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Research Paper

Ammonia loss from simulated post-collection storage of scraped and flushed dairy-cattle manure

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A series of laboratory scale studies were conducted, over a period of 23 d, to evaluate NH_3 losses from simulated storages of scraped manure and flushed manure on the basis of similar: (i) exposed-surface-area to volume ratio (ESAVR), and (ii) exposed-surface-area (ESA). Based on similar ESA; NH_3 flux during the 23-d study period from the storage of scraped manure ranged from 2.7 to 1.4 g m^{-2} d^{-1} compared to a range of 2.2 to 1.8 g m^{-2} d^{-1} from storage of flushed manure. This resulted in significantly higher total NH_3 loss from the storage of scraped manure (2034 ± 107 mg) compared to that from the storage of flushed manure (1739 ± 53 mg). Ammonia flux ranging from 5.9 to 2.4 g m^{-2} d^{-1} was observed from the storage of scraped manure with similar ESAVR to that of the flushed manure storage. In the latter case, however, the total NH_3 losses from either type of storage were not significantly different. The mean cumulative NH_3 lost from the simulated storages of flushed manure was 1739 ± 53 mg, while the mean loss from the simulated storages of scraped manure was 1752 ± 56 mg. The results from this study indicate that for geometric similar post-collection storages (i.e. similar ESA), flushing manure mitigates NH_3 emissions more than scraping manure, during post-collection storages: at least within the initial 23-d storage duration simulated in this study. In contrast, however, there was no indication of any advantage of using one system over the other if the post-collection storages were based on similar ESAVRs.

1. Introduction

Agricultural activities, including concentrated animal feed operations (CAFOs), account for up to 80% of the total ammonia (NH_3) emissions on a global scale (USEPA, 2002). In Europe, NH_3 emissions from CAFOs and fertiliser applications are believed to account for almost 90% of the total anthropogenic NH_3 release (Bujjsman, Maas, & Asman, 1987). Ammonia emissions occur from multiple sources in a CAFO including animal housing, bedding, solids and liquids separation areas, manure storage facilities (e.g. manure pits, manure piles, under-floor pits, anaerobic lagoons, etc), and also from land application of manure (Liang, Westerman, & Arogo, 2002; Ndegwa, Hristov, Arogo, & Sheffield, 2008). Impacts of NH_3 emissions, in general, range from adverse effects on sensitive ecosystems, eutrophication, environmental acidification, animals and human health, visibility impairment due to haze formation, aerosol formation, and odours. Fortunately, NH_3

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Nomenclature

NH_3	Ammonia, mg l^{-1} or mg
d	Day
w/w	Ratio of weights
n	Number of replicates
x	Times
P	*p*-value
TAN	Total ammoniacal nitrogen, mg l^{-1}
TS	Total solids, mg l^{-1} or %
TKN	Total kjeldahl nitrogen, mg l^{-1}
CAFO	Concentrated animal feeding operation
ESAVR	Exposed-surface-area to volume ratio
ESA	Exposed-surface-area
ANOVA	Analysis of variance
LSD	Least significant difference
ICL	Idaho conservation league
IDEAL	Independent dairy environmental action league
USEPA	United States Environmental Protection Agency

emissions can be reduced significantly using select manure handling, manure management, and manure treatment techniques (de Boer, Smits, Mollenhorst, van Duinkerken, & Monteny, 2002; Gay & Knowlton, 2005; Ndegwa et al., 2008).

The greatest loss of nitrogen in a livestock operation is due to NH_3 volatilisation from anaerobic lagoons, with only about 20–25% of total nitrogen retained in the lagoon liquid being available for fertilising croplands or pastures (ICL & IDEAL, 2005). In addition to lowering the fertiliser value of the manure, NH_3 volatilisation results in poor air quality which is a public concern. Previous studies have reported on the impacts of manure handling practices on NH_3 emissions within barns but not on the impacts of the handling systems on NH_3 emissions in post-collection storage facilities such as lagoons and scraped manure pits, which are generally considered responsible for the largest portion of NH_3 loss in a dairy, in the US (ICL & IDEAL, 2005; Mukhtar, Mutlu, Capareda, & Parnell, 2008).

