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Subject: Manure Slurry Application Report
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1- Introduction & Objectives

Manure sources are commonly used to supply the nutrient needs of dairy silage corn and forage crops. However, land application of manure sources can result in large emissions of ammonia [NH₃] and major greenhouse gases which include carbon dioxide [CO₂], nitrous oxide [N₂O], and methane [CH₄] if not applied properly. Greenhouse gases from dairy land application could contribute to climate change. Further, NH₃ emissions from land application can lead to high levels of NH₃ in the local areas which can cause nuisance and atmospheric pollution. It is desirable to cut these emissions and improve environmental quality.

Factors influencing greenhouse gases and NH₃ emissions from dairy land application include dietary, housing and manure handling systems; climatic conditions such as temperature, humidity, and wind; soil properties such as texture and pH; and manure application rate and method.

There are several options available for applying solid and liquid manure (e.g., broadcasting with or without incorporation, surface spreading, liquid surface application, shallow or deep injection). Liquid manure can be applied through irrigation systems or spread as a slurry. Application of liquid manure through irrigation systems is very common in California dairy farms. This experiment monitored and compared greenhouse gases and NH₃ emissions from manure slurry application by injection and surface spreading through a drag-hose in a dairy forage field in central California. This technology is relatively new in California.

The drag-hose is a liquid manure application system where the application unit is attached to the source (lagoon) by a long flexible hose, see Figure 1. A pump moves the liquid down the hose to a manure applicator mounted on the tractor, and the application unit injects the manure 10 to 15 centimeters (4 to 6 inches) deep into the soil with a closed slot technique (slurry was fully covered after injection by closing the slots). Little data is available regarding greenhouse gases and NH₃ emissions from different drag-hose equipment.

Greenhouse gases and NH₃ were monitored using the Environmental Protection Agency (EPA) Surface Isolation Flux Chamber approach and a real-time photoacoustic field gas-monitor (INNOVA model 1412, LumaSense Technologies, Inc, Denmark).

The experimental field site was near Hilmar in a commercial dairy. The silage corn was planted on May 23 and harvested on September 23, 2010. Slurry application and emission measurements started on September 27 in the field that had already been worked out for corn stubble at the time of measurements.



Tractor in front helps with moving/relocating the hose around the fields when necessary, and tractor in the back carries the flexible hose and injects the manure slurry.

Figure 1. Drag-hose manure injection system.

The main objective of this study was to evaluate the relative climate and environmental benefits of manure slurry injection method compared to surface spreading. The specific objectives were to quantify and statistically compare greenhouse gases and NH₃ gas fluxes from two different land application methods, surface spreading versus drag-hose injection.

In general, surface application increases the air contact of the slurry and thus could enhance emissions. Injection application, on the other hand, reduces the air contact but can promote anaerobic conditions which could enhance emissions.

2- Field Data Collection

Manure slurry was applied to a silage corn field on a sandy loam soil in the Hilmar area on September 27, 2010. Two treatments were studied in this project: manure slurry injection and surface spreading. Gaseous fluxes of CO₂, N₂O, CH₄, and NH₃ following land application were measured in the field. These gases were monitored immediately after the application, next day, and two days after the effluent application. Soil samples from the test areas were collected for physical and chemical analysis. Manure slurry samples were also taken for chemical analysis. Gases were measured with the EPA flux chamber technique.

The experiment included three replications for injection and surface applications, replicated twice at each sampling site. A total of 12 locations were sampled in this study for three days. Background samples from areas not treated with manure slurry were also taken in the first day. Figure 2 shows the locations of the experimental site.



[Produced using Google Earth]

Figure 2. Locations of flux chamber measurements for injection and surface treatments.

Soil Samples

The U.S. Department of Agriculture soil classification for the experimental site is Hilmar loamy sand (map unit symbol HgA). Results from particle size analysis for particle size distribution are shown in Table 1, which indicate similar soil properties at different locations.

Table 1. Particle size distribution of sample locations.

