EMISSIONS FROM A DAIRY WASTEWATER STORAGE POND, MANURE PROCESSING AREA, AND COMPOSTING YARD IN SOUTH-CENTRAL IDAHO

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ABSTRACT

The purpose of this study was to evaluate the concentrations and emission rates of ammonia (NH_3) and hydrogen sulfide (H_2S) from a wastewater storage pond, manure processing area, and composting area from a 5,000 cow freestall scrape dairy located in south-central Idaho over a 6-month period. Pollutant concentrations were measured using an Ultraviolet Differential Optical Absorbance Spectrometer, and emission rates were calculated using backward Lagrangian modeling via the WindTrax model. Measurements were collected continuously at a final 15-minute integration time. Significant seasonal variability in both concentrations and emission rates of all pollutants were observed between warm (5/31/05 – 9/14/06) and cold (9/15/06 – 12/7/06) periods. Average summertime concentrations adjacent to a 24.2 acre (9.8 hectare) wastewater storage pond were found to be 556.3 ppb for NH_3 and 33.4 ppb for H_2S, with emission rates averaging 28.5 $\mu g/m^2/s$ and 4.3 $\mu g/m^2/s$, respectively. During the cold period, concentrations were found to average 366.3 ppb for NH_3 and 310 ppb for H_2S, with emission rates averaging 18.4 $\mu g/m^2/s$ and 41.5 $\mu g/m^2/s$, respectively. These emission rates are similar to those found from dairy lagoons in Ohio, Texas, and Washington. Average concentrations downwind of a 13.3 hectare composting area during the warm period were found to be 472.2 ppb for NH_3 and 83.1 ppb for H_2S, with average emission rates of 33.4 $\mu g/m^2/s$ and 15.9 $\mu g/m^2/s$, respectively. During the cold season, average downwind concentrations were 270.7 ppb for NH_3 and 461.7 ppb for H_2S, and emission rates averaged 17.3 $\mu g/m^2/s$ and 81.6 $\mu g/m^2/s$, respectively. These emission rates for (NH_3) were similar to those observed in Texas and Washington.

INTRODUCTION

Agriculture has been cited as the largest contributor to non-point source pollution in the USA by the U.S. Environmental Protection Agency (National Research Council, 2003). This situation is repeated in Europe and other parts of the world (Chadwick et al., 2000). Since 1944, the number of livestock farms in the USA and worldwide has decreased, while farm size and productivity have increased considerably (USDA, 1999; World Bank, 2005). Confined Animal Feeding Operations (CAFOs) have become the norm for commercial animal production, especially in the USA and parts of Europe. A high concentration of animals means increasing concentrations of animal wastes, emissions become concentrated in relatively small areas, and new handling, treatment, and disposal challenges have been increased.

During the animal production cycle, the storage of manure, and its application on the field, many gases may be emitted such as NH_3, nitrous oxides (NOx), H_2S, and Volatile Organic Compounds (VOC). Ammonia is produced as a result of natural animal and bacterial processes. Agriculture is recognized as a major contributor of NH_3 emissions, contributing about 55-56% of global NH_3 emissions (Schlesinger and Hartley, 1992). In the USA, approximately 85% of ammonia emissions come from livestock operations (USEPA, 2000).

Over the last 25 years, residential areas have grown closer or mixed with agricultural areas in rural USA, raising conflicts regarding human health, odor, esthetics, and local environmental impact. At the national level, the emission of environmental reactive gases that increase air pollution and produce negative environmental effects like acid rain, eutrophication of water bodies, and particulate matter (PM) increase have negatively affected some regional environments. At a global level, there is increasing concern with global climate change and the effect of human activities on those trends, such as global warming and trans-boundary pollution (National Research Council, 2003; FAO, 2006). In this context, several countries are committed to emissions reduction and control policies to minimize the impact of human activities, agriculture among them. One of the most difficult tasks has been the accurate quantification and prediction of emissions from agriculture, especially from each type of CAFO. The objectives of this study were to quantify the concentrations and emission rates of nitrogenous and sulfurous compounds from a wastewater storage pond, manure processing area, and composting area on a 5,000 milking head freestall scrape dairy in south-central Idaho using Ultra Violet Differential Optical Absorbance Spectroscopy and backward Lagrangian modeling via WindTrax. The effects of seasonal and micrometeorological conditions on the emission rates were also evaluated.

