Author(s)

First Name	Middle Name	Surname	Role	Email
Atilla		Mutlu	ASAE Member	atilla@tamu.edu

Affiliation

Organization	Address	Country
Texas A&M University System	Biological and Agricultural Engineering 201 Scoates Hall MS 2117 College Station, TX 77843	USA

Author(s)

First Name	Middle Name	Surname	Role	Email
S.		Mukhtar	ASAE Member	mukhtar@tamu.edu

Affiliation

Organization	Address	Country
Texas A&M University System	Biological and Agricultural Engineering 201 Scoates Hall MS 2117 College Station, TX 77843	USA

Author(s)

First Name	Middle Name	Surname	Role	Email
S.	C.	Capareda	ASAE Member	sergio@cora.tamu.edu

Affiliation

Organization	Address	Country
Texas A&M University System	Biological and Agricultural Engineering 201 Scoates Hall MS 2117 College Station, TX 77843	USA

Author(s)

First Name	Middle Name	Surname	Role	Email
C.	N.	Boriack	ASAE Member	cboriack@tamu.edu

Affiliation

Organization	Address	Country
Texas A&M University System	Biological and Agricultural Engineering 201 Scoates Hall MS 2117 College Station, TX 77843	USA

Author(s)

First Name	Middle Name	Surname	Role	Email
R.	E.	Lacey	ASAE Member	ron-lacey@tamu.edu

Affiliation

Organization	Address	Country
Texas A&M University System	Biological and Agricultural Engineering	USA

	201 Scoates Hall MS 2117 College Station, TX 77843	

Author(s)

First Name	Middle Name	Surname	Role	Email
B.	W.	Shaw	ASAE Member	bw-shaw@tamu.edu

Affiliation

Organization	Address	Country
Texas A&M University System	Biological and Agricultural Engineering 201 Scoates Hall MS 2117 College Station, TX 77843	USA

Author(s)

First Name	Middle Name	Surname	Role	Email
C.	B.	Parnell, Jr.	ASAE Member	c-parnell@tamu.edu

Affiliation

Organization	Address	Country
Texas A&M University System	Biological and Agricultural Engineering 201 Scoates Hall MS 2117 College Station, TX 77843	USA

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Summer Ammonia Emission Rates From Free-Stall and Open-Lot Dairies in Central Texas

Atilla Mutlu, Graduate Research Assistant, atilla@tamu.edu

Saqib Mukhtar, Associate Professor, mukhtar@tamu.edu

Sergio C. Capareda, Assistant Professor, scapareda@tamu.edu

Cale N. Boriack, Graduate Research Assistant, cboriack@tamu.edu

Ronald E. Lacey, Professor, r-lacey@tamu.edu

Bryan W. Shaw, Associate Professor, b-shaw@tamu.edu

Calvin B. Parnell, Jr., Professor, c-parnell@tamu.edu

Texas A&M University, Biological and Agricultural Engineering Department, 2117 TAMU, College Station, TX 77843-2117

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Abstract. *Summer ammonia (NH_3) emission rates (ERs) were compared between free-stall (cows in barns) and open-lot dairies (cows on earthen corrals) each housing nearly 2000 lactating cows in central Texas. A protocol using flux chambers was employed to determine these ammonia ERs from both dairies. Data including (NH_3) concentrations and climatic conditions were collected and ammonia ERs were calculated for the free-stall dairy in summer of 2003 and the open-lot dairy in summer of 2004. Ammonia concentration measurements were made using chemiluminescence-based analyzers. The ground level area sources (GLAS) including free stalls, open lots, separated solids, primary and secondary lagoons, milking parlors and compost site were used to estimate (NH_3) emissions. The estimated emission rates for free-stall and open-lot dairy were 63.1 ±31.1 kg.day^{-1} and 20.6 ±1.6 kg.day^{-1}, respectively. Lagoons (65%) and open-lot corrals (55%) were the highest contributors to (NH_3) emission for the free-stall and the open-lot dairy.*

The difference between the overall emission rates from each dairy was due to waste management practices and animal population density. Higher ammonia ERs from the free-stall dairy as compared to the open-lot dairy were due to higher (NH_3) concentration as a result of greater manure loading of lagoons and barns in the free-stall dairy as compared to open-lot dairy lagoons and corrals.

Keywords. ammonia, free-stall dairy, open-lot dairy, emission rate, flux chamber.

