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CASE STUDY: On-Farm Evaluation of Liquid Dairy Manure Application Methods to Reduce Ammonia Losses

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ABSTRACT

The volatilization of NH_3 from land-applied manure is not only a loss of valuable N, but also an air quality concern because NH_3 plays a role in the formation of airborne particulate matter, which can be a health hazard. The relative differences in potential NH_3 losses from land application of liquid dairy manure were determined via 3 methods: surface application, Aerway incorporation (shallow incorporation with a rolling tine aerator), and subsurface injection. Liquid manure was applied at a rate of 190 m^3/ha on 4 farms with average N and P application rates ranging from 28 to 130 kg N/ha and 6 to 36 kg P/ha, respectively. Average NH_3 concentrations were measured with passive samplers for 3 d after manure application and ranged from 0.03 to 0.21 mg NH_3-N/m^3. There were main effects of sampler height, day, and application method. The greatest NH_3 concentrations occurred during the first 48 h after manure application. Concentrations of NH_3 measured at 1 m (averaged over 48 h) indicated that surface and Aerway applications had the greatest concentrations (0.16 and 0.17 mg NH_3-N/m^3, respectively) whereas subsurface injection of manure resulted in a 67% decrease in NH_3 concentration, which was similar to the control plots (0.06 and 0.04 mg NH_3-N/m^3, respectively). Subsurface injection was the best method of liquid manure application for minimizing NH_3 losses.

Key words: ammonia, dairy manure, Aerway, soil injection, best management practice

INTRODUCTION

The state of Idaho has recently experienced rapid growth of the dairy industry. The number of milk cows has increased by approximately 88% in the past decade, with a 122% increase in milk production (National Agricultural Statistics Service, 2007). Idaho is the second largest milk producer among the 12 western states and has become the fourth largest milk-producing state (National Agricultural Statistics Service, 2007). In 2006, there were 477,193 milking cows in Idaho, with 71% of these being located in the Magic Valley region of southern Idaho (United Dairymen of Idaho, 2006).

The concentration of dairy production in the Magic Valley has led to increased land application of manure from these operations within the valley. One impact of land application of these manures is the loss of NH_3 because of volatilization, which is a concern from an air quality perspective because NH_3 plays a role in the formation of airborne particulate matter of less than 2.5 µm, which can be a health hazard (McCubbin et al., 2002; Erisman and Schaap, 2004). In addition, subsequent deposition of NH_3 can lead to damaged vegetation (Fangmeier et al., 1994), reduced biodiversity of natural ecosystems (Sutton et al., 1993), and the nitrification of water bodies (Hutchinson and Viets, 1969).

Concern over the impacts on air quality of large-scale dairy operations has led to the development of a set of rules for the control of NH_3 from dairy farms, which were developed by the Idaho State Department of Agriculture, Idaho Department of En-

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vironmental Quality, the University of Idaho, dairy farm industry representatives, and environmental organization representatives. The rules require dairy farms exceeding specified animal unit thresholds to implement industry best management practices (**BMP**) to control NH_3 emissions through a permit by rule. A permit by rule is a simplified and expedited process whereby a facility that emits air pollutants may register with Idaho Department of Environmental Quality, and the permit conditions are addressed in the rule rather than a site-specific permit.

The permit by rule applies to dairy farms with a capacity to produce 100 or more tons of NH_3 emissions per year. The capacity to produce this NH_3 load is based on the number of animal units or mature cows and the type of manure collection system, and ranges from 2,293 to 7,089 animal units. The rules prescribe various BMP to control NH_3 emissions ranging from installing certain types of waste storage and treatment systems to implementing composting practices and exporting manure. Because land application of manure is also a source of NH_3 emissions, BMP such as injection of lagoon slurry and incorporation of solid manure are considered effective in reducing NH_3 losses from the operations, although there has been no validation or quantification of these reductions.

Brunke et al. (1988) reported that NH_3 flux from surface-applied manure declined rapidly over the period of 10 h and that incorporation of manure led to an 85 to 90% decrease in NH_3 losses. Sullivan et al. (2003) showed that NH_3 losses after swine effluent application to bermudagrass pasture decreased steadily over a 5-d period, with 60% of the total NH_3 volatilization taking place within 4 d of application. Morken and Sakshaug (1998) reported a 62% decrease in NH_3 losses when manure slurry was directly injected into the ground vs. by surface broadcast application, and that the majority of losses occurred over the first 24-h period.