Sample Date	Sample Location	%Sand	%Silt	%Clay	Soil Texture
9/27/2010	Surface 1 & 2	74%	16%	10%	Sandy Loam
9/27/2010	Surface 3 & 4	80%	10%	10%	Sandy Loam
9/27/2010	Surface 5 & 6	81%	10%	8%	Loamy Sand
9/27/2010	Injection 1 & 2	82%	11%	8%	Loamy Sand
9/27/2010	Injection 3 & 4	78%	12%	10%	Sandy Loam
9/27/2010	Injection 5 & 6	79%	11%	10%	Sandy Loam

Reference method: Soil, Plant and Water Reference Methods for the Western Region 1, 2003, 2nd Edition. Plant, Soil and Water Reference Methods for the Western Region. 1994. R. G. Gavlak, D. A. Horneck, and R. O. Miller. WREP 125.

Soil samples were analyzed for moisture content (percentage) and results are presented in Table 2. As expected, soil samples from surface spreading had higher moisture contents.

Table 2. Soil moisture content at different locations and dates.

Treatment	Sample Location	Moisture Content		
		9/27/2010	9/28/2010	9/29/2010
Background	01	5.0%		
Background	02	4.8%		
Surface	1	34.5%	22.3%	16.6%
Surface	2	41.6%	28.0%	20.0%
Surface	3	46.3%	30.4%	8.9%
Surface	4	42.3%	40.2%	35.7%
Surface	5	52.9%	31.0%	24.0%
Surface	6	45.4%	41.9%	29.3%
Injection	1	6.4%	3.2%	3.7%
Injection	2	4.3%	5.0%	3.2%
Injection	3	4.5%	3.0%	4.1%
Injection	4	10.3%	4.3%	4.8%
Injection	5	7.0%	6.7%	4.1%
Injection	6	5.7%	2.8%	2.4%

Soil samples were collected and sent to a private laboratory (Dellavalle Laboratory, Inc.) for chemical analysis and results are given in Table 3.

Table 3. Report of soil analysis for different locations.

Sample Location	Saturation Percentage (SP)	pHs	Electrical Conductivity (dS/m)	Nitrate, NO ₃ -N (mg/kg)	Total N (%)
Background 02	66	6.4	0.99	92	0.53
Surface 2	50	7.5	2.90	58	0.47
Surface 4	49	6.1	1.11	80	0.35
Surface 6	53	7.4	2.60	59	0.46
Injection 2	67	7.7	1.75	106	0.67
Injection 4	57	6.1	1.13	103	0.40
Injection 6	49	5.8	0.87	70	0.42

Slurry Samples

At the beginning of the slurry application, the slurry was too diluted for land application and the grower decided to use thicker slurry. The diluted slurry was applied in locations Surface 1 and 2 only. The thicker slurry was used in all other locations. Table 4 shows the slurry characteristics such as total nitrogen (TN), ammonium nitrogen (NH₄-N), electrical conductivity (EC), and pH for both thicker slurry (sample 1) and diluted slurry (sample 2). The analysis was performed by Dellavalle Laboratory, Inc.

Table 4. Report of slurry analysis.

Samples	pH	EC	EC	NO ₂ -N	NO ₃ -N	Total	Total	Total N
		µmhos/cm	dS/m	mg/L	mg/L	NH ₄ -N	TKN	TN
Sample 1	7.4	3,020	3.02	<0.1	<0.1	237	681	681
Sample 2	7.1	2,140	2.14	<0.1	<0.1	234	199	199

Emission Measurements

Emissions were measured with INNOVA multi-gas monitor and a flux chamber technique. The INNOVA gas analyzer was setup with a 20-second sampling integration time, which would allow for detection of low gas concentrations. The required time to complete one round of measurements was approximately 150 seconds. Three rounds of measurements were taken at each sampling location and then averaged for the location.

Surface Isolation Flux Chamber (flux chamber) was used to collect the emission data. The main EPA technical reference for flux chamber measurement was used to prepare the recommended protocol (Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber, Users Guide, EPA /600/8-86/008, Radian Corporation, February 1986).