MATERIALS AND METHODS

The study was performed at a 5,000 milking head dairy facility in Wendell, south-central Idaho. Cows were housed in freestall barns that were scraped using a vacuum truck. There were no calves raised in the facility. Both production freestalls and hospital barns are cleaned by vacuum unit that dumps the slurry into a collection pit. The slurry then goes through one of four screw press solid separators. The liquid portion from the screw presses goes to one of the four gravity separator units, and the separated solids go to composting. The gravity separators also receive the wastewater from the milking barn. The liquid portion of the gravity separation goes to the storage pond, and the solid portion goes to composting or direct land application. About 75% of the composted solids are used as bedding material for freestalls; those composted solids not used as bedding are land applied.

Air pollutant concentration measurements were made using Ultra Violet Differential Optical Absorption Spectroscopy (UV-DOAS) (UV Sentry. Cerex, GA). Wind direction, velocity, and temperature data were obtained with a three dimensional (3-D) anemometer (R.M. Young). Data collection and processing were made using Cerex software. Emission rates were obtained using the backward Lagrangian stochastic model (bLs) via WindTrax (Thunderbeach Scientific, 2006).

Measurements were performed from June 01, 2006 (station two), June 07 (station one), and June 12 (station three), to December 07, 2006 (all stations). During this six month period, monitoring was continuously performed 24 hours a day. Data was transferred weekly to a mobile storage unit and transferred to a PC in the lab. Storage pond water temperature was registered continuously from July 27, 2006 to December 07, 2006. Meteorological data from the Idaho Department of Environmental Quality (IDEQ) meteorological station was available from July 21, 2006. UV Sentry systems were installed on stationary positions inside wooden shelters. Station 1 (west storage pond) was positioned on the west shore of the 24.2 ac (9.8 ha) wastewater storage pond. Station 2 was positioned on the east shore of the same pond (east storage pond), also covering the west boundary of the 32.8 ac (13.3 ha) composting yard (compost yard). Station 3 (processing area) was positioned on the eastern boundary of the 4.4 ac (1.8 ha) manure processing area. The water temperature probe was located on the east shore of the storage pond, and was submerged 19.6 inches (50 cm) below the water surface. The UV Sentry Control Program was set to calculate average gaseous concentrations every five minutes. 3-D wind data and temperature using Navajo was set at 15 minutes. The final concentration and emission rate calculation was performed every 15 minutes via WindTrax. Prediction thresholds (R^2) were set to be 0.8 or higher for sulfur (S) compounds, and 0.5 or higher for all other compounds. Statistical analysis was performed using Statistical Analysis System (SAS 9.1). Data was separated by warm season (May 30th to September 14th) and cold season (September 15th to December 7th) based on the local temperature trend change. Each section was also divided into daylight and nighttime periods. Finally, a "typical day" was created averaging hourly data for each season.

RESULTS AND DISCUSSION

On the west side of the storage pond during the warm season, averages were: NH_3 concentration was 586.8 ppb; NH_3 emission rate was 21.52 $\mu g/m^2/s$; H_2S concentration was eight ppb; H_2S emission rate was 0.43 $\mu g/m^2/s$. During the cold season, averages were: NH_3 concentration was 329.8 ppb; NH_3 emission rate was 10.03 $\mu g/m^2/s$; H_2S concentration was 45.7 ppb; H_2S emission rate was 2.99 $\mu g/m^2/s$. (Table 1).

