Tentative Final Report

to TCFA

Ammonia and other gaseous emissions from beef cattle feedyards

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NOTE: All data presented in this report are preliminary and are not ready for general release.

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Project Title: Ammonia and other gaseous emissions from beef cattle feedyards

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Summary:

Air quality (odor, dust, PM-10 and PM-2.5 particulates, etc.) is a major concern of the general public, regulatory agencies, and cattle feeders. Appreciable amounts of nitrogen (N) can be lost from feedlot surfaces and contribute to air quality concerns. Ammonia may be the primary source of N losses in feedyards. In addition to being a potential odor concern, ammonia is considered a PM-2.5 precursor because it can react with atmospheric sulfurous- and nitrous oxides to form chemical particles classified as PM-10 and PM-2.5 particulates. By decreasing ammonia emissions, both the quality of air and the quality of feedlot manure may be improved.

In initial studies the methods to sample air at feedyards for ammonia concentration were developed. A one week-long intensive air sampling was conducted at a cooperating feedyard in August 2002 and a second was conducted during January 2003. These trials used gas washing (bubbling air through a weak acid solution to trap the ammonia) and passive samplers (acid treated filters) to measure ammonia concentrations within the feedyard and on the downwind side of the yard. Ammonia emissions were tentatively determined using micro meteorology methods (flux-gradient with gas washing and Box model with passive samplers). In July 2003 a four-week sampling event was conducted at the same feedyard (see agreement 58-6209-2-010) which included the use of open-path lasers and closed chambers to measure ammonia, methane, and nitrous oxide emissions. Tentative results from the August 2002 trial suggest there may be problems with the use of the "box model" in combination with passive samplers positioned at a single height to calculate ammonia emissions from the feedyard. This may be related to difficulty in extrapolating ammonia concentrations to the "top of the plume" under some atmospheric conditions. However, these samplers may still work for determining ammonia concentrations at many sites within or downwind of the feedyard. Results from the three runs suggest ammonia concentrations and emissions tend to have a diurnal pattern with greatest

emissions during the day and lowest emissions during the night. Ammonia emissions during the summer are approximately 2 x those in the winter. We believe this may be due to the effects of temperature on microbial activity and ammonia diffusion in the pen surface. Similarly, the diurnal changes in ammonia concentrations and emissions are related to temperature, solar radiation, and wind. Very tentative results of the July 2003 study suggest the retention pond may be a significant contributor to the overall ammonia emissions from the feedyard. Additional preliminary results from the July 2003 trial using the passive samplers suggest downwind ammonia concentrations (at heights of 1.5 and 3 meters) tend to decrease rapidly and approach back ground concentrations approximately 800 meters downwind of the yard. During stable atmospheric conditions (ie. inversions) the ammonia concentrations downwind of the yard may remain elevated for a good distance downwind.

In concert with this study, ammonia emissions were measured from a simulated feedlot surface. Feces and urine from steers fed either an 11.5% crude protein or 13% crude protein diet were applied to the simulated surfaces on five occasions. Ammonia emissions were determined using the integrated horizontal flux method. Ammonia losses from the circle treated with manure from calves fed a 13% crude protein diet were approximately 30% greater than values from calves fed 11.5% crude protein. Emissions were also highly dependent upon temperature with greater losses during the summer than during the winter. Ammonia losses were greatest immediately after application of the manure then decreased with time. However, if a rain occurred, a second burst in ammonia losses was noted.

A lab-scale system was used to estimate potential ammonia losses from waste water retention ponds and the factors that control ammonia losses. Ammonia losses were affected by pH, and ammonium concentration.

Possible emissions of methane and nitrous oxide are being studied in the July 2003 sampling.

Experimental Protocols

Trial 1: August, 2002:

Ammonia concentrations and tentative ammonia emissions were determined using two methodologies for one week at a cooperating feedyard. On the third day of sampling a 0.5 inch rain occurred. Thus we were able to measure ammonia concentrations and emissions during hot-dry conditions, immediately after a rain, and during the pen drying period.

Flux gradient method: Six meter towers were set up on the north and south sides of a cooperating feedyard. Ammonia concentrations (determined using gas washing), wind speed, and air temperature were determined at 6 heights (1, 2, 3, 4, 5, and 6 meters). Ammonia concentrations were determined at 3 to 9 hour intervals (0600 to 0900, 0900 to 1200, 1200 to 1500 , 1500 to 1800, 1800 to 2100, 2100 to 0600 hours) and ammonia emissions during each timed interval were determined using the flux gradient method.