The flux chamber used in this experiment is a clear cylindrical enclosure with a clear spherical top and the following technical data:

- Material of flux chamber: Acrylic resin
- Material of tubing: Teflon
- Height of cylinder: 0.24 m
- Height of half sphere: 0.17 m
- Total Height: 0.41 m
- Diameter: 0.495 m
- Ground surface area: 0.19 m²
- Total volume: 64.5 liters

Sweep air flow (ultra-zero compressed air) was initiated immediately after the placement of flux chambers using 1/4-inch Teflon tubing with stainless still quick-disconnect fitting. The sweep air was adjusted and constantly maintained to deliver 10 liters per minute throughout the measurements using a pressure regulator, metering valve, and rotameter. Sample collection was initiated at steady-state, assumed to be after four residence intervals, or 30 minutes. All 1/4-inch Teflon sample lines were purged with ultra-zero air before sampling. Flux chambers fully washed before the measurements and washed or dry-wiped between sampling locations.

The emission flux was calculated as:

$$E = C Q/A$$

where E is the emission flux ($\text{mg m}^{-2} \text{min}^{-1}$), C is the measured concentration (mg m^{-3}), Q is the sweep air flow ($\text{m}^3 \text{min}^{-1}$), and A is surface area enclosed by the flux chamber (m^2). The following photos show the flux chambers.



Figure 3. Flux chambers- injection treatment site.



Figure 4. Flux chambers- surface treatment site.

One of the main environmental factors affecting gaseous emissions is the ambient air temperature. The air temperature inside the flux chamber is usually higher than ambient air temperature due to enclosure. Table 5 shows the averages of ambient and flux chamber air temperature at the time of measurements. The air temperatures were relatively high in this field experiment. Note that the air temperature inside the flux chamber was always higher in the injection method than in the surface method due to lower soil moisture contents in the drag-hose application method.

Table 5. Average air temperature at the time of flux chamber measurements.

Date	Ambient Air Temperature, °C	Flux Chamber Air Temperature, °C	
		Surface Method	Injection Method
9/27/2010	32.2	33.8	39.4
9/28/2010	33.1	37.5	44.0
9/29/2010	33.0	38.8	46.0

3- Results

The average of net emission flux ($\text{mg m}^{-2} \text{min}^{-1}$) for various gases are presented in Table 6. Background emissions were subtracted from all the measured emissions to provide net emissions.

Measured emission fluxes for N_2O ranged from 0.04 to $0.26 \text{ mg m}^{-2} \text{min}^{-1}$; CO_2 ranged from 11 to $121 \text{ mg m}^{-2} \text{min}^{-1}$; CH_4 ranged from zero (not detected) to $0.65 \text{ mg m}^{-2} \text{min}^{-1}$; and NH_3 ranged from zero (not detected) to $0.52 \text{ mg m}^{-2} \text{min}^{-1}$.

Table 6. Statistics for various net emission fluxes ($\text{mg m}^{-2} \text{min}^{-1}$) for both surface spreading and drag-hose injection treatments.

Gas	Treatment	Date	Mean	Std. Deviation	Max	Min	N
Nitrous Oxide	Background	9/27/10	0.005				2
	Injection	9/27/10	0.064	0.03	0.11	0.04	6
	Injection	9/28/10	0.069	0.01	0.08	0.06	6
	Injection	9/29/10	0.070	0.02	0.10	0.05	6
	Surface	9/27/10	0.102	0.04	0.15	0.04	6
	Surface	9/28/10	0.188	0.06	0.26	0.13	6
	Surface	9/29/10	0.139	0.05	0.21	0.08	6
Carbon Dioxide	Background	9/27/10	22.928				2
	Injection	9/27/10	51.514	24.88	98.99	32.47	6
	Injection	9/28/10	28.941	11.87	47.37	12.70	6
	Injection	9/29/10	28.626	15.54	53.76	11.37	6
	Surface	9/27/10	63.957	32.59	121.59	31.20	6
	Surface	9/28/10	43.348	23.88	74.95	18.66	6
	Surface	9/29/10	36.437	13.85	58.90	21.82	6
Methane	Background	9/27/10	0				2
	Injection	9/27/10	0.168	0.01	0.18	0.14	6
	Injection	9/28/10	0.172	0.13	0.36	0.05	6
	Injection	9/29/10	0.008	0.01	0.02	0	6
	Surface	9/27/10	0.218	0.10	0.41	0.14	6
	Surface	9/28/10	0.176	0.23	0.65	0.07	6
	Surface	9/29/10	0	0	0	0	6
Ammonia	Background	9/27/10	0				2
	Injection	9/27/10	0.028	0	0.10	0	6
	Injection	9/28/10	0	0	0	0	6
	Injection	9/29/10	0	0	0	0	6
	Surface	9/27/10	0.248	0.21	0.52	0	6
	Surface	9/28/10	0.022	0	0.06	0	6
	Surface	9/29/10	0.001	0	0	0	6

Average measured net emission fluxes for surface spreading and drag-hose injection treatments are shown in Figures 5 through 8.