Table 1. Seasonal descriptive statistics: Storage pond, West side.

Season= Warm

Variable	Number of samples	Mean	Median	Std Dev	Std Error	Maximum
NH_3 Conc. ppb	1,789	586.8	6770	369.3	8.7	1,131
NH_3 Emission rate $\mu g/m^2/s$	1,789	21.52	18.72	18.77	0.44	90.64
H2S Conc. ppb	1,789	8	0	28.2	0.7	215.5
H_2S Emission rate $\mu g/m^2/s$	1,789	0.43	0	1.70	0.04	18.36

Season= Cold

Variable	Number of samples	Mean	Median	Std Dev	Std Error	Maximum
NH_3 Conc. ppb	1,221	329.8	301.1	212.8	6.1	813.3
NH_3 Emission rate $\mu g/m^2/s$	1,221	10.03	9.11	7.32	0.21	43.04
H_2S Conc. ppb	1,221	45.7	0	102.2	2.9	441.5
H_2S Emission rate $\mu g/m^2/s$	1,221	2.99	0	7.61	0.22	47.08

On the east side of the storage pond during the warm season, averages were: NH_3 concentration was 556.3 ppb; NH_3 emission rate was 28.52 $\mu g/m^2/s$; H_2S concentration was 33.5 ppb; H_2S emission rate was 4.32 $\mu g/m^2/s$. During the cold season, averages were: NH_3 concentration was 366.3 ppb; NH_3 emission rate was 18.47 $\mu g/m^2/s$; H_2S concentration was 310 ppb; H_2S emission rate was 41.54 $\mu g/m^2/s$. (Table 2).

Table 2. Seasonal descriptive statistics: Storage pond, East side.

Season= Warm

Variable	Number of samples	Mean	Median	Std Dev	Std Error	Maximum
NH_3 Conc. ppb	1,737	556.3	570.7	152.1	3.6	854.2
NH_3 Emission rate $\mu g/m^2/s$	1,737	28.53	29.59	14.03	0.34	115.20
H_2S Conc. ppb	1,737	33.5	0	173.7	4.2	2,052
H_2S Emission rate $\mu g/m^2/s$	1,737	4.32	0	27.97	0.67	356.30

Season= Cold

Variable	Number of samples	Mean	Median	Std Dev	Std Error	Maximum
NH_3 Conc. ppb	2,117	366.3	379.6	170.2	3.7	727.1
NH_3 Emission rate $\mu g/m^2/s$	2,117	18.47	17.99	10.62	0.23	67.40
H_2S Conc. ppb	2,117	310	0	409.8	8.9	2,155
H_2S Emission rate $\mu g/m^2/s$	2,117	41.54	0	63.75	1.39	353.30

On the manure processing area during the warm season, averages were: NH_3 concentration was 427.2 ppb; NH_3 emission rate was 49.04 $\mu g/m^2/s$; H_2S concentration was 9.3 ppb; H_2S emission rate was 1.91 $\mu g/m^2/s$. During the cold season, averages were: NH_3 concentration was 228.8 ppb; NH_3 emission rate was 35.54 $\mu g/m^2/s$; H_2S concentration was 96.3 ppb; H_2S emission rate was 35.10 $\mu g/m^2/s$. (Table 3).

Table 3. Seasonal descriptive statistics: Manure processing area.

