ON-FARM COMPARISON OF MANURE APPLICATION METHODS IN TERMS OF AMMONIA AND ODOR EMISSIONS AND COSTS

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ABSTRACT

Ammonia and odor emissions from land application of dairy manure, and costs associated with manure land application methods are serious concerns for dairy owners, regulators, and the general public. Odor and ammonia samples from agricultural fields receiving liquid dairy manure applied by surface broadcast and subsurface injection were collected and analyzed. Costs associated with both of the manure application methods were estimated. The test results showed a 68% reduction in ammonia emissions with subsurface injection vs. surface broadcast over a two-day period across two fields. Olfactometry results showed subsurface injection reduced odor emission by 33% compared with surface broadcast; therefore, applying liquid dairy manure by subsurface injection could be recommended as one of the best management practices to control ammonia and odor emissions. The estimated costs associated with surface broadcast were lower than subsurface injection. Further studies evaluating both the manure application costs and agronomic benefits of retained manure N fertilizer in soil are warranted to conclude which manure application method is more economically viable.

INTRODUCTION

Dairy production stands as the single largest agricultural pursuit in the state of Idaho. Currently, Idaho has roughly 550 dairy operations with 580,000 milk cows. Over 70% of milk cows are located in the Magic Valley in southern Idaho. A number of dairies in the Magic Valley use flushing systems resulting in huge amount of lagoon water which is applied to crop lands near the lagoons via irrigation systems. The volatilization of ammonia (NH₃) from the irrigated lands is not only a loss of valuable nitrogen (N), but also causes air quality concerns (Hristov et al., 2011). The land spreading of animal manure accounts for approximately one-third of the total NH₃ emissions from agriculture (Misselbrook et al., 2000) so there has been much interest in the adaptation of dairy manure land application techniques as industry best management practices (BMP) to abate NH₃ emissions. Another impact of land application of dairy manure is odor. Manure spreading has been identified as producing more annoying odor to nearby residents than does the livestock facility itself (Jacobson et al., 2001).

Injection incorporates manure directly beneath the soil surface and thus minimizes odor and NH₃ emissions during application. A range of manure injection technologies have been in use for some time, and they typically lead to reductions in NH₃ emissions of 40 to over 90% compared to broadcast application (Wulf et al., 2002). However, it is still new to Idaho and there has been no quantification of these reductions under Idaho conditions. The objectives of this research were to 1) evaluate the manure injection method under Idaho conditions in terms of mitigating odor and NH₃ emissions, and 2) estimate costs associated with the manure injection method.
MATERIALS AND METHODS

The on-farm tests were conducted on a dairy in southern Idaho. The dairy had approximately 3,500 milking cows managed in a free-stall and open-lot mix set-up. Waste was flushed from lanes running adjacent to the feeding alleys and from the milking parlor. The wastewater passed through solids removal equipment and basins and then into three lagoons in series. Manure used for the field tests was from the last lagoon. The on-farm manure application trials conducted at two sites were comprised of two manure application methods: broadcast and injection (Figure 1). At each of the sites, a square plot of approximately 3,600 m² in the western portion of the site was used for broadcast and the rest of the land was used for injection.

Figure 1. Manure application method with drag hose: a) injection and b) broadcast.

The manure lagoon was agitated before and during application. Manure was pumped from the lagoon directly to the application field via drag hoses. The two manure application methods were demonstrated with the same equipment. Injection placed manure behind the equipment shanks in a band of approximately 8 in. deep. Broadcast was realized by lifting the shanks above ground so manure was applied on the soil surface at the same pumping rate. Manure was applied from east to west and back again until the site was finished. The equipment shanks were lifted only when the equipment was in the designated 3,600 m² square plot for surface application. After manure application in the site, three towers, each 1.5 m high, were placed in a north-to-south orientation with approximately 15 m spacing. The middle tower was placed at the center of the manure surface applied plot. Three towers were placed in the manure injected field parallel to the ones in the manure broadcasted plot and approximately 200 m apart to avoid or minimize cross-contamination between the two manure application methods. Another three towers were placed 50 m upwind (north) of the site. These towers were used for holding passive NH₃ samplers.