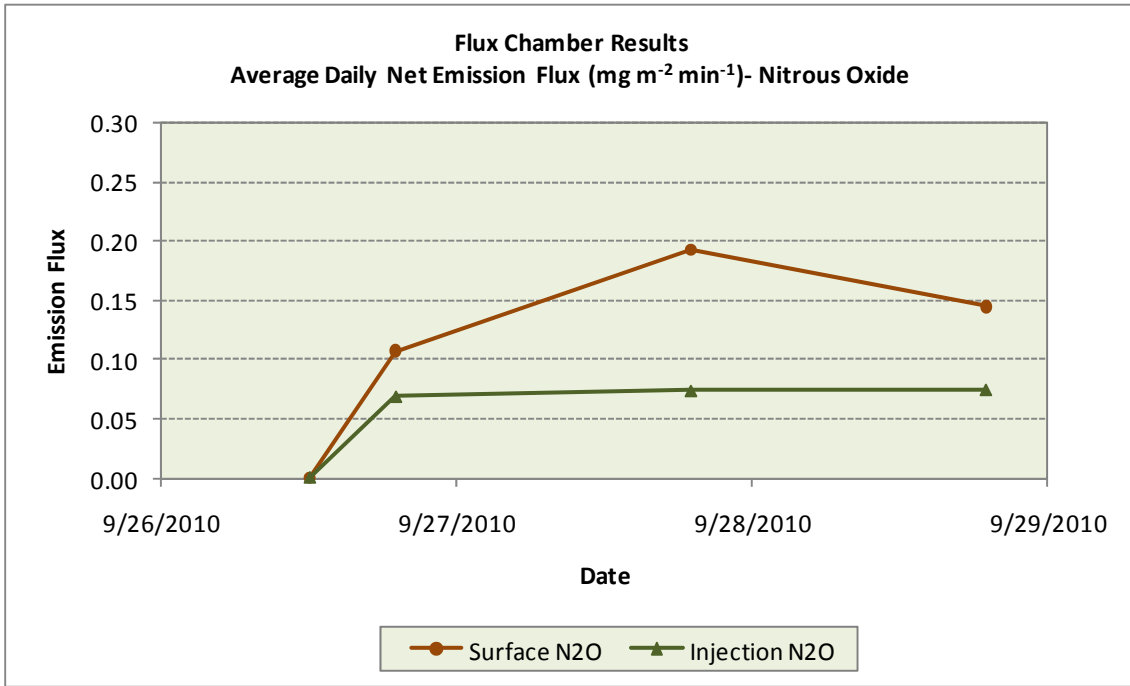


Figure 5. Average measured N2O fluxes.