Season= Warm

Variable	Number of samples	Mean	Median	Std Dev	Std Error	Maximum
NH_3 Conc. ppb	660	427.2	399.4	209.2	8.1	1,006
NH_3 Emission rate $\mu g/m^2/s$	660	49.04	38.95	32.46	1.26	187.0
H_2S Conc. ppb	660	9.3	0	68.5	2.7	725.4
H_2S Emission rate $\mu g/m^2/s$	660	1.91	0	14.48	0.56	157.80

Season= Cold

Variable	Number of samples	Mean	Median	Std Dev	Std Error	Maximum
NH_3 Conc. ppb	363	228.8	171.2	170.2	8.9	955
NH_3 Emission rate $\mu g/m^2/s$	363	35.54	28.89	27.73	1.46	211.50
H_2S Conc. ppb	363	96.34	0	167.1	8.8	450.2
H_2S Emission rate $\mu g/m^2/s$	363	35.10	0	67.73	3.55	301.0

On the composting area during the warm season, averages were: NH_3 concentration was 472.2 ppb; NH_3 emission rate was 33.38 $\mu g/m^2/s$; H_2S concentration was 83.1 ppb; H_2S emission rate was 15.90 $\mu g/m^2/s$. During the cold season, averages were: NH_3 concentration was 270.8 ppb; NH_3 emission rate was 17.34 $\mu g/m^2/s$; H_2S concentration was 461.7 ppb; H_2S emission rate was 81.64 $\mu g/m^2/s$. (Table 4).

Table 4. Seasonal descriptive statistics: Composting yard area.

Season= Warm

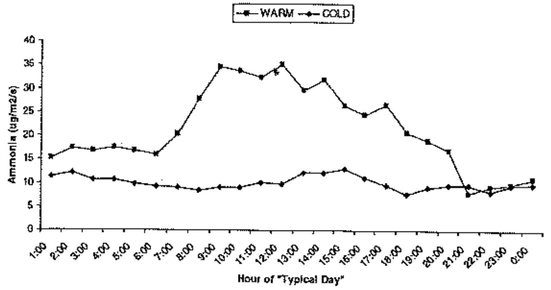
Variable	Number of samples	Mean	Median	Std Dev	Std Error	Maximum
NH_3 Conc. ppb	2,738	472.2	471.8	160.4	3.1	838.6
NH_3 Emission rate $\mu g/m^2/s$	2,738	33.38	25.96	24.36	0.47	176.60
H_2S Conc. ppb	2,738	83.1	0	238.6	4.6	1,632
H_2S Emission rate $\mu g/m^2/s$	2,738	15.90	0	58.78	1.12	1,204

Season= Cold

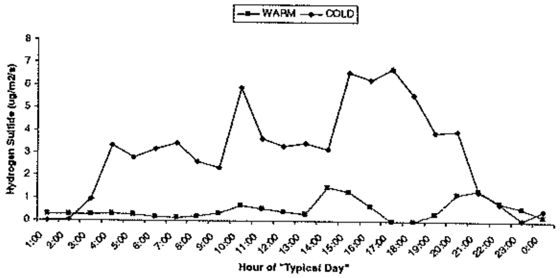
Variable	Number of samples	Mean	Median	Std Dev	Std Error	Maximum
NH_3 Conc. ppb	3,162	270.88	227.8	156.8	2.8	737.5
NH_3 Emission rate $\mu g/m^2/s$	3,162	17.34	15.21	13.30	0.24	301.0
H_2S Conc. ppb	3,16	461.7	589.7	342.9	6.1	1,120
H_2S Emission rate $\mu g/m^2/s$	3,162	81.64	63.91	79.86	1.42	576.0

NH_3 and H_2S concentrations and emission rates were found to have a wide variability between seasons ($P<0.05$) in all positions (Figure 1). Warm season was characterized by higher NH_3 concentrations and emission rates in all positions as expected; with peaks during the daytime period. Cold season was characterized by much higher concentrations and emissions rates of H_2S in all positions, with higher peaks of H_2S during the daytime. These unexpected results are likely due to the action of the thermocline cycle of the pond that can bring up material deposited on the bottom of the pond during the warm season. This, coupled with the associated temperature changes in the pond and in the air, can increase bacterial activity. Another important factor is the increase in air stability and common occurrence of thermal inversions during the cold season that maintain the air mass static, concentrating emissions in the area. The composting yard area had a lower terrain level, which allows water accumulation during periods of precipitation. Coupled with the incomplete mixing of composting rows, this allows anaerobic conditions on the bottom of each row, and the composting area in general.