The two most common types of manure handling systems, in the dairy industry in the US, are flushing and the scraping systems (USEPA, 2009). In a flushed-dairy system; large quantities of water flush urine and faeces excreted by the animals along a sloped alley into gutters that then deliver the flushed manure into a storage tank or a lagoon. The flushed liquid manure can also be delivered into a pumping pit where it is then pumped into storages or other treatment facilities. The flushing water can either be recycled diluted manure, or fresh water. Research has shown that flushing offers drier floors, and cleaner facilities for the animals (Harner, Brouk, Smith, & Murphy, 2005). In the manure-scraping systems, either a tractor-mounted scraping-blade, or an automatically controlled stand-alone scraping-blade is used for manure scraping. With a tractor-mounted scraper, manure is swept from one end of the manure alley to the other end. In an automatic alley scraping system, a hinged v-shaped chain driven plough is continuously or periodically dragged to draw manure to one end of a manure alley. The scraped manure is usually stored temporarily in solid-stacks in a manure pit or loaded directly onto a manure spreader for immediate land application.

While numerous studies have been conducted to learn which of the two systems mitigate ammonia emissions from the barns more than the other (Ndegwa et al., 2008), no study in the available literature has evaluated NH_3 emissions from post-collection storages of both scraped and flushed manures. The overall objective of this research was, therefore, to evaluate NH_3 emissions from post-collection storages of scraped and flushed manure in simulated controlled lab-scale systems to determine potential NH_3 emissions mitigations from adoption of one system over the other or replacement of one system with the other. Two studies were conducted to achieve the overall goal of this research: (i) evaluation of NH_3 emission flux from simulated storage of scraped and flushed manures based on similar exposed-surface-area to volume ratios (ESAVR), and (ii) evaluation of NH_3 emission flux from storage of simulated scraped and flushed manures based on similar exposed-surface-areas (ESA) of the storages. The assumption in objective (i) was that there was an option in the selection of manure handling system at the design stage and hence the design of the storage facility as is the case in a new dairy, while objective (ii) assumed an existing dairy and replacement of flushing with a scrape system, for example, without a parallel change in the storage facility.

2. Materials and methods

2.1. Faeces and urine collection

Separate faeces and urine samples obtained fresh from lactating cows in controlled studies conducted at University of Idaho, Moscow, ID, US, were used to conduct the studies reported in this article. Fresh faecal samples were collected either from the animal rectum or from the ground immediately upon being voided, while fresh urine samples were obtained by massaging animal vulva. The urine and faeces samples were frozen to minimise microbial degradation. Samples were thawed under ambient conditions overnight prior to the commencement of the studies.

2.2. Manure reconstitution

To objectively compare NH_3 emissions from the respective storages of scraped and flushed manure, it is essential that the source of the manure be similar in all respects. This type of study is, therefore, nearly impossible to conduct in full-scale field studies. To ensure similarity of manure, both scraped manure and flushed manure were reconstituted from the same batches of separately collected urine and faeces. The simulated post-collection storages of both types of manures were then evaluated in similar controlled environmental conditions in the laboratory.

To reconstitute scraped manure, samples of thawed urine and faeces were mixed in the ratio of 1.0:1.68, which constitutes faeces and urine in dairy manure as normally excreted (Hristov et al., 2009). This ratio was similar to published urine to faeces ratios (w/w) ranging from 1.0:1.4 to 1.0:1.9 observed in excretions of lactating dairy cows (Morse, Nordstedt, Head, & van Horn, 1994; Vander Pol, Hristov, Zaman, & Delano, 2007 and Vander Pol, Hristov, Zaman, & Delano, & Schneider, 2008). Flushed manure was reconstituted by 2.5 times dilution of the reconstituted scraped manure using ordinary tap water (Pfost & Fulhage, 2004). Details of preparations of the respective manures are given in Table 1. The characteristics of the reconstituted scraped and flushed manures are presented in Table 2. The values of total kjeldahl nitrogen (TKN) and total ammoniacal nitrogen (TAN) in the reconstituted flush manure were compatible with the 2.5 dilution factor of the reconstituted scraped manure. The TKN and TAN in the reconstituted flushed manure were approximately 2.5 and 2.2 times less than that in the reconstituted scraped manure. The pH and specific weight did not significantly change during the dilution process of scraping manure to reconstitute flushed manure.