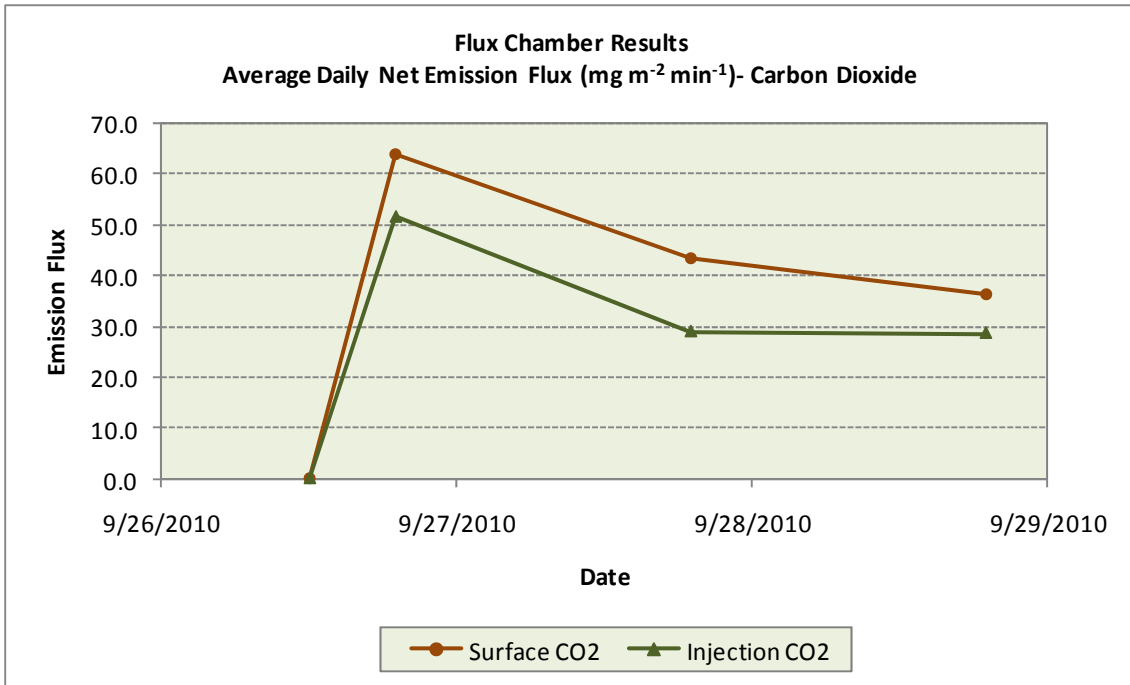


Figure 6. Average measured CO2 fluxes.

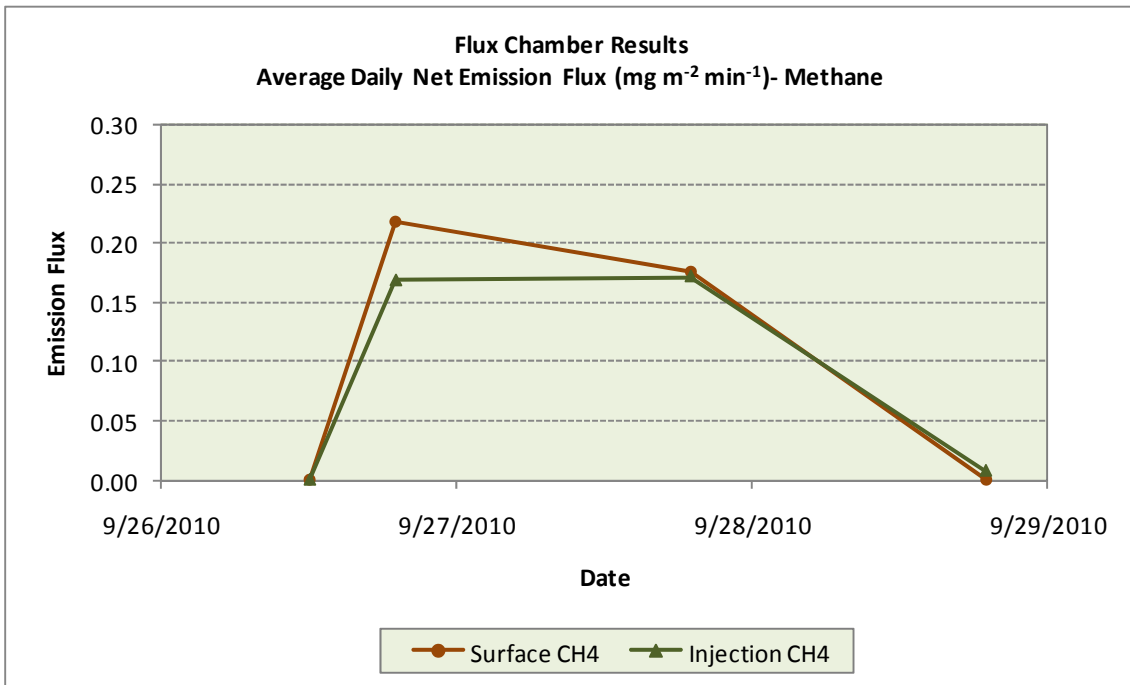


Figure 7. Average measured CH₄ fluxes.