Introduction

Major sources of ammonia (NH_3) emissions include animal feeding operations (AFOs), fertilizer use, waste management, mobile sources and industrial point sources. There are large uncertainties in the variation of emitted concentrations, seasonal variation, and the spatial distribution for each of these source categories (Chitjian and Mansell, 2003). Those uncertainties may hinder obtaining accurate NH_3 emissions estimates.

Animal waste is a major source of NH_3 emission into the atmosphere. High-protein ration, which contains surplus nitrogen, is commonly used as animal feed. Surplus nitrogen is excreted in manure (urine and feces) and microbial activity converts part of this nitrogen in to $NH_{3.}$, The rate of NH_3 volatilization is influenced by a number of factors including concentrations of manure NH_3 and urea, temperature, air velocity, surface area and moisture content (Gay, 2005) and pH level (Becker and Graves, 2004).

The National Research Council (NRC, 2003) identified NH_3 emissions as a major air quality concern at regional, national, and global levels. Currently, NH_3 emissions from animal agriculture are not regulated. However, the EPA issued National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ (USEPA, 1997). Ammonium compounds make-up a large portion of $PM_{2.5}$. and therefore, NH_3 emissions may be regulated in the near future. The regulations aimed at reducing $PM_{2.5}$ emissions will likely require reductions in NH_3emissions from animal feeding operations (Chitjian and Mansell, 2003).

The potential for additional federal air quality regulations accelerates the need for accurate estimates and effective management practices for reducing NH_3emissions. It is important to obtain real-time, direct estimates of emissions from different NH_3 emission sources at animal feeding operations (AFOs) There is a need, therefore, for robust and accurate techniques for the measurement of NH_3 emissions from AFOs to provide reliable data on both current levels of emission and potential abatement strategies. There is also a need to characterize NH_3 emissions by using process-based modeling approaches to estimate emissions from concentrated AFOs.

Flux chambers may be used to measure gaseous emissions, especially NH_3, from the ground level area sources (GLAS). At an AFO, these sources may include lagoons, compost piles, manure storage, open lots and animal buildings.

In this study, NH_3 concentrations were measured from GLAS and converted to emission rates to potentially develop source specific NH_3 emission control strategies. The objective of this study was to compare summer NH_3emission rates of free-stall and open-lot dairies using a flux chamber protocol. This protocol resulted in real-time estimations of NH_3 concentrations, emission fluxes and rates from the free-stall and open-lot dairy GLAS in central Texas.

Materials and Methods

A free-stall dairy and an open-lot dairy in central Texas were chosen to estimate NH_3 emissions using a USEPA approved flux chamber measurement protocol. A description of each sampling site is given below.

Free-stall dairy

A free-stall dairy in central Texas was chosen to estimate NH_3 emission rates in the summer of 2003. A total of 1840 lactating cows and 250 dry cows were housed at the dairy during this study. Cows were housed on the dairies in open lots and free stalls. The free-stall dairy included free-stall type housing and a small portion of open lot unit. There were three free-stall barns located on this dairy.

Accumulated manure in free-stalls was removed by flushing four times a day. The flushed slurry was then conveyed to a solids separator system for liquid-solid separation. The separated liquid was transported to the first cell (lagoon 1) of an anaerobic lagoon. The effluent from lagoon 1 was conveyed to a second cell (lagoon 2) with a pipe outlet for storage and irrigation of crop and pastureland. The rate of manure production was generally higher near feed bunkers and water tanks. The scraped manure was stockpiled and either land applied or composted on-site (Mutlu et al. 2004).

Open-lot dairy:

Approximately 2000 lactating cows were housed at the open-lot dairy during this study in the summer of 2004. This dairy included 12 earthen corrals which were centralized feeding and watering areas and free standing shelters for relief from severe weather conditions. Each corral was an un-paved, confined area with access to feed bunkers and water tanks. Accumulated manure in these lots was removed by scraping using tractor mounted blades once a day. The scraped manure was stockpiled on-site between lagoons and the corrals.

There were two lagoon cells (lagoon 1 and lagoon 2) for storage and treatment of liquid manure at this dairy. Lagoon 1 received waste water from the milking parlor and runoff from corrals. Lagoon 2 was used to store effluent from lagoon 1 and to irrigate crop and pasture land.