A soil temperature probe with data logger was placed 3 cm below the soil surface to record soil temperatures in 15 min increments. Ambient weather data were obtained from the local Airport. The ambient weather conditions and soil temperature at the test sites over the test period are shown in Table 1.
<table>
<thead>
<tr>
<th>Item</th>
<th>Site 1</th>
<th></th>
<th>Day 2</th>
<th></th>
<th>Site 2</th>
<th></th>
<th>Day 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average wind speed, m/s</td>
<td>5.0</td>
<td></td>
<td>4.2</td>
<td></td>
<td>4.2</td>
<td></td>
<td>3.1</td>
</tr>
<tr>
<td>Air temperature, average(minimum, maximum), °F</td>
<td>61 (42, 78)</td>
<td></td>
<td>49 (45, 63)</td>
<td></td>
<td>49 (45, 63)</td>
<td></td>
<td>47 (38, 61)</td>
</tr>
<tr>
<td>Average relative humidity, %</td>
<td>28</td>
<td></td>
<td>53</td>
<td></td>
<td>53</td>
<td></td>
<td>51</td>
</tr>
<tr>
<td>Soil temperature, average(minimum, maximum), °F</td>
<td>51 (48, 56)</td>
<td></td>
<td>47 (43, 51)</td>
<td></td>
<td>47 (41, 52)</td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>

*Data were not correctly recorded.

Air samples were collected from the first test site right after manure application using Tedlar® bags. One air sample was collected at 1 m above ground from each of the three towers located in the broadcast plot, injection site, and background, respectively. A total of nine air samples were collected and analyzed within 24 h after collecting the air samples.

Nine field day attendees were also invited to evaluate odor emitted from the broadcast plot, injection field, and background, respectively using direct perception odor scoring cards. Each attendee was requested to circle one number from 0 (lowest odor perception) to 10 (highest odor perception) that matched his/her odor perception.

Ogawa passive NH₃ samplers were used to determine the time-averaged concentrations of NH₃ at each sampling location. The NH₃ samplers were installed on each tower at heights of 0.5 and 1 m to determine the NH₃ concentration at each location. The passive NH₃ samplers were changed approximately every 24 h over a two-day period after manure application. The two-day period was based on previous studies (Bittman et al., 2005; Leytem et al., 2009).

The passive NH₃ samples were analyzed using a flow-injection analysis system (Quickchem 8500, Lachat Instruments, Milwaukee, WI) at the USDA Northwest Irrigation and Soils Research Laboratory (NWISRL). Concentrations of NH₃-N were calculated with the following equation:

\[
\text{NH}_3\text{-N (mg/m}^3\text{)} = 1000000 \left( \frac{\text{cm}^3}{\text{m}^3} \right) \times \frac{\text{NH}_4\text{-N (mg/L)} \times \text{extractant volume (L)} \times \text{deployed time (min)} \times 31.1 \left( \frac{\text{cm}^3}{\text{min}} \right)}{31.1 \left( \frac{\text{cm}^3}{\text{min}} \right)}
\]

Where NH₄-N (mg/l) is the concentration of extracted NH₄-N from passive sampler filters and 31.1 (cm³/min) is a constant used to calculate diffusion to the filter. Details regarding the calculation of NH₃ concentrations can be found in Roadman et al. (2003).

For each test site, about 1 L of liquid manure was collected and transported to a commercial lab (Stukenholtz Laboratory, Inc., Twin Falls, Idaho) for pH and total N analysis. The manure pH, total N, and calculated total N application rates are shown in Table 2. The liquid manure application rate was approximately 20,000 gal/acre on both the test sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Manure pH</th>
<th>Manure total N concentration (mg/L)</th>
<th>Manure Total N Application Rate (kg/ha) (kg/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>7.4</td>
<td>3433</td>
<td>635 (257)</td>
</tr>
<tr>
<td>Site 2</td>
<td>7.3</td>
<td>3519</td>
<td>655 (265)</td>
</tr>
</tbody>
</table>
Cost analysis was carried out for four different manure land application systems. Cost calculations are based on 500 h annual use for the tractor and 200 h annual use for the injection system. Equipment costs were determined using the MACHCOST program from the University of Idaho’s department of Agricultural Economics and Rural Sociology. Equipment data were provided by John Smith at Smith Equipment Co. Rupert, ID. Some machinery data were taken from “Costs of Owning and Operating Farm Machinery in the Pacific Northwest” PNW 346.

