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Aerobic treatment of liquid swine manure using polymer: Evaluation for ammonia emissions reduction and nitrogen retention

Gopi Krishna Kafle [a, *], Lide Chen [b, **], Benton Glaze [c], Terry Tindall [d], Sai Krishna Reddy Yadanaparthi [e]

[a] Biological Systems Engineering, Washington State University, Pullman, WA 99164, USA
[b] Department of Biological and Agricultural Engineering, University of Idaho, Moscow, ID 83844, USA
[c] Department of Animal and Veterinary Science, University of Idaho, Moscow, ID 83844, USA
[d] J.R. Simplot Company, Boise, ID 83702, USA
[e] Environmental Science Program, University of Idaho, Moscow, ID 83844, USA

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ABSTRACT

In the present study, the effectiveness of polymer (maleic-itaconic acid) on ammonia (NH_3) emissions reduction and in retaining nitrogen (N) in fresh liquid swine manure (SM) was evaluated. The relationship between pH and NH_3 emission was also determined. Different doses of polymer (namely Treatment 1 = T1 = 0.8 L polymer/ton of manure, Treatment 2 = T2 = 1.6 L polymer/ton of manure, Treatment 3 = T3 = 2.4 L polymer/ton of manure, and Treatment 4 = T4 = 3.2 L polymer/ton of manure) were added to the SM and its effects were observed for 30 d. The tests results showed significant reduction in pH for T1, T2, T3 and T4 compared to control (C). For the short term (up to 3d) T2, T3, and T4 showed significantly lower NH_3 gas concentrations than C, however, for the long term (up to 10–20 d) only T4 continued to indicate significantly lower NH_3 gas concentrations. Although numeric observations were reported for other treatments (T1, T2 and T3), no significant differences in NH_3 gas concentrations were found. The NH_3 emissions reductions were calculated in the range of 81–92%, 31–88%, −39–61%, 6 −41%, −106% to −6% for the treatment period of 1, 3, 10, 20 and 30 d, respectively. The addition of polymer resulted in no significant difference in total ammonia nitrogen (TAN) and NO_3^-−N concentration. However, the addition of polymer had a significant influence on total Kjehldahl nitrogen (TKN) and soluble chemical oxygen demand (SCOD) concentration. The NH_3 gas emissions strongly correlated with the manure pH (R^2 = 0.911–0.999).

1. Introduction

Swine is the most widely consumed meat product in several countries of the world, and its production is predicted to rise in the next few decades (FAO, 2012; Kafle et al., 2015; Philippe and Nicks, 2015). Livestock slurry, including swine manure (SM), is an important nutrient source for crops but its nutrient value decreases over time by significant losses of nitrogen (N), attributed greatly to the volatilization of ammonia (NH_3) (Pain et al., 1987; Hartung and Phillips, 1994). The largest emitters of NH_3 are China, the European Union and the United States with 15.2, 3.8 and 3.7 Tg NH_3 per year, respectively (Philippe et al., 2011). Worldwide, swine farming is responsible for approximately 15% of NH_3 emissions related to livestock (Olivier et al., 1998). Emissions from housings are the major source, accounting for approximately 50% of swine NH_3 (Philippe et al., 2011). Loss of NH_3 via volatilization from animal houses, hardstandings, and manure stores decreases the nutrient value of manure (Sørensen and Amato, 2002). The variation of NH_3 emissions from manure causes variability in fertilizer efficiency which results in a decline in crop growers' reliance on manure as a source of N for plants. This may result in excess N supply to crops, risking a declination in crop quality and inclination in losses of N to the environment by leaching of nitrate (NO_3^-) and emission of nitrous oxide (N_2O) and dinitrogen (N_2) (Sommer et al., 2006). In addition to the monetary loss, NH_3 volatilization and subsequent

* Corresponding author.
** Corresponding author.
E-mail addresses: gopikafle@yahoo.com, gopikrishna.kafle@wsu.edu (G.K. Kafle), lchen@uidaho.edu (L. Chen).

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deposition can cause soil acidification and ground and surface waters pollution (McCrory and Hobbs, 2001). In the livestock housing, NH_3 emissions can adversely affect the performance, health, and welfare of both animals and workers (Donham and Gustafson, 1982; McCrory and Hobbs, 2001). Similarly, atmospheric NH_3 emissions contribute to ecosystem fertilization, acidification, and eutrophication (NRC, 2003).

The livestock manure N transformation process includes (1) mineralization of organic N into NH_3, (2) assimilation of N into organic matter, (3) nitrification of N into nitrite (NO_2^-) and into NO_3^-, and (4) finally, denitrification of N into dinitrogen (N_2) with nitrous oxide (N_2O) as a potential by-product (Philippe et al., 2011). Reduction of N losses from livestock farms should be started with proper animal feeding and management to decrease N excretion. Even with better management, a huge amount of N ends up in manure (Rotz, 2004). A major portion of this excreted N can rapidly change into NH_3, which may promptly volatilize and escape into the atmosphere. Volatile loss starts soon after excretion and continues through all manure handling processes until the manure nutrients are incorporated into soil (Rotz, 2004). Ammonia volatilization is directly related to the proportion of aqueous NH_3 in the total ammonia nitrogen (TAN). Generally, at a steady temperature, pH determines the equilibrium between ammonium NH_4^+ and NH_3 with a lower pH favoring the NH_4^+ form and hence lower potential of NH_3 volatilization (Ndegwa et al., 2008). The transformation and loss of ammonia are very sensitive to manure pH; there is almost no measurable free ammonia at pH of 4.5, relatively low loss occurs below a pH of 6.0 and very high loss occurs when the pH exceeds 8.0 (Muck and Steenhuis, 1982; Hartung and Phillips, 1994).