Isolation Flux Chamber Sampling Protocol

Real-time samples from free-stall and open-lot dairy were collected continuously using isolation flux chamber method to determine the emission rates of NH_3 from different ground level area sources (GLAS) . Isolation flux chambers have been used to measure emission fluxes of volatile organic compounds (VOCs) and inorganic gaseous pollutants from a wide variety of sources (Eklund, 1992). The design of the flux chamber includes a hemispherical top (dome) and a cylindrical skirt (Figure 1). Odotech Incorporated supplied the hemispherical top for use in this research (Odotech Inc. Montreal, Canada).

Mukhtar et al. (2003) described the flux chamber used in this study. The dome contained four symmetrical holes with stainless steel fittings. A tubing inlet located at one of the stainless steel fittings allowed for the flow of sweep air into the chamber. A fitting on the top of the hemisphere allowed for the pollutant stream to be conveyed to a chemiluminescence analyzer. Two of these holes were used to connect the flux chamber to Teflon® and low density polyethylene (LDPE) tubing used to move the sweep air (contaminant free zero grade air) and sampling air (polluted air from flux chamber) to and from the flux chamber for purging and sampling, respectively.

In this technique, the emitting surface is covered by the flux chamber. The area of the flux chamber covered surface (“foot-print” area of the chamber) was 0.192 m^2 .

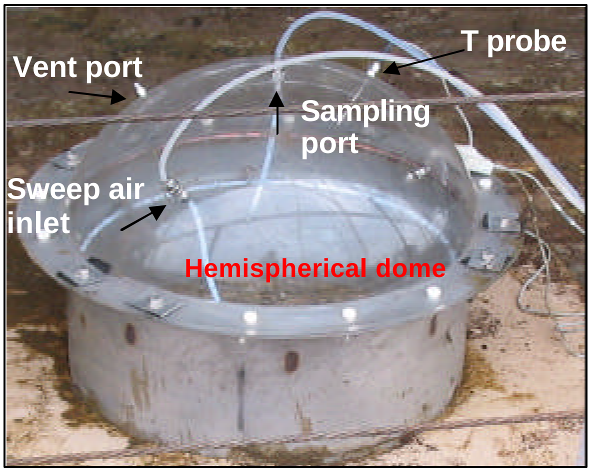

Figure 1. View of isolation flux chamber.

Based on the measurement protocol, NH_3 –free air from a zero air generator (Model 737-12, AADCO Instruments, Village of Cleaves OH) at 7L/min air flow rate was used for 30 minutes to achieve 3.5 residence times to purge the chamber followed by a 30-min NH_3 sampling period (Mutlu et al. 2004). The detail of isolation flux chamber protocol have been provided by Mukhtar et al. (2003), Mutlu et al. (2004), Boriack et al. (2004b) and Capareda et al. (2005).

Measurement of Ammonia Concentrations

On-site measurements for these studies were conducted by using a mobile laboratory. The mobile laboratory included NH_3 analyzers, air flow mixing devices, a multiplexer system including mass flow controllers, a zero air generator, gas cylinders and power generator for electricity.

A chemiluminescence analyzer (Model 17C, Thermo Environmental Instruments, TEI, Massachusetts) was used to measure NH_3 for real time and continuous sampling.

The TEI analyzer was calibrated using known concentrations of NH_3 and nitric oxide (NO), certified standard gases guaranteed by the manufacturer (Praxair, Inc., Danbury, CT) to be within ± 2% accuracy. Mass flow controllers (MFC) (Aalborg, Inc. Orangeburg, New York) were used to control air flow rates. MFCs were necessary to regulate the amount of air supplied to chamber and to the analyzer.

For these studies, an improved automated-air flow control device (multiplexer) was used (Boriack et al. 2004b). The multiplexing procedure was created using the LabView software (National Instruments, Version 6.1, Austin, TX).The program allowed for controlling and regulating all MFCs automatically and simultaneously. Ambient air, source, and chamber temperatures and chamber relative humidity were measured and recorded using HOBO sensors and data-loggers (Onset Computer Corporation, Pocasset, MA).

The flux chambers were covered with insulated shrouds to minimize potential for over heating of the chamber when exposed to the environment. This insulation kept inside temperature of the chamber similar to the ambient temperature (Table 2 and Table 4).

Additional measurement details were provided by Mukhtar et al. (2003), Mutlu et al. (2004), Boriack et al. (2004a), (2004b) and Capareda et al. (2005).