To evaluate the effectiveness of BMP for land application of liquid dairy manure, NH_3 concentrations from test plots were measured using 3 different application methods, surface broadcast, Aerway incorporation (shallow incorporation with a rolling tine aerator), and subsurface injection, to determine relative differences in potential NH_3 losses from these application methods.

MATERIALS AND METHODS

Field Trials

The on-farm trials were conducted at 4 dairy farms located in southern Idaho ranging in size from approximately 200 to 10,000 milking cows. Each farm used a pond to capture runoff water from the open lots as well as wash water from the milking parlors. The pond was used as the source of liquid manure at each of the sites. The treatments at all sites comprised 3 manure application methods (Figure 1): surface broadcast, incorporation using an Aerway system (Aerway SSD, Holland Equipment Ltd., Norwich, Ontario, Canada), and subsurface injection (Balzer Inc., Mountain Lake, MN). At each of the farms, 3 plots of approximately 120 m^2 were arranged in a north-to-south orientation with approximately 50 m between plots to avoid cross-contamination between treatments, because the prevailing winds are normally from the west. The previous crops at 3 of the sites were corn, with one site having barley as the previous crop; 2 of the sites had been disked after harvest and the other 2 were left as corn stubble fields (Table 1).

Manure lagoons were agitated before and during application. Manure was pumped from the lagoon directly to the application equipment. The 3 treatments were applied sequentially during the same day. Subsurface injection placed manure behind the shank in a band approximately 30 cm deep. Aerway application incorporated manure in approximately the top 10 cm of soil with a rolling tine aerator. The Aerway implement was used to apply manure for the surface treatment with the tines in a raised position to avoid disturbing the soil surface.

Within each plot, 3 towers were placed in line perpendicular to the prevailing wind direction and spaced approximately 15 m apart, with the middle tower at the center of the plot. Passive NH_3 samplers (Ogawa & Co. USA Inc., Pompano Beach, FL) were

Figure 1. The 3 manure application methods used to apply dairy lagoon liquids.

Table 1. Manure content and application rates of N and P at the 4 dairy farms and field conditions present at the time of manure application

	Manure nutrient concentration,[1] mg/kg		Manure application rate,[1] kg/ha		
Treatment	TKN	P	TKN	P	Field condition
Farm 1					Corn, disked after harvest, manure applied
Injection	636	45	119	8	
Aerway	625	46	117	9	
Surface	615	42	115	8	
Farm 2					Barley, disked
Injection	296	31	55	6	
Aerway	274	30	51	6	
Surface	275	31	51	6	
Farm 3					Corn, not tilled
Injection	629	170	118	32	
Aerway	691	214	129	40	
Surface	766	198	143	37	
Farm 4					Corn, not tilled
Injection	NA[2]	NA	NA	NA	
Aerway	116	233	22	44	
Surface	187	241	35	45	

[1]TKN-N = total Kjeldhal N in the manure or land applied; P = total P in the manure or land applied.

[2]NA = not applicable.

installed on each tower at a height of 1, 2, and 4 m to determine the NH_3 concentration at each location. Ammonia samplers were changed approximately every 24 h over a 3-d period after manure application. Background concentrations of NH_3 entering the sites were determined by placing 3 towers at an upwind location of the treatment plots following the same procedure described previously. Details regarding the design and calculation of NH_3 concentrations can be found in Roadman et al. (2003). Concentrations from passive samplers are time-average concentrations for the amount of time the sampler was exposed to the air and were calculated with the following equation: mg NH_3-N/m^3 = [NH_3-N (mg/L)/min deployed]/(31.1 cm^3/min) × 1,000,000, where NH_3-N (mg/L) is the concentration of extracted NH_3-N and 31.1 cm^3/min is a constant used to calculate diffusion to the trap (Roadman et al., 2003).

A meteorological station was located adjacent to the application sites and recorded air temperature, soil temperature, wind speed, solar radiation, and relative humidity during the experimental period. Measurements for wind speed, air temperature, and humidity were made at 2 m, and soil temperature was measured at 5 cm below the soil surface. All meteorological instruments were interfaced to a 21X Micrologger (Campbell Scientific Inc., Logan, UT), which recorded data in 10-min increments. Ambient weather data at each farm over the experimental period are shown in Table 2.