2.3. Simulated manure storages and instrumentation

A schematic diagram of the system configuration used in this study, which was used in previous similar studies (Misselbrook, Powell, Broderick, & Grabber, 2005; Ndegwa, Vaddella, Hristov, & Joo, 2009; Shi, Parker, Cole, Auvermann, & Mehlhorn, 2001), is shown in Fig. 1. This system essentially consisted of a simulated-manure-storage, an acid bottle to trap the emitted NH_3, a flow-meter to regulate sweep-air, and a vacuum pump to pull air through the system. Acid sampling for the analysis of the trapped NH_3 was done every day during the first week, every two days during the second week, and every three days during the third week of the experiment. Immediately after sampling, samples were analysed for TAN concentrations using standard methods (APHA, 1992). Each type of manure storage was evaluated in triplicate. The studies were conducted at an average temperature of 17 °C. Ambient air was drawn using a vacuum pump to sweep the NH_3 emissions from the manure surface in each set-up. The airflow rate was controlled at a rate of 1 l min^{-1} using a flow-meter and a critical orifice. The air carrying NH_3 emitted from the headspace of manure storage was passed through 150 ml of 0.2 M sulphuric acid contained in 250 ml gas wash bottles to trap the emitted NH_3.

2.4. NH_3 emissions based on ESAVR

The goal of this study was to determine NH_3 emissions from flush and scraped manures in post-collection storages based on similar ESAVR. In practice, scraped manure occupies less storage than flushed manure. In proportion, scraped manure would occupy approximately 2.5x less storage than flushed manure because of the 2.5x dilution factor, with water, from scraped manure to flush manure (Table 1). Flushed and scraped manure were reconstituted from separate urine and faeces samples and ordinary tap water as described above. The storage of reconstituted flush manure and the scraped manure were simulated in two different storages each providing similar ESAVR to the both the stored reconstituted flushed and scraped manures. The storages of both scrape and flush manures were cylindrical. The exposed-surface-area of scrape manure storage was 183 cm^2, while that for flush manure was 411 cm^2. The storages of scraped and flushed manures contained approximately 1301 and 3317 ml of manure, respectively. The ESAVR of the simulated storages of reconstituted flushed manure was, therefore, approximately 0.12 cm^2 ml^{-1} while the simulated storages of the reconstituted scraped manure was approximately 0.14 cm^2 ml^{-1}. Although these surface-to-volume ratios were not exactly the same, they were considered close enough for the purpose of this study.

Table 1 – Preparation of scrape and flush manures from urine and faeces.

Manure	Urine (g)	Faeces (g)	Water added (g)	Total manure weight (g)
Simulated scrape	500	840	–	1340
Simulated flush	500	840	2010	3350

Table 2 – Characteristics of the reconstituted scrape and flush manures.

Property	Reconstituted scrape manure	Reconstituted flush manure
TS (%)	13.52 ± 0.15[a]	4.13 ± 0.18
pH	8.2 ± 0.1	8.5 ± 0.06
TAN (mg l^{-1})	2595.2 ± 40.9	1202.6 ± 50.5
TKN (mg l^{-1})	5893 ± 98.7	2323.7 ± 89.2
Specific weight (g ml^{-1})	1.03 ± 0.01	1.01 ± 0.004

a Mean ± standard deviation ($n = 3$).

2.5. NH_3 emissions on the basis of ESA

The goal of this study was to quantify and compare NH_3 emissions from scraped and flushed manures in the post-collection storages based on the same exposed-surface-areas (411 cm^2) of the respective simulated storages. The assumption here was that both the scraped and flushed manures were stored in geometrically similar post-collection storages. As alluded to earlier, this will occur if a producer converted from a flushing system to a manure-scraping system but then decides to continue using the old storage facility without modifications.