Ammonia Flux and Emission Rate Calculations

To estimate the emission rates, mass concentrations and emission flux values must be known. Measured NH_3 concentrations were converted into mass concentrations (C_{mass}). Emission rates were calculated for each individual GLAS using equation (2).

Once the concentration in mass per volume was determined, equations (1) and (2) were used to calculate NH_3 flux and rate, respectively:

$$EFl_{NH_3} = \frac{C_{mass} \times V_{fc}}{A_{FC}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where

C_{mass} = Mass concentration, (µg/m^3)

EFl_{NH3} = NH_3 gas emission flux (µg/m^2-s)

V_{fc} = Volumetric flow through the flux chamber (m^3/s)

A_{FC} = Aarea of flux chamber ("footprint", 0.192 m^2)

$$ER = EFlxA_{sc} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where:

ER = Emission rate, kg/day.

EFl_{NH3} = NH_3 gas emission flux (µg/m^2-s)

A_{sc} = Area of source (GLAS), m^2.

Measured NH_3 concentrations (in ppm) were corrected for NH_3 adsorption through the flux chambers. The procedure for accounting for adsorption losses has been described by Capareda et al. (2005).

Data Analysis Process for Open-lot Dairy

For the open-lot dairy, each corral had areas (dry, shaded and feeding areas) of varying cow density and hence manure (feces and urine) loading. Dry area was marked by minimum cow activity and manure loading while the feeding area had the highest cow activity and manure loading. A frequency diagram (histogram) of 72 randomly measured NH_3 concentrations in two corrals (Fig. 2) exhibited a non-normal distribution. A log transformation of these data resulted in a normal distribution (Fig. 3). After transformation of these data, a F-test on the normalized NH_3 concentrations was performed to assess significant differences among dry, shaded and feeding areas of these corrals. Ammonia concentrations measured from other GLAS at open-lot dairy had normal distributions and therefore, no transformation of these was performed.

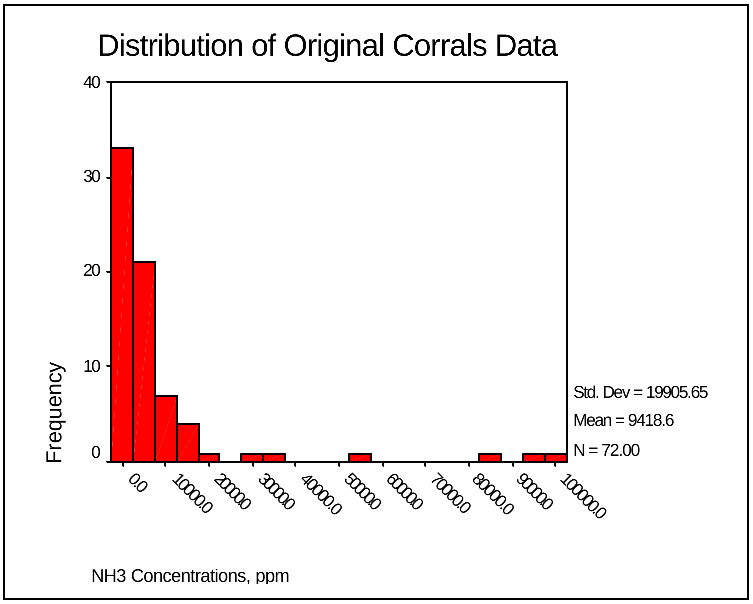

Figure 2. Histogram of original data from open-lot dairy corrals.