NH_3-N Sampler Preparation and Analysis

The disassembled components of the passive samplers were thoroughly cleaned before each use (to avoid contamination and carryover) by rinsing with deionized water, soaking in a 1 *M* HCl bath, rinsing again with deionized water, and then air-drying in a

Table 2. Ambient weather conditions recorded at the application sites over the experimental period

	Farm			
Item	1	2	3	4
Average wind speed, m/s	4.2	4.0	4.0	3.2
Air temperature (minimum), °C	0.8	−0.2	0.6	5.9
Air temperature (maximum), °C	16.1	23.3	22.9	24.3
Average soil temp at 5 cm, °C	7.2	11.6	13.4	13.1
Average relative humidity, %	61	59	59	64
Average solar radiation, W/m^2	149	203	175	132

clean hood. The filters (which trap NH_3) were prepared by saturating a clean filter with 100 µL of 2% (wt/vol) citric acid and air-drying before assembling the samplers (filters were purchased from Ogawa & Co. USA Inc.). Assembled samplers were then placed into airtight containers and transported to the field for deployment. Immediately after collection in the field, samplers were placed back into the airtight containers and then transported to the laboratory. The filters were carefully removed from the samplers with clean forceps and transferred into 15-mL centrifuge tubes, where they were extracted with 5 mL of 1 *M* KCl for 30 min, with the extractant analyzed for NH_4-N via flow-injection analysis (Quickchem 8500, Lachat Instruments, Milwaukee, WI).

Manure Collection and Analysis

For each plot, a grab sample (~1 L) of liquid manure was collected and transported to the laboratory for analysis (1 sample was missed for the injection treatment at farm 4). Manure was digested using the Kjeldahl method (US Environmental Protection Agency, 1974), with total Kjeldahl N determined via flow-injection analysis (Quickchem 8500, Lachat Instruments) and total P determined via inductively coupled optical emissions spectrometry (Optima 4300 DV, Perkin Elmer Inc., Waltham, MA). The manure N and P concentrations and calculated N and P application rates are shown in Table 1. The liquid application rate was approximately 190 m³/ha on all plots, with average N and P application rates ranging from 28 to 130 kg N/ha and 6 to 36 kg P/ha, respectively.

Statistics

Ammonia concentrations were tested for normality by using the Shapiro-Wilk test with the CAPABILITY procedure (SAS Institute, 2004). Where results suggested nonnormality, variables were square root transformed before statistical analyses, with untransformed numbers presented in the text. The data were analyzed using the MIXED procedure of SAS. Data were analyzed using a full factorial model that included application method, sampler height, day, and their interactions as fixed effects, with farm as a random effect. Where appropriate, means separation was carried out using the difference of the least squares means with Tukey-Kramer adjustment and an α level of 0.05. Statements of statistical significance were based on $P < 0.05$ unless otherwise stated.