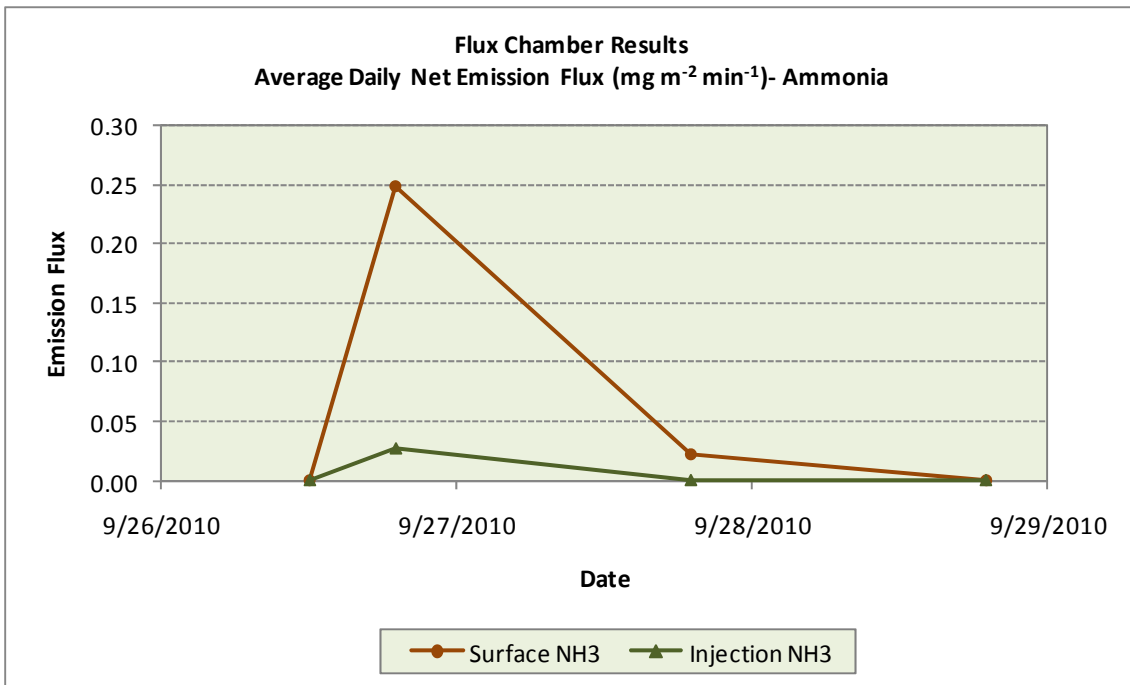


Figure 8. Average measured NH₃ fluxes.

As expected, gas fluxes increased from the low background levels to the maximum levels right after land application and then decreased over time, except N₂O which remained relatively high in the following days. This may be due to denitrification process by microorganisms under partial anaerobic conditions. In general, surface spreading showed higher emissions for NH₃, N₂O, and CO₂ than injection. It appeared that land application treatment had no effect on CH₄ emissions. Nevertheless, not all emission differences between the land application treatments were significant.

Analysis of variance (ANOVA) tests were conducted using the SPSS statistical software (SPSS version 18; SPSS, Inc.) to determine whether significant differences existed in emissions between surface spreading and drag-hose injection treatments ($\alpha = 0.05$). The null hypothesis (H_0) tested was that, on average, the emissions were equal (H_0 : there is no difference between emissions of injection and surface land application).

The observed NH₃ emissions immediately after land application averaged 0.248 and 0.028 mg m⁻² min⁻¹, respectively. These means are significant ($\alpha = 0.05$). In the second day of land application, NH₃ emissions declined to 0.022 and zero (not detected) in surface and injection treatments, respectively, which were not statistically different. The NH₃ emissions were very low in both treatments in the third day after the slurry application.

The measured N₂O emissions averaged 0.102 and 0.064 mg m⁻² min⁻¹, respectively, for surface spreading and injection treatments immediately after the land application. However, the difference between the means was not significant at $p = 0.05$. In the second day, both treatments had higher N₂O emissions but surface treatment had a much higher value, 0.188 and 0.069 mg m⁻² min⁻¹. In the third day of application, N₂O values of injection did not change much (0.07) but that of surface spreading declined to 0.139 mg m⁻² min⁻¹. The differences between N₂O emissions of surface and injection were statistically significant ($\alpha = 0.05$) in the second and third day of land application. In general, injection could increase the potential for N₂O emissions. Denitrification is the main source of N₂O that is controlled by soil aeration and moisture content and can occur in unsaturated soil with oxygen-depleted zones within soil aggregates. Apparently, anaerobic conditions that favor N₂O emissions did not occur soon enough in the injection treatment in this light soil. Surface treatment shows higher N₂O emission flux than injection treatment perhaps due to higher soil moisture (see table 2 for moisture contents in different days).