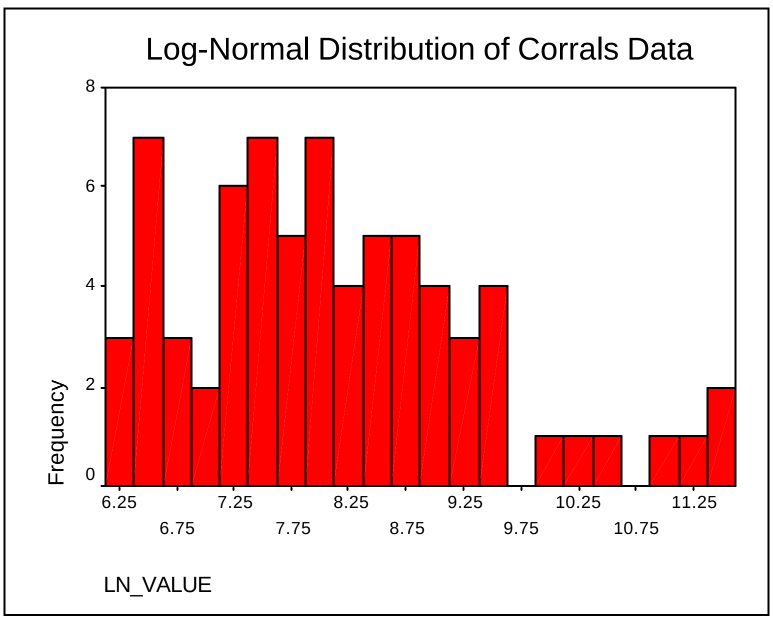

Figure 3. Log-Distribution of corrals data in open-lot dairy.

Results and Discussion

Free-stall dairy

The first study was conducted at a free-stall dairy in the summer of 2003. Fifty-five samples were collected with the isolation flux chamber method to estimate the emission rates of NH_3

from GLAS including an onsite composting operation, free-stall barns, crowding area (adjacent to the milking parlor) separated solids and lagoons. Additionally, for better understanding of NH_3 emissions variations from the free-stall barn, emissions were measured on the feed and non–feed sides and from bedding and watering areas of the barn.

Ammonia concentrations varied highly among and from within areas of GLAS at the free-stall dairy. These concentrations ranged from 1.9 ppm at the composting site to 74.0 ppm on the feeding side of the free-stalls. Results of NH_3 concentration and estimated emission rates are shown in Table 1.

Table 1. Ammonia concentrations and emission rates for free-stall dairy.

GLAS	Number of Samples	Concentration (ppm)	Mass Concentration (μg/m^3)	Flow Rate (L/min)	Emission Flux (μg/m^2/s)	Area (m^2)	Emission Rates (kg/day)
Compost	11	1.9 ± 1.6[b]	1321	7.10	0.81 ±0.7 [b]	16600	1.2 ±0.97 [b]
Freestall	14					9790	
Non-feed	5	57.5 ± 50.5	33349	7.09	20.5 ±23	2700	4.8 ±5.4
Feed	5	74.0 ± 72.4	51574	7.09	31.8 ±31	3090	8.5 ±8.3
Bedding	2	2.4 ± 22.2	1698	7.09	1.05 ±9.5	3800	0.3 ±3.1
Water Area	2	21.7 ± 84.4	15113	7.09	9.3 ±36.2	200	0.1 ±0.63
Open Lot	8	4.8 ± 3.9	3317	7.10	2.05 ±1.7	38000	6.8 ±5.5
Crowding Area	4	9.6 ± 8.2	6690	7.03	4.06 ±3.4	925	0.3 ±0.3
Separated Solids	4	3.7 ± 7.2	2428	7.09	1.5 ±2.9	109	0.01 ±0.03
Lagoon 1	8	32.8 ± 7.1	22878	7.10	14.1 ±3.0	19200	23.4 ±5
Lagoon 2	6	28.1 ± 2.9	19588	7.10	12.1 ±1.3	17000	17.7 ±1.9
Statistic	55[a]	-	-	-	-	101624[a]	63.1 [a] ±31.1

[a] Summation

[b] 95% confidence interval (CI)

Feed area of the free-stall barn had the highest NH_3 concentration followed by the non-feed side, water area and bedding. The feed side of the barn had the most amount of dairy waste accumulation, resulting in the highest NH_3 emissions. Waste around water tanks was diluted due to water spillage by cows in the vicinity, resulting in lower NH_3 emissions than those from feed and non-feed sides. Bedding was composted separated solids with most of the nitrogen tied up in organic matter and very little NH_3 volatilization, hence the lowest NH_3 emissions were measured from the bedding area.

Open lots had lower NH_3 concentrations than free-stalls due to minimum cow activity and lighter loading of manure as compared to free-stalls. Lagoon 1 had higher NH_3 concentrations than lagoon 2 due to greater loading of flushed manure in lagoon 1.

The overall estimated summer emission rate of NH_3 was 63.1 ±31.1 kg day^{-1} for this facility. It was notable that 65% of overall NH_3 emission rates were contributed by two lagoons during the summer sampling. Free-stalls contributed an additional 22% to the overall NH_3 emission rates.