For this study, flushed and scraped manures were also reconstituted from separately collected fresh urine and faeces, and tap water. Equivalent amounts of flush and scrape

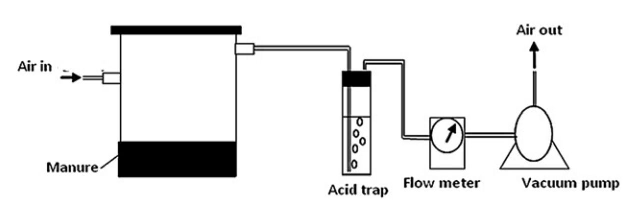

Fig. 1 – A schematic diagram of one of the simulated storages of manure used in our studies.

manures; 3350 g simulated flush manure, and 1340 g of reconstituted scraped manure were each placed in respective storages with similar geometry and hence the same exposed-surface-area. Ammonia emissions from each of these simulated storages were also conducted in triplicate, for the 23-d storage period.

2.6. *Data analysis*

Ammonia emissions from the respective post-collection storages were evaluated based on: (i) total cumulative NH_3 emissions (mg), and (ii) ammonia emissions fluxes (g m^{-2} d^{-1}). Dynamic NH_3 emission rates were computed from the regression plots of the cumulative NH_3 emissions with storage time. Dynamic emission fluxes were obtained by dividing the respective dynamic NH_3 emission rates by the exposed-surface-area of the corresponding storages. An ANOVA was performed on the treatment means using SAS (SAS Institute Inc, 2003) at the significance level of $\alpha = 0.05$. If the results of ANOVA indicated significant differences amongst the treatment means, multiple pair-wise comparisons were performed using the Least Significant Difference (LSD) method to separate the means.

3. Results and discussion

3.1. *NH_3 emissions on the basis of ESAVR*

The goal of this study was to compare NH_3 emissions from simulated flushed manure storage with emissions from simulated scraped manure storage based on the similar ESAVRs. The plots of cumulative NH_3 losses and the dynamic NH_3 fluxes from simulated storages of scraped and flushed manure evaluated at similar ESAVRs are given in Fig. 2. Within experimental errors, the three triplicates, in both cases, were also congruent as indicated by the respective standard deviations represented by the error bars (Fig. 2a). The ANOVA performed on the total cumulative NH_3 losses from the two storages, over the 23 d study duration, however, were not significantly different ($P = 0.80$). The mean NH_3 lost from the simulated storages of flushed manure was 1739 ± 53 mg, while mean loss from the simulated storages of scraped manure was 1752 ± 56 mg. The dynamic NH_3 fluxes, on the other hand, ranged from a high of 5.9 g m^{-2} d^{-1} in d 1 to a low of 2.4 g m^{-2} d^{-1} in d 23 from the storages of scraped manure, and from a high of 2.0 g m^{-2} d^{-1} in d 1 to a low of 1.7 g m^{-2} d^{-1} from the storages of flushed manure (Fig. 2b). The NH_3 emission fluxes from simulated scraped manure storage were significantly higher than emission fluxes from simulated flushed manure storages. This explains the similarity observed between total NH_3 loss from both simulated scraped and flushed manure storages over the 23-d study period: i.e. although the ESA of the storage of flushed manure was greater than that of the storage of scraped manure, the latter storage compensated with a higher NH_3 flux.

On the basis of the results from this study, we conclude that there is no significant difference in NH_3 loss during post-collection storages of either scraped, or flushed-dairy manure if similar ESVARs are maintained in the respective storages.