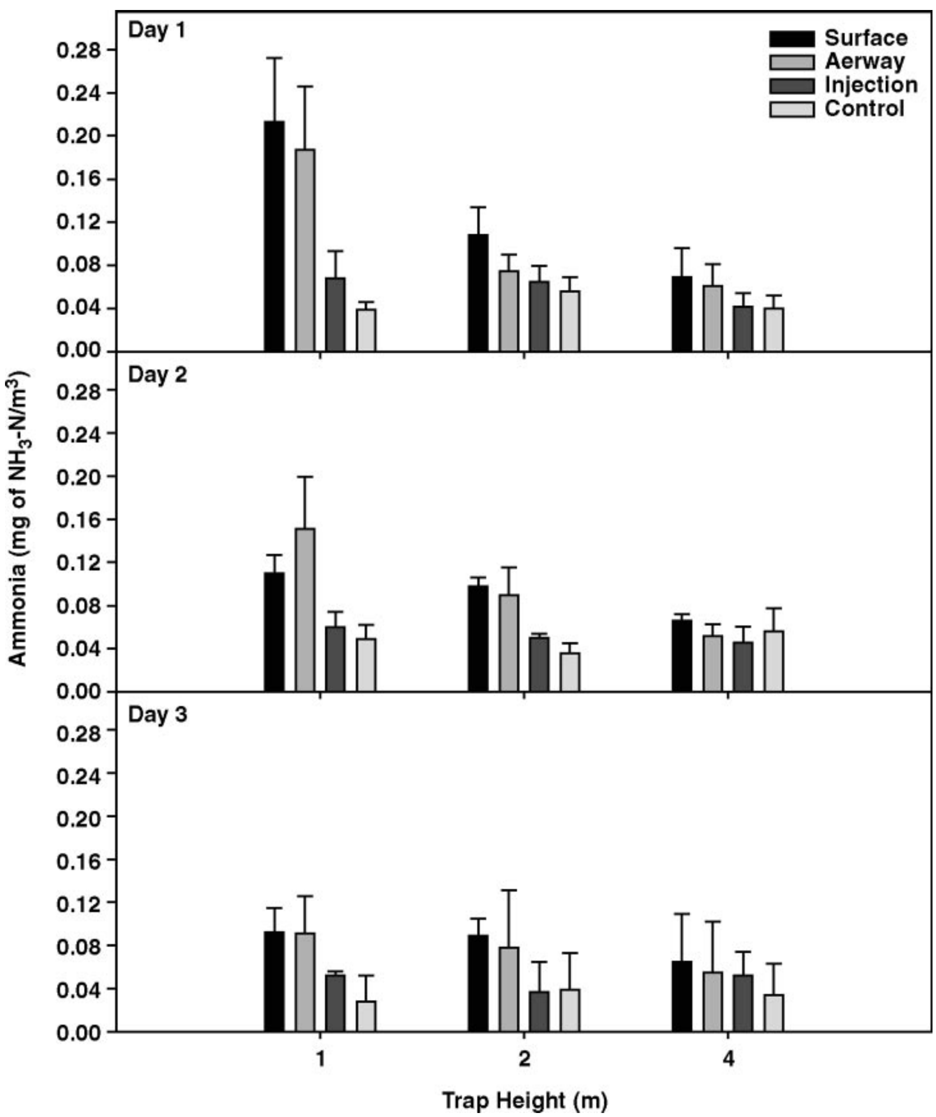

Figure 2. Ammonia concentrations determined for each manure application method over 3 d at 1, 2, and 4 m. Error bars represent the SD of the mean.

RESULTS AND DISCUSSION

The average concentrations of NH_3 ranged from 0.03 to 0.21 mg NH_3-N/m³ over the 3-d period. There were significant main effects ($P < 0.001$) of sampler height, day, and application method, with all interaction terms being not significant. The placement of the samplers had a significant effect on measured NH_3 concentrations, with concentrations being negatively correlated with height of sampler (Figure 2). Average NH_3 concentrations (averaged across treatments and days) decreased by approximately 50% (0.10 to 0.05 mg NH_3-N/m³) as the height of trap placement increased from 1 to 4 m above the soil surface. This trend was likely due to increased dilution of NH_3 with background air as distance increased between the sampler and the NH_3 source. This suggests that it is advisable to place samplers at lower heights to increase sensitivity for measuring treatment differences.

Ammonia concentrations averaged over treatment and height were 0.09, 0.07, and 0.06 mg NH_3-N/m^3 for d 1, 2, and 3, respectively. The greatest NH_3 concentrations were found during the first 48 h after manure application (Figure 2). This is similar to the results of Sullivan et al. (2003), who reported that NH_3 volatilization rates from land-applied swine effluent peaked immediately after application and then rapidly declined to background emissions 4 to 6 d after treatment. Beauchamp et al. (1982) also reported that NH_3 fluxes from land-applied liquid cattle manure were greatest during the first and second day and diminished during succeeding days. Bittman et al. (2005) reported that approximately 85% of NH_3 emissions from land application of liquid dairy manure occurred during the first 24 h. This suggests that immediate incorporation of manure is needed to minimize NH_3 losses and that the benefits are greater when manure is incorporated within 48 h.

Average NH_3 concentrations (averaged across all farms) were 0.11, 0.10, 0.05, and 0.04 mg NH_3-N/m^3 for the surface, Aerway, subsurface injection, and control treatments, respectively. When the full model was used, there was a main effect of application method on NH_3 concentrations following the trend: surface = Aerway > subsurface injection > control. The effect of treatment on NH_3 concentration averaged over d 1 and 2 at a 1-m height is shown in Figure 3 (there was no significant difference between NH_3 concentrations for these days at a 1-m height). The average NH_3 concentrations in this case followed the trend: surface = Aerway > subsurface injection = control. There was a 67% decrease in NH_3 concentration when liquid manure was applied by subsurface injection vs. surface or Aerway application, which did not differ. Hoff et al. (1981) reported an 80% decrease in NH_3 losses by injecting liquid swine manure compared with surface application. Morken and Sakshaug (1998) reported a decrease of 62% in NH_3 losses when manure slurry was injected directly into the ground vs. surface applied. These literature values are very similar to those determined in the present study and indicate that injection of manure is an excellent way to decrease NH_3 losses from land-applied liquid manures.