Box model: Ten 3-meter towers were setup on the north (downwind) side of the feedyard at 80 meter intervals. Ammonia concentrations at 3 meters were determined using passive samplers. Ammonia concentrations were determined at intervals (0600 to 0900, 0900 to 1200, 1200 to 1500 , 1500 to 1800, 1800 to 2100, 2100 to 0600 hours) and ammonia emissions were calculated using a box model described by the University of California.

Pond and pen surface chemistry. Samples were obtained from the retention pond on three occasions. Samples were analyzed for pH, temperature, and ammonia-nitrogen. Pen surface samples were obtained from 3 pens each day and analyzed for pH, dry matter, N, P, nitrate, and ammonia-N.

Trial 2, January, 2003:

Procedures were essentially the same as in Trial 1, however, because the direction of winds in the winter vary greatly from winds in the summer, the flux gradient tower was set up in a hospital pen near the center of the feedyard and the 3-meter towers were set up along the fence line in a working alley near the flux gradient tower. Sampling intervals were also longer than in July being 0900 to 1300, 1300 to 1700, and 1700 to 0900 hours. Temperatures ranged from a low of 10 degrees F to a high of 65 F.

Trial 3, Ammonia losses from simulated feedlot surfaces:

This research was conducted on simulated feedlot surfaces at USDA-ARS-CPRL.

Artificial feedlot surfaces: In a native pasture soil and vegetation were removed from three circular areas to a depth of 6 inches. The circles were 5 meters in diameter: this area was approximately the space that would be occupied by 5 steers in a feedlot pen when animals are allotted 150 square feet each. The soil was replaced with a manure:soil mixture obtained from a near-by feedyard and packed. A three meter tower for mounting of gas washing bottles (to trap ammonia) was placed in the middle of each circle.

Feces and urine: Eight crossbred steers weighing approximately 900 pounds were confined in tie stalls. Four steers were fed a 92% concentrate diet containing 13% crude protein and four steers were fed a diet containing 11.5% crude protein. Total feces and urine excreted were collected each day for 7 days and stored at 34 F. After seven days the samples for each protein treatment were throughly mixed, partitioned into 3 gallon plastic bags (feces) or 1 gallon jugs (urine) and stored frozen.

Sampling: On five dates (April 2002, July 2002, October 2002, January 2003, April 2003) portions of the urine and feces were thawed and applied to two of the simulated feedlot surfaces. Each circle was partitioned into 1 meter squares and to each square were applied approximately 45 grams of feces and 250 milliliters of urine. Feces and urine from steers fed the 11.5% protein diet were applied to one circle and feces and urine from steers fed the 13% protein diet were applied to a second circle. No feces or urine was applied to the third circle. The total quantity of feces and urine applied to each circle was approximately equal to the output of 5 steers for one day.

Ammonia concentrations, wind speed, and air temperature were measured at 5 heights. Ammonia flux from the artificial pen surface was calculated using the integrated horizontal flux micro-meteorology method. Actual times of sampling varied somewhat with each sampling event.

Trial 4: Ammonia losses from experimental retention ponds:

The composition of water from the retention pond of feedyards suggested that the retention pond could potentially be a major source of ammonia losses. Therefore, a lab-scale study was conducted to obtain preliminary data on the possible ammonia losses from retention ponds.

Water was collected from retention ponds at the USDA-TAES research feedlot and at three commercial feedyards. Two liters of Bushland retention pond water were added to each of 36 plastic chambers, amendments (if any) were added, and the chambers were sealed. Two liters of retention pond water from the three cooperating feedyards were added to additional chambers but no amendments were added. Ammonia losses were determined over a 14-day sampling period. Treatments were in a 3 x 2 x 3 factorial arrangement. Ammonia emissions from lagoons are controlled by pH, ammonium concentration, temperature, and air turbulence (primarily determined by wind speed over the surface). To test some of these factors the main effect treatments included the following: 1) pH adjustment - initial pH raised to 9.5 with NaOH, initial pH lowered to 6.5 with HCl, or initial pH not changed, 2) dilution - no dilution or diluted 50:50 with water, 3) urea - 0, 1, or 2 grams of urea added.

Trial 5: Methane and nitrous oxide losses from a feedyard.