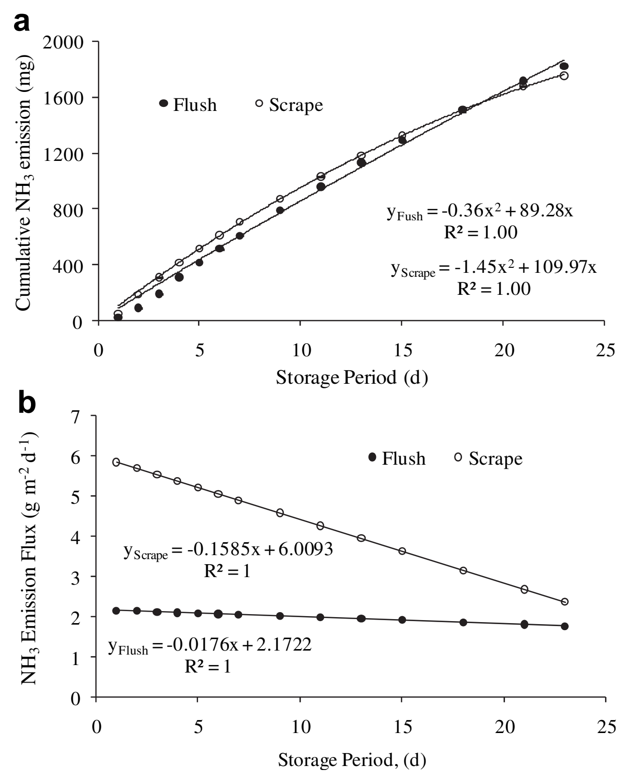

Fig. 2 – Ammonia emissions from storages of reconstituted flushed and scraped manure based on equivalent exposed-surface-area to volume ratio: (a) cumulative loss (mg), and (b) dynamic ammonia flux (g m^{-2} d^{-1}). Vertical bars in (a) represent standard errors of means ($n = 3$).

Since previous research has indicated that manure flushing mitigates NH_3 emissions more than manure scraping in confined barns, we can infer that: manure flushing from barns is probably superior to manure scraping in the overall mitigations of NH_3 emissions in CAFOs if the post-collection storages of manure were based on similar ESVARs.

Based on the results presented in Fig. 2, it appears that for prolonged storage beyond the 23-d storage period invedstigated in this study, the situation may be different because (i) NH_3 flux from the scrape manure declines more rapidly, whereas the NH_3 flux from flushed manure stays more or less constant, and (ii) the cumulative ammonia emissions from the flushed manure seems poised to exceed the total emissions from scraped manure. The rapid decline of NH_3 flux from scraped manure may be attributed to crust formation, which was apparent on the exposed surface of the scraped manure storage. No crust, however, was observed on the surface of the flushed manure. In our study, batch storage of both scraped and storage manures were used, which may promote crust formation on the surface of scrape manure. In the field, however, daily addition of scraped and flushed manures would be deposited into the respective storages and this practice would probably reduce crust formation. On the other hand, our results indicate that, design of storage practices that encourage crust formation from scraped manure, would greatly mitigate NH_3 emissions. The authors recommend future studies focus on longer storage periods with daily or more frequent additions of fresh manure to better mimic field conditions in order to answer some of the questions raised in this research.

3.2. NH_3 emissions on the basis of ESA

The goal of this study was to evaluate NH_3 emissions from simulated storages of flushed against emissions from storage of scraped manures; disregarding the importance of ESAVR. The assumption in this study was that the flushing system was replaced with a scraping system and that the storage facility previously used for the flushed manure, henceforth, was used for the scrape manure. The plots of cumulative NH_3 loss and the dynamic NH_3 fluxes from simulated storages of scraped and flushed manures are presented in Fig. 3. It is also evident that, the three triplicates were also in agreement as indicated by the negligible standard deviations represented by the error bars in Fig. 3a. The dynamic NH_3 fluxes (Fig. 3b) ranged from a high of 2.7 g m^{-2} d^{-1} in day 1 to a low of 1.4 g m^{-2} d^{-1} in day 23 and from high of 2.0 g m^{-2} d^{-1} in day 1 to a low of 1.7 g m^{-2} d^{-1} in day 23, while cumulative total NH_3 losses were 2034 ± 107 and 1739 ± 53 mg from the simulated storages of scraped manure and flushed manure, respectively. Based on the results of one-way ANOVA, both the NH_3 fluxes and the cumulative total NH_3 losses from simulated storages of scraped and flushed manures, were significantly different.