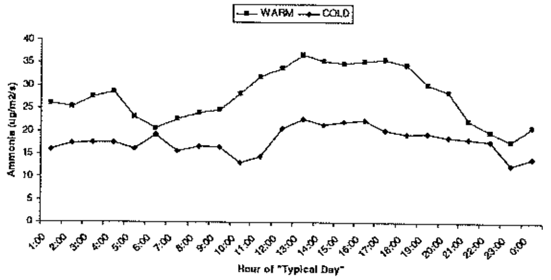
Storage pond, West side NH_3 emission rates per season



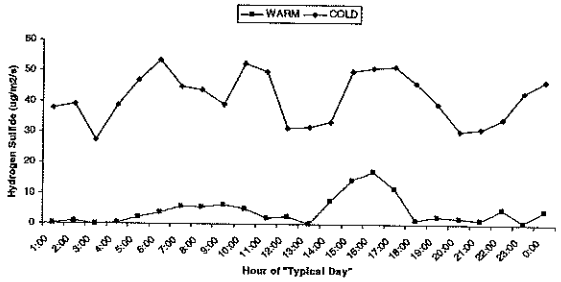
Storage pond, West side H_2S emission rates per season



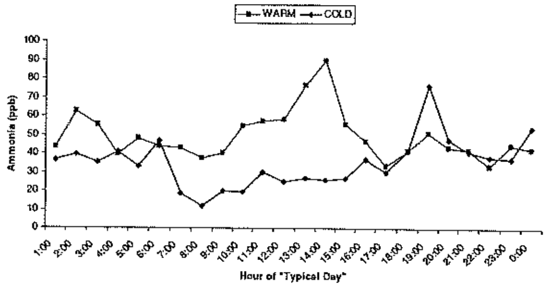
Storage pond, East side NH_3 emission rates per season



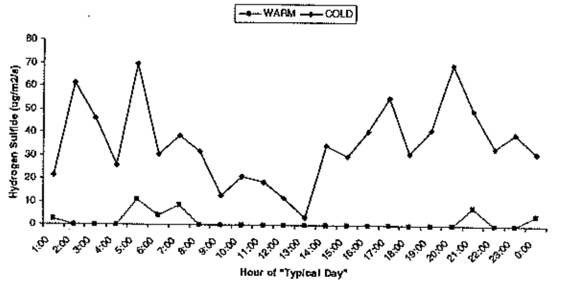
Storage pond, East side H_2S emission rates per season



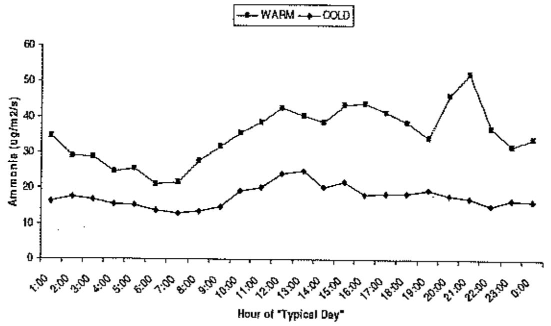
Manure processing area NH_3 emission rates per season