The measured CO₂ fluxes of surface spreading were higher than drag-hose injection treatments in all days of measurements, and on average, the differences ranged from 20% to near 50%. The differences of CO₂ fluxes between surface spreading and drag-hose treatments were not statistically significant in any days of flux measurements. In the third day after the land application, the fluxes of CO₂ were still higher than the background treatment, which could indicate aerobic microbial activities due to slurry application.

The observed CH₄ emissions were mixed, showing no differences between the land application treatments. Right after application, the averages of CH₄ flux were 0.218 and 0.168 mg m⁻² min⁻¹ for surface and injection treatments, respectively. In the second and third day of application, CH₄ emissions of both treatments were very similar, around 0.17 mg m⁻² min⁻¹ and near zero, respectively.

4- Conclusions

Greenhouse gas (CO₂, N₂O, and CH₄) emissions from dairy effluent application can contribute to climate change. Further, NH₃ volatilization from such applications is currently viewed as a potential local air quality problem. It is desirable to reduce such emissions from anthropogenic sources like land application to improve the environmental quality.

Manure can be applied in different forms (e.g., solid, liquid, slurry) and by various methods (e.g., surface spreading, incorporation, injection), which would result in different degrees of gaseous emissions. Further, manure storage and handling systems before land application play an important role in gaseous emissions. The amount of emissions from land application is highly variable depending upon manure and soil characteristics and the environmental conditions. Thus, all the related processes should be considered together when evaluating the net seasonal environmental benefits.

Greenhouse gas releases and volatile NH₃ losses following slurry manure injection using a drag-hose and surface application were quantified and compared in this short study under a contract with SusCon. Measurements of greenhouse gases and NH₃ emissions from liquid manure land application were made using the EPA Surface Isolation Flux Chamber approach.

The results of this field experiment showed statistical difference ($\alpha = 0.05$) in the emissions of NH₃ and N₂O and no statistical difference ($\alpha = 0.05$) in the emissions of CO₂ and CH₄ from slurry application methods of surface spreading and drag-hose injection.

The results of this study can be summarized as follows:

- Carbon dioxide emissions: No significant differences were observed in CO₂ emissions between surface spreading and drag-hose injection method. In general, land application is not considered a significant CO₂ source compared to other CO₂ sources in the soil-crop environments.
- Methane emissions: The CH₄ emission fluxes were generally low and the land application methods appeared to have no effect on CH₄ emissions in this experiment.
- Nitrous oxide emissions: Surface spreading emitted more N₂O in all 3 days of measurements, about 2 times more N₂O on average. Unlike other gases which increased sharply after application and declined in the following days, N₂O emissions increased in the second day of land application and remained relatively high in the third day.
- Ammonia emissions: The drag-hose injection method produced much less NH₃ gas flux in the first day of measurement following land application, approximately 9 times less NH₃ emissions. NH₃ emissions in both treatments were negligible in the second and third days of land application.
- Results of this experiment showed that significant volatilization of NH₃ can occur right after manure slurry application, and drag-hose injection can minimize the NH₃ losses. Overall, surface spreading emitted more greenhouse gases into the atmosphere and thus showed higher global warming potential. Injecting the slurry into the soil appeared to be an effective way to reduce greenhouse gases and NH₃ losses. The injection tool in drag-hose application creates sub-surface cavities and

manure slurry is injected into the closed-slot cavity through the drag-hose thus minimizing slurry exposure to air and reducing NH₃ volatilization.

- A large portion of NH₃ volatilization and the loss of greenhouse gases from dairy can occur in land application. Yet, limited field experiments are available on how manure application practices (i.e., surface vs. subsurface) affect NH₃ and greenhouse gas emissions in California. More data is needed in this field. While the data from this experiment compared short-term emissions of NH₃ and greenhouse gases for surface and injection methods, long-term manure management practices, including manure storage and farming operations are very important in determining seasonal emissions for the dairy and cropping systems.