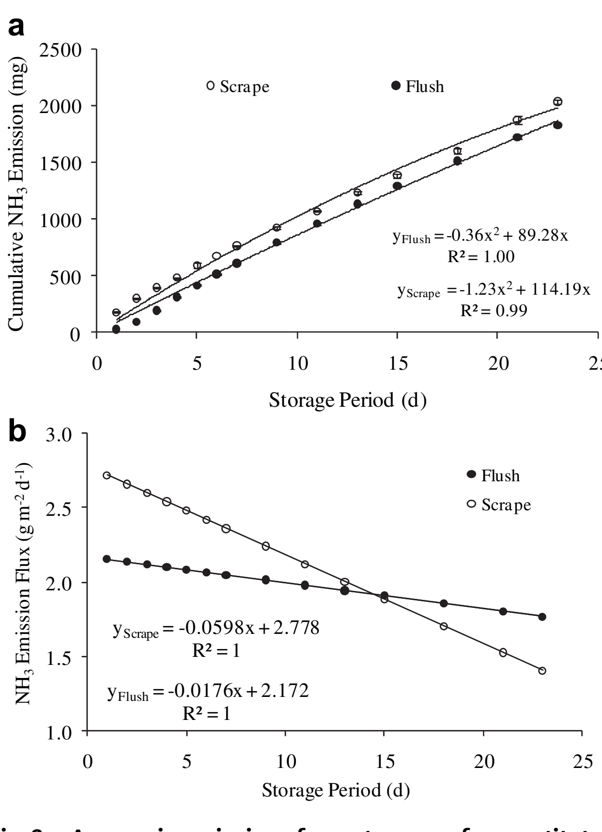

Fig. 3 – Ammonia emissions from storages of reconstituted flush and scrape manure based on similar exposed-surface-areas: (a) cumulative loss (mg), and (b) dynamic ammonia flux (g m^{-2} d^{-1}). Vertical bars in (a) represent standard errors of means (n = 3).

From these results, we infer that, for geometrically similar storages (with respect to ESA), post-collection storage of scraped manure will result in significantly higher NH_3 loss than the storage of flush manure; at least within the first 23 d of storage examined in this study.

The NH_3 flux range of 2.0 to 1.7 g m^{-2} d^{-1} from the simulated storage of flush manure compared well with previously reported NH_3 fluxes from lagoons and other storages of dairy-flushed wastewaters. In a field study, Rumburg et al. (2008) reported NH_3 fluxes ranging between 2.6 and 13 g m^{-2} d^{-1}. Other studies by Smith, Cumby, Lapworth, Misselbrook, and Williams (2007) at both pilot and field scales reported NH_3 fluxes ranging from 1.0 to 7.6 g m^{-2} d^{-1}. From their field studies McGinn et al. (2008) reported NH_3 emission fluxes ranging from 3.6 to 8.6 g m^{-2} d^{-1}. However, NH_3 emission fluxes averaging 0.03 ± 0.013 g m^{-2} d^{-1} in winter, at an average temperature of 6.6 °C, and 1.13 ± 0.19 g m^{-2} d^{-1} in summer, at an average temperature of 29 °C, reported from field studies by Mutlu et al. (2004) using a dynamic chamber method from two anaerobic dairy lagoons do not closely agree with the results of our laboratory studies. In general, the fluctuations of environmental conditions under which McGinn et al. (2008), Mutlu et al. (2004), Rumburg et al. (2008), and Smith et al. (2007) field and pilot studies were conducted, compared to our controlled laboratory conditions, may explain the observed discrepancies. Our studies were also conducted using single batches of manures with no daily addition of manure as is usually the case in field studies. In addition, no two manures are exactly the same because manure properties are affected by many factors such as animal diets, barn management, manure collection and conveyance, manure processing and treatment, etc, prior to storage.

4. Summary and conclusions

A series of laboratory simulation studies were conducted to evaluate NH_3 losses from post-collection storages of dairy manure from two common manure handling systems found in the US: manure flushing and manure scrapping. The conclusions from these studies are:

1. Although the NH_3 fluxes from simulated storages of scraped and flushed manures, based on similar ESAVR, were significantly different, the respective total cumulative NH_3 lost during the 23 d study period were not significantly different. These results thus do not indicate any advantage of scraping the manure over flushing the manure, or vice versa, if the designs of the storages of flushed and scraped manure were based on similar ESAVRs.
2. The NH_3 fluxes and the total cumulative NH_3 losses during the 23 d study period from post-collection storages of flushed and scraped manure in similar storages (i.e. on the basis of ESA) were significantly different. Ammonia emission from the storage of scrape manure was significantly higher than that from storage of flush manure. These results imply that if scraped and flushed manures are stored in geometrically similar post-collection storages, higher NH_3 emissions would occur from the storage of scraped manure.

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