Manure processing area H_2S emission rates per season



Composting yard area NH_3 emission rates per season



Composting yard area H_2S emission rates per season

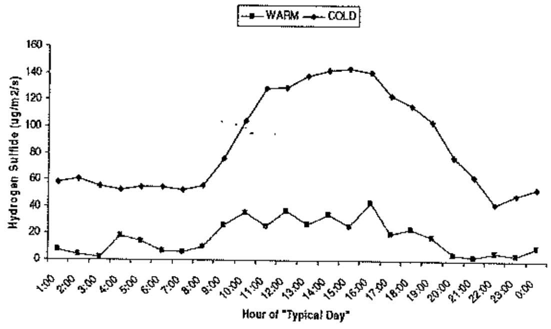
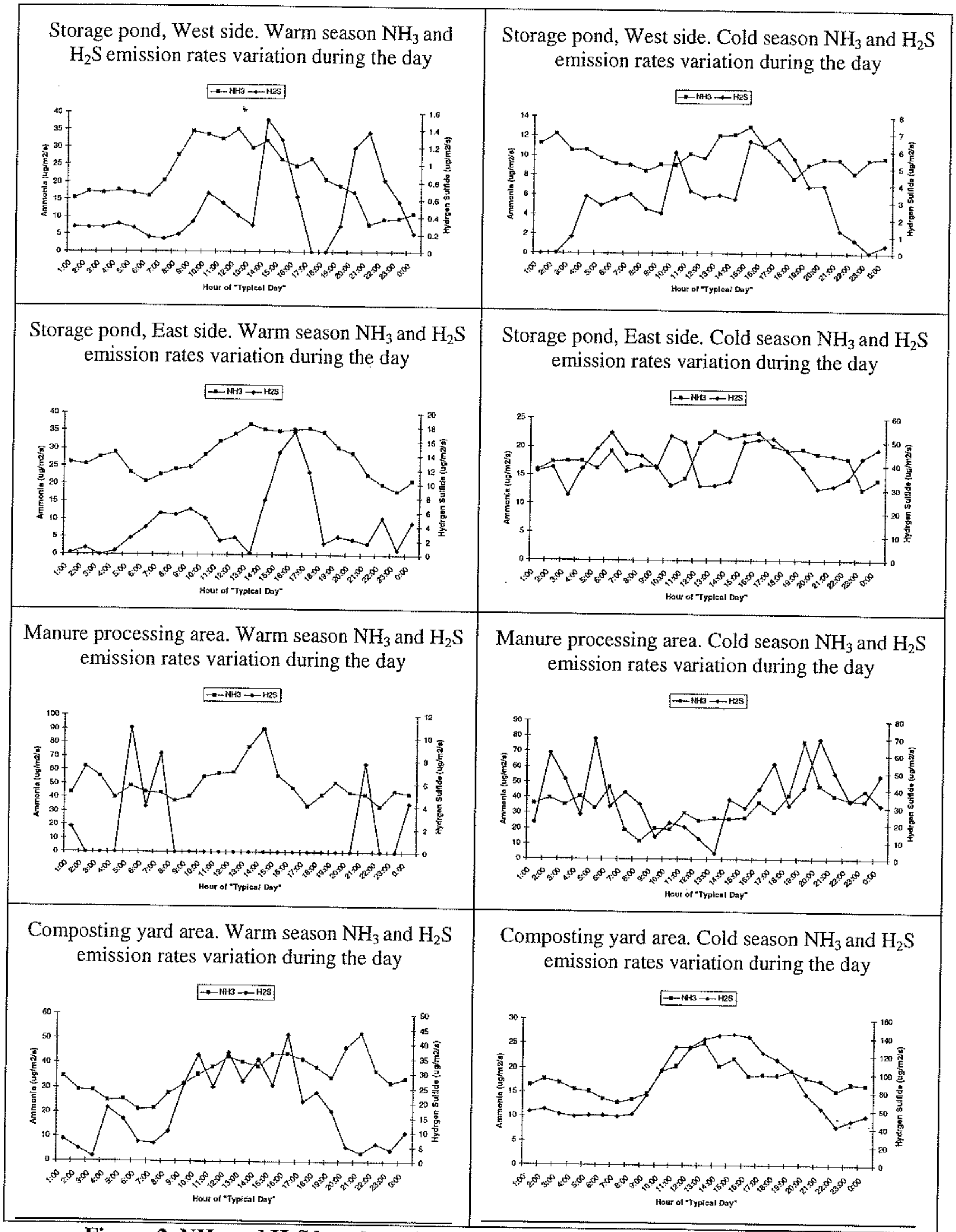