In the present study, there was no difference between surface application of liquid manure and Aerway application, which incorporates the liquid into the soil surface. This is similar to the findings of Gordon et al. (2000), who reported no difference in NH_3 volatilization when using the Aerway equipment for incorporation vs. surface application. However, in the study by Gordon et al. (2000), the Aerway was used either before slurry application or after, whereas in the present study the manure was applied immediately before the tines of the Aerway system. Contrary to the present findings, Bittman et al. (2005) reported a 48% reduction in NH_3 emissions with Aerway incorporation vs. surface application of liquid dairy manure. In the study by Bittman et al. (2005), the application rates were approximately 2.5-fold less than the rates used in the present study and the plots were harvested pasture, which may have improved incorporation of the liquid manure over that found in the present study and therefore reduced emission rates.

Based on the results of the present study, the use of liquid manure injection would be the best BMP for reducing NH_3 emissions from land application sites. Additionally, immediate incorporation of surface-applied manure is advisable, because most of the NH_3 losses occurred within the first 48 h. Shallow incorporation of liquid manure provided no reduction in NH_3 losses compared with surface application and would therefore not be a suitable BMP for reducing NH_3 volatilization at application rates similar to those used in this study.

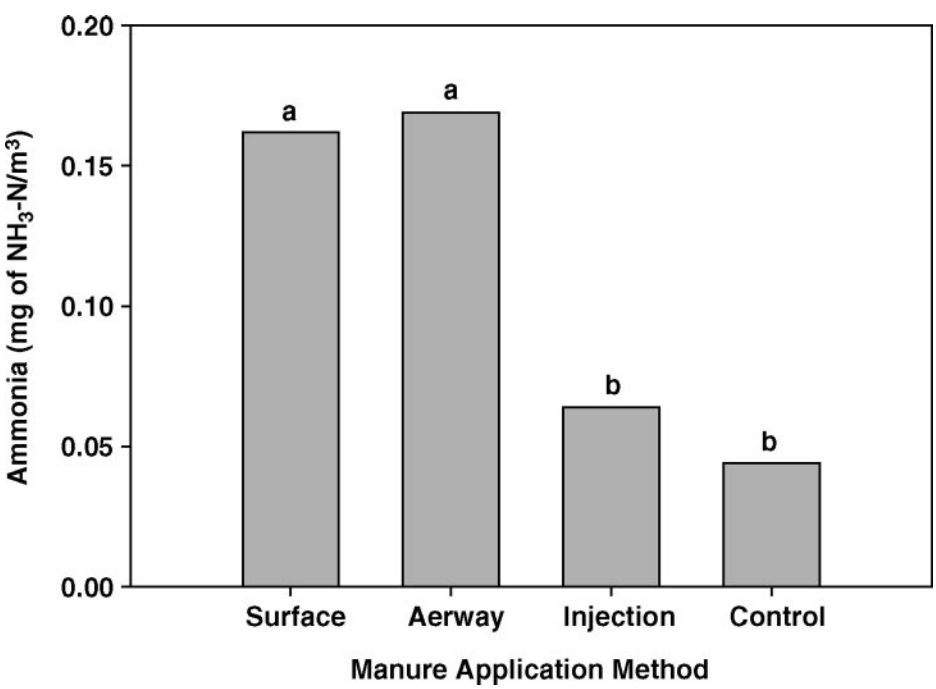

Figure 3. Ammonia concentrations for the manure application treatments averaged over 2 d at 1-m height. [a,b]Treatments with the same letter are not statistically different at $P = 0.05$.

IMPLICATIONS

Subsurface injection of manure reduced average NH_3 concentrations by 67% compared with surface or

Aerway application. Both the surface and Aerway applications had the same NH_3 concentrations, indicating that shallow incorporation of manure (Aerway) did not have an effect on potential NH_3 losses and therefore is not an appropriate BMP to reduce NH_3 volatilization from liquid manure application at these rates. Ammonia concentrations were greatest during the first 48 h after application, indicating that immediate incorporation of surface-applied manure is necessary to reduce NH_3 losses.

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