Storage of livestock manure has been regarded as a major source of NH_3 emissions (Hartung and Phillips, 1994), with reported N losses ranging from 3 to 60% of initial total N (Muck and Steenhuis, 1982; Dewes et al., 1990). Van Horne et al. (1998) reported that major part of the N entering the lagoon is lost to the atmosphere. Commonly, a series of lagoons are used where the effluents from the first become the influent of the next and there could be 70% or more of the N entering a series of lagoons lost to the atmosphere (Van Horne et al., 1998). Similarly, Harper et al. (2000) found that less than 1% of the initial N entering the first lagoon was recovered from the final lagoon and applied to cropland. Given its adverse economic and environmental impacts, reducing NH_3 emissions from manure has been of great interest to academics, regulators, livestock farmers, environmentalists, and the public.

Different methods have been recommended and tested for mitigating NH_3 volatilization from excreted manure which include decreasing N excretion through manipulating feeding rations, decreasing volatile NH_3 in the manure, and separating urine from feces to lower contact between urease and urine (Ndegwa et al., 2008). Methods for lowering volatile NH_3 in manure include lowering manure pH, which shifts the equilibrium in favor of NH_4^+ over NH_3; using chemical additives that bind NH_4–N; and applying biological nitrification-denitrification to convert NH_4^+ into non-volatile N-species such as NO_2^-, NO_3^-, or gaseous N (Ndegwa et al., 2008). Other methods for mitigating NH_3 emissions target emitting surfaces, and include capturing air using physical covers and treating the captured air using bio-filters or/and scrubbers (Ndegwa et al., 2008; Kafle and Chen, 2014; Kafle et al., 2015), and manure subsurface injection during land application. Manure collection facility designs and appropriate facility management are also essential for abating NH_3 emissions (Ndegwa et al., 2008).

Earlier studies have clearly demonstrated the effectiveness of pH reduction in the mitigation of NH_3 volatilization from different livestock manures (Ndegwa et al., 2008). Acidification of swine and cattle slurries from a pH of 8 to a pH of 1.6 using H_2SO_4 reduced NH_3 emissions progressively and completely stopped NH_3 volatilization at a pH of 5.0 in pig slurries and at a pH of 4.0 in cattle slurries (Molloy and Tunney, 1983). Jensen (2002) maintained a pH of 5.5 using H_2SO_4 in swine slurry in full-scale sow-confinement housings with slatted floors and manure pits under-the-floor. In a similar study, Stevens et al. (1989) used H_2SO_4 to acidify cow and swine slurries to pHs of 5.5 and 6.0, respectively. Ammonia volatilization was reported to be effectively reduced by 95% in the lab and by 82% in the field under such pH conditions. In another study, NH_3 loss reductions of 14–57% were reported by Pain et al. (1990) when the pH of cattle slurry was lowered to 5.5.

More Than Manure (MTM), a maleic-itaconic copolymer product, was developed by Specialty Fertilizer Products (Verdesian Life Sciences, Cary, NC 27513) for improving manure fertilizer use and reducing NH_3 emission from manure. The objectives of this study were to: (1) evaluate the effect of the polymer (MTM) on mitigating NH_3 gas emissions from fresh liquid SM, (2) evaluate the effect of the polymer on retaining N in liquid SM, and (3) to derive the relationship between pH and NH_3 gas emissions.

2. Materials and methods

2.1. Swine manure and polymer

Fresh SM was collected from a commercial swine farm (swine nursery barn) in Kimberly, Idaho on March 14, 2014. A shallow pit with depth of 0.6 m was constructed below the slatted floor to collect manure and washing water. Around 60–70% of total volume in the shallow pit was drained to the lagoons every 5 d. The manure was sampled from a drained pipe connected to a lagoon. The collected manure was then transported back to the University of Idaho Twin Falls Research and Extension Center. The characteristics of SM are shown in Table 1.

The polymer was prepared from the mixture of maleic-itaconic copolymer partial calcium salt and maleic-itaconic copolymer partial ammonium salt, 30–60% w/w total solids solution in water. The pH, specific gravity and freezing range of the polymer was 3.0, 1.2 and −5 °C, respectively.

2.2. Experimental setup and design

The experimental setup for the tests is shown in Fig.1. The collected manure was mixed before being randomly distributed into 16 twenty-liter buckets. Five liters of manure were placed in each bucket without any pretreatments. Three of the 16 buckets were randomly chosen to be controls and treatments with four different doses (namely Treatment 1 = T1 = 0.8 L polymer/ton of manure, Treatment 2 = T2 = 1.6 L polymer/ton of manure, Treatment 3 = T3 = 2.4 L polymer/ton of manure, Treatment

Table 1
Characteristics of swine manure used for the tests. The manure was stored in a shallow pit below slatted floor for around five days in pig nursery barn.

Parameter	Units	Mean ± SD
Total solids (TS)	%	5.5 ± 0.2
Volatile solids (VS)	%	4.7 ± 0.1
VS/TS		0.86 ± 0.02
pH		6.18 ± 0.05
Total volatile fatty acids (TVFA)	mg/L	7956 ± 346
Alkalinity (mg/L)	mg/L	1952 ± 246
Crude protein (CP)[a]	% TS	26.88 ± 0.88
Crude fiber (CF)[a]	% TS	20.40 ± 0.29
Ether extract (EE)[a]	% TS	9.40 ± 0.06
C/N ratio[a]		12:1

SD: Standard deviations.
[a] Adapted from Kafle and Chen, 2014.

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