Figure 1. NH_3 and H_2S emission rates daily variation during warm and cold seasons

All positions showed hourly variability on concentrations and emission rates during the day (Figure 2). In the warm season, NH_3 concentrations and emission rates were higher during daylight time. In the cold season, NH_3 emission rates decreased drastically, and higher concentrations recorded during nighttime were likely due to thermal inversions action that concentrate gases in the area. H_2S concentrations and emission rates during the warm season showed some increase during daytime. During the cold season, the increase in H_2S concentrations and emission rates in all positions is very noticeable; it is likely due to the increase of bacterial activity during light hours. Even when air temperatures were below freezing point, bacteria continued to produce H_2S on the sub-surface of the storage pond, compost piles, and manure piles.



Storage pond, West side. Warm season NH_3 and H_2S emission rates variation during the day

Storage pond, West side. Cold season NH_3 and H_2S emission rates variation during the day

Storage pond, East side. Warm season NH_3 and H_2S emission rates variation during the day

Storage pond, East side. Cold season NH_3 and H_2S emission rates variation during the day

Manure processing area. Warm season NH_3 and H_2S emission rates variation during the day

Manure processing area. Cold season NH_3 and H_2S emission rates variation during the day

Composting yard area. Warm season NH_3 and H_2S emission rates variation during the day

Composting yard area. Cold season NH_3 and H_2S emission rates variation during the day

Figure 2. NH_3 and H_2S hourly emission rates variation during a "typical day".

CONCLUSIONS AND RECOMMENDATIONS

This study determined the average concentrations and emission rates of NH_3 and H_2S from the wastewater storage pond, manure processing area, and composting area on a 5,000 cow freestall scrape dairy located in south-central Idaho. Gaseous measurements were made using Ultra Violet Differential Optical Absorbance Spectroscopy and backward Lagrangian modeling via WindTrax. The following conclusions and recommendations were made:

- Highest NH_3 concentrations and emission rates were found during the warm season downwind of the storage pond, processing area, and composting yard.
- Highest H_2S concentrations and emission rates were found during the cold season downwind of the storage pond, processing area, and composting yard. The highest H_2S concentration and emission rates were found downwind of a poorly drained composting yard area.
- NH_3 concentrations in all locations were less than those reported by Mutlu, et al. (2005), but emission rates were much higher. These differences are likely due to differences in methodology. Further studies are necessary to compare different methods like UV-DOAS, wind tunnel, and flux chamber coupled with chemiluminescence conducted at the same location and time.
- Significant predictive relationship ($R^2= 0.69$, $p< 0.05$) was found for NH_3 concentration on the east side of storage pond during the warm season on wind speed, temperature, relative humidity, solar radiation, and water temperature; while atmospheric pressure was found not to be significant. During the cold season ($R^2= 0.92$, $p = 0.05$) wind speed, temperature, pressure, relative humidity, and solar radiation were found to be significant; while water temperature was found not to be significant.
- Significant predictive relationship ($R^2= 0.89$, $p < 0.05$) was found for NH_3 emission rates on the east side of storage pond during the warm season on wind speed, solar radiation, pressure and water temperature; while temperature and relative humidity were found not to be significant. During the cold season ($R^2= 0.93$, $p < 0.05$) wind speed, temperature, relative humidity, solar radiation, and water temperature were found to be significant; while pressure was found not to be significant.
- Significant predictive relationship ($R^2= 0.92$, $p < 0.05$) was found for H_2S concentrations on the east side of storage pond, during the warm season where relative humidity was found to be significant; while the rest of variables (wind speed, temperature, pressure, solar radiation, and water temperature) were found not to be significant. During the cold season ($R^2= 0.93$, $p < 0.05$) all variables were significant.

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