being part of the carbon cycle and not an additional source of CO_2 (Kulling et al., 2001). While this logic is sound, it is still important to quantify CO_2 emissions to understand the carbon cycling at a dairy farm. In this study, we investigated the influence of AD, SLS, and the combination of AD and SLS on CO_2, CH_4, N_2O, and NH_3 emissions during storage and for one growing season after manure application to the field.

2. Methods & materials

Emissions from processed and unprocessed manure during storage and land application were monitored for CH_4, CO_2, N_2O, and NH_3. Manure collected was measured over a 182-day storage study and upon completion was applied to the field where gas measurements continued for 126 days.

2.1. Manure collection and storage

Manure streams were collected in the pump room of two dairy facilities in 0.21 m^3 barrels for the storage portion of the study. Raw manure at farm 1 (R1), digested manure at farm 1 (D1), digested separated liquids at farm 1 (DL1), and digested separated solids at farm 1 (DS1) were collected from a dairy with a mixed plug-flow digester and screw press separators. The digester operates at a mesophilic range and is loaded with skid steer collecting manure three times per day. Two Bauer™ model # 855 screw press separators are used at the facility for manure solid-liquid separation after digestion with a 260 mm press and 520 mm dewatering section with 0.5 mm screen widths. After separation, at this facility, the digested solids are used for bedding and the separated liquids are stored and then land applied. Raw manure at farm 2 (R2), separated liquid at farm 2 (L2), and separated solids at farm 2 (S2) were collected from the USDA dairy facility located in Prairie du Sac, WI. The dairy uses wheat straw for bedding and collects manure with an automatic scraper. Manure is then pumped to a Vincent™ KP-10 screw press separator with a 372 mm press section and 800 mm dewatering section with 0.381 mm screen widths. Manure was collected from two farms as sampling digestion and separation alone and the combination of the two was not possible at the farm scale. At farm 1 only digested manure (D1) was an input to the separator and no infrastructure existed to separate only R1, therefore an additional farm was required to analyze the effects of separation alone.

Manure slurries and separated liquids were stored in 0.21 m^3 plastic barrels filled with 0.185 m^3 of each manure stream from November 2013 to May 2014. In Wisconsin, separated solid piles are often stored in large unturned piles, impending oxygen supply. Therefore, separated solids in the study were stored in barrels with the lid open. A headspace of 15–20 cm was left at the top of the barrel for gas emission measurements. The mass of manure was

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