Exact Wilcoxon Two-Sample Tests (SAS PROC NPAR1WAY WILCOXON, SAS institute, 2011) were employed for the odor direct perception score data. The NH$_3$ data were analyzed using the SAS PROC MIXED procedure. T-tests (excel) were performed for the odor olfactometry data. Statements of statistical significance were based on $P < 0.05$.

RESULTS AND DISCUSSION

The average odor concentrations were 44, 61, and 92 OU/m$^3$ for background, injection, and broadcast, respectively as shown in Figure 2. Subsurface injection reduced odor emission by 33% compared with surface broadcast. The Wilcoxon tests showed significant differences between the broadcast and background and between the injection and broadcast, and no significant difference between the injection and background was detected.

![Figure 2. Olfactometry odor results.](image)

Average NH$_3$ concentrations, as shown in the Figure 3, during the two-day monitoring period across both the sites and sampling heights were 0.83, 0.27, and 0.22 mg NH$_3$-N/m$^3$ for the broadcast, injection, and background, respectively. There was a 68% decrease in NH$_3$ concentration when liquid dairy manure was applied by injection vs. broadcast. The results indicate the injection of liquid manure is an appropriate method to significantly reduce NH$_3$ emissions from land applied liquid manure and could be recommended as an industry BMP to reduce NH$_3$ emissions.
Ammonia concentrations averaged over height and site were 1.01/0.65 (Surface broadcast), 0.25/0.29 (subsurface injection), and 0.28/0.16 (Background) mg NH₃-N/m³ for the first/second day, respectively. The highest NH₃ concentrations were measured during the first 24 h after manure broadcast. Ammonia emissions in the broadcast fields were reduced 35% in the second day compared with the first day. This suggests that immediate incorporation of manure is required to reduce NH₃ emissions and that the sooner the incorporation occurs, the greater are the benefits in terms of NH₃ losses. Average NH₃ emissions across fields and sampling heights showed a reduction of 75% and 56% for the first and second day, respectively when injection was compared with broadcast. These results reflect that volatilization of NH₃ is reduced by minimizing the surface exposure of manure with the air and improving the contact with the soil. Previous studies (Misselbrook et al., 2002) also reported that the injection method reduced the peak emission rate observed in the first few hours after application, with differences in emission rates on subsequent days being of less significance and ultimately reaching equality. Based on the NH₃ emission reductions from the first two days of this study, along with the previous findings, it is reasonable to hypothesize that the injection method could reduce total cumulative NH₃ emissions leading to higher N retention in the soil, thus higher N fertilizer value for plants.

The cost analysis results are shown in Figure 4. The broadcast cost per acre is lowest mainly due to the need of smaller tractor and its almost continuous operation and higher operating speed. Although the broadcast system has the lowest cost per acre the applied manure is on the surface. To retain the N fertilizer value the manure would need to be incorporated very soon after broadcast application which would involve another machine operation, thus costing extra money beyond the manure broadcast.
CONCLUSIONS

Subsurface injection can reduce both the odor and NH$_3$ emissions compared with surface broadcast; therefore, applying liquid dairy manure by subsurface injection could be recommended as one of the BMPs to control NH$_3$ and odor emissions. The highest NH$_3$ emission rate from liquid dairy manure applied to land occurs immediately after manure application and the NH$_3$ emission rate decreased dramatically within the first two days after application, indicating that immediate incorporation of manure is needed to reduce NH$_3$ emissions and the sooner the incorporation occurs, the greater are the benefits in terms of NH$_3$ loses. The estimated costs associated with surface broadcast were lower than subsurface injection. Further studies evaluating both the manure application costs and the agronomic benefits of retained manure N fertilizer in soil are warranted to conclude which manure application method is more economically viable.

REFERENCES