Ground level area source surface, ambient and chamber temperatures and chamber relative humidity (RH) values are presented in Table 2. Chamber RH data was unavailable for several GLAS due to limited number of humidity sensors. The average ambient summer temperature was 31.5 °C. No condensation was observed inside the chamber because GLAS, chamber and ambient temperatures were nearly the same during summer measurements.

Table 2. Weather data of sampling location in free-stall dairy.

Sampling Site	Barometric Pressure	GLAS Temp.	Chamber Temp.	Ambient Temp.	Chamber RH
	[kPa]	[°C]	[°C]	[°C]	[%]
Compost	97.36 ±0.07[a]	43.17 ±7.1[a]	39.13 ±1.8[a]	33.34 ±1.6[a]	36.00 ±29[a]
Free Stall					
Non-Feed side	97.2 ±0.07	25.79 ±3.16	30.12 ±2.05[a]	33.38 ±1.33	-
Bedding	97.3 ±0.0	33.91 ±56.1	33.18 ±5.4	34.60 ±0.2	-
Feed side	97.20 ±0.05	27.02 ±2.78	31.09 ±2.48	33.34 ±3.14	-
Water Area	97.00 ±0.0	23.79 ±2.07	31.47 ±4.4	34.53 ±2.76	-
Open Lot	97.15 ±0.05	30.63 ±3.5	35.30 ±3.1	33.27 ±1.43	64.00 ±27
Crowding	97.14 ±0.03	21.54 ±1.0	24.20 ±1.0	25.62 ±1.0	73.00 ±2
Separated Solid	97.56 ±0.22	34.01 ±5.2	32.66 ±4.7	-	-
Lagoon 1	97.05 ±0.2	29.48 ±1.2	29.68 ±1.8	29.61 ±2.3	87.00 ±9
Lagoon 2	97.24 ±0.08[a]	28.42 ±0.7	27.71 ±2	26.67 ±1.9	89.00 ±11

[a] 95% confidence interval (CI)

Open-lot Dairy

The second study was conducted at an open-lot dairy in the summer of 2004. One hundred twenty six samples were collected from GLAS of the dairy which includes two earthen corrals, primary and secondary lagoons, the milking parlor and its alley. This dairy had 12 earthen corrals for milking cows. Each corral had similar total area (8570 m^2). Two corrals were randomly chosen to represent the entire dairy. Approximately 165 milking cows were fed in each corral.

Results of NH_3 concentration and estimated emission rates are shown in Table 3. Ammonia concentrations ranged from 0.8 ppm for the milking parlor alley to 11.2 ppm for lagoon 1.

Table 3. Ammonia concentrations and emission rates for open-lot dairy.

GLAS	Number of Samples	Concentration (ppm)	Mass Concentration (µg/m^3)	Flow Rate (L/min)	Emission Flux (µg/m^2/s)	Area (m^2)	Emission Rates (kg/day)
Open Lots (earthen corrals)	72	2.9 (±0.1)[b]	2076 (±44)	7.1 (±0.01)	1.3 (±0.3)	102840	11.4 (±0.2)
Lagoon-1	8	11.2 (±0.9)	7810 (±657)	7.1 (±0.01)	4.8 (±0.4)	6273	2.6 (±0.2)
Lagoon-2	35	3.8 (±0.6)	2660 (±444)	7.1 (±0.01)	1.6 (±0.3)	46094	6.5 (±1.1)
Milking Parlor	6	5.6 (±4.1)	3896 (±2877)	7.1 (±0.02)	2.4 (±1.8)	500	0.1 (±0.1)
MP Alley	5	0.8 (±0.4)	575 (±306)	7.1 (±0.02)	0.4 (±0.2)	1500	0.05 (±0.02)
Statistic	126[a]	-	-	-	-	157207[a]	20.6[a] ± 1.6

[a] Summation

[b] 95% confidence interval (CI)

As noted in the Methods section, corral NH_3 data exhibited a non-normal distribution (Fig. 2) and a log transformation was performed that resulted in a log-normal distribution (Fig. 3) Once log-distribution normalized the data, the F-test was run to see any significant NH_3 concentration difference among the feeding, shaded and dry areas of the corral. It was determined that NH_3 concentrations from the dry area were significantly lower than concentrations from feeding and shaded areas ($p_{dry-feeding}$ =0.00< 0.05 and $p_{dry-shaded}$ =0.01< 0.05). The feeding area had higher NH_3 concentrations than shaded area but they were not statistically significant. Mean values of three corral areas are illustrated in Figure 4.

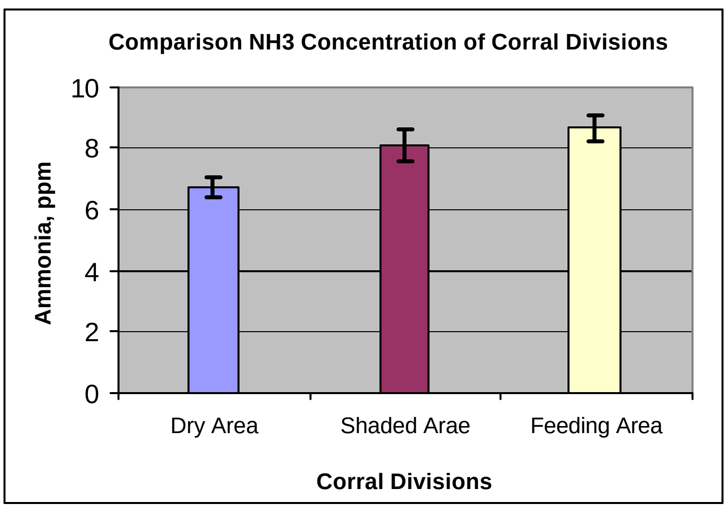

Figure 3. Comparisons of corral divisions in open-lot dairy.

The overall estimated emission rate of NH_3 was 20.6 ±1.6 kg day^{-1} for this facility. Fifty five % of overall NH_3 emission rate was contributed by the earthen corrals. The lagoons contributed an additional 44% to the overall NH_3 emission rates in the open-lot dairy. Lagoon 1 had higher NH_3 concentrations than lagoon 2 due to greater loading of manure and wastewater in lagoon 1.

GLAS surface, ambient and chamber temperatures and chamber and ambient relative humidity (RH) values are presented in Table 4.

Table 4. Weather data of sampling location in open-lot dairy.

Sampling Site	Barometric Pressure	GLAS Temp.	Chamber Temp.	Ambient Temp.	Chamber RH	Ambient RH
	[kPa]	[°C]	[°C]	[°C]	[%]	(%)
Open Lots (Earthen Corrals	96.3[a](±0.01)[b]	27(±0.4)	26.8(±1.3)	27.1(±1.3)	95.4(±5.8)	75.8(±5.2)
Laggon-1	96.7(±0.01)	29.7(±1.3)	29.4(±1.2)	28.9(±1.2)	72(±18)	NA
Lagoon-2	96.7(±0.04)	28.2(±0.2)	27.2(±0.5)	25.9(±0.7)	82.8(±2.8)	72.5(±4.5)
Milking Par.	96(±0.02)	30.3(±1.1)	30.6(±0.8)	30.6(±0.8)	87.3(±26)	NA
MP Alley	96.3(±0.1)	302(±1.7)	28.3(±0.7)	27.3(±1)	81.8(±53)	NA

[a] Average

[a] 95% confidence interval (CI)

As in the previous study, no condensation was observed inside the chamber due to similar values of GLAS, chamber and ambient temperatures. The average ambient summer temperature was 28.5 °C.

Conclusions

There is a need for a robust and accurate technique to measure NH_3 emissions from animal feeding operations (AFOs) to obtain reliable emissions data and to develop abatement strategies. Two studies were conducted to estimate summer NH_3 emission rates (ERs) at a free-stall and an open-lot dairy in Central Texas in 2003 and 2004, respectively. Ammonia emission rates were estimated with an improved flux chamber protocol. This USEPA approved process-based flux chamber method allowed collection of continuous and real time NH_3 emissions data. The estimated emission rates for free-stall and open-lot dairy were 63.1 ±31.1 kg.day^{-1} and 20.6 ±1.6 kg.day^{-1}, respectively. Lagoons and open-lot corrals were the highest contributors of NH3 emission at these dairies.

The difference in the overall emission rate from each dairy was due to different waste management practices and animal population density (corrals vs. free-stall). Higher NH_3 ERs from the free-stall dairy as compared to the open-lot dairy were due to higher NH_3 concentration as a result of greater manure loading of lagoons and barns as compared to open-lot dairy lagoons and corrals.

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