Methane emissions determined by the Backward Lagrangian Stochastic (bLS) model using Open path lasers: Methane open-path lasers were set up at various distances downwind of a cooperating feedyard (40, 200, or 800 meters) for three weeks in July 2003. The lasers continuously monitored methane concentrations at a height of 1.5 meters. These concentrations, combined with meteorology data and readings from a sonic anemometer, will be used in the bLS model to determine methane emissions. This model is able to determine the methane plume coming from the yard and is also able to predict methane concentrations at various distances from the yard.

Methane emissions from the retention pond: For one week in July 2003 methane concentrations were determined on the downwind side of the retention pond using open path lasers. The temperature of the retention pond was continuously monitored using HOBO data loggers suspended in the pond at approximately 100 meter intervals. On 10 days samples were obtained from the pond at 5 locations. The pH and temperature were determined immediately. Samples were frozen and will be analyzed for total nitrogen and ammonia nitrogen.

Methane and nitrous oxide emissions from the pen surface using chambers: Twelve PVC chambers (8 inches in diameter) were driven into the surface (depth of 6 inches) of three pens from which cattle had recently (ie less than 24 hours earlier) been removed. The chambers were routinely left open, but at various intervals the chambers were sealed and air samples were obtained from the chamber interior at 0, 30, 60, and 90 minutes using gas tight syringes. The samples will be analyzed for methane and nitrous oxide using gas chromatography. The increase in methane and nitrous oxide concentrations over time is a measure of methane and nitrous oxide flux rate. To additional chambers either water (to simulate a 0.5 inch rainfall) or urine (to simulate a single urination) collected from steers fed a high concentrate diet was applied and methane and nitrous oxide concentrations were measured as described.

Trial 6. Downwind ammonia concentrations.

During the July 2003 sampling event at a commercial feedyard, passive (with two co-located active samplers) samplers were set up 10, 25, 50,100, 200, 400, and 800 meters north of the feedyard at heights of 1.5 and 3.0 meters. This is the prevailing downwind side of the yard. Samplers were changed out at 0600,1200, and 1800 hours each day. Samplers were extracted and analyzed for ammonia to determine ammonia concentrations on the downwind side of the yard.

Tentative Results

Trial 1: August, 2002:

Tentative ammonia emissions calculated using the flux gradient and box model methods are presented in Table 1. On average, calculated emissions were approximately 30 to 35% of total daily nitrogen fed. Tentative ammonia emissions calculated using the box model were highly variable but in general tended to be higher that those using the flux gradient method. On several occasions the values determined using the box model seemed to be unreasonably high. The box model assumes that atmospheric ammonia concentrations on the downwind edge of the feedyard decrease with height in a log linear fashion and that this change is consistent across the entire width of the yard. The value for the height of the ammonia plume is determined by extrapolation. Under some atmospheric conditions these assumptions may not be valid and thus give elevated values for ammonia emissions. In addition, when pens were cleaned near a sampler the ammonia concentrations at that segment of the feedyard edge were greatly elevated and could potentially cause an overestimation of ammonia emissions.

There was a diurnal pattern in ammonia concentrations and emissions with highest values during the day and lowest values at night. Immediately following the rain event ammonia emissions appeared to decrease. However during the drying period emissions tended to be greater than during the hot-dry period.

Table 1. Calculated preliminary ammonia flux determined using the flux gradient method and box model of Ashbaugh (micrograms / m**2/ second) and average ammonia concentrations 30 meters north of the feedyard (micrograms/m**3) at a height of 3 meters in August 2002

Day	Time interval, hours	Flux gradient	Box model		Concent-ration	Misc. information
			Tower only	Passives		
Mon	1100 to 1300	46.5	49.5	55.4	555	
Mon	1300 to 1600	65.5	36.2	38.7	678	
Mon	1600 to 1900	49.9	58.7	46.3	384	
M-T	1900 to 0700	26.5	83.9	108.9	336	
Tue	0700 to 1400	24.8	64.4	56.9	350	Rain
Tue	1400 to 1900	39.1	-	-	548	poor profile
T-W	1900 to 0700	41.8	-	-	549	poor profile
Wed	0700 to 1000	58.2	68.6	67.6	798	
Wed	1000 to 1300	56.3	(171.6)	(163.1)	730	
Wed	1300 to 1600	52.7	(126.7)	(140.8)	882	
Wed	1600 to 1900	64.2	85.3	(100.4)	632	
W-T	1900 to 0700	34.6	39.7	39.4	494	
Thur	0700 to 1000	-	(80.3)	(97.9)	604	
Thur	1000 to 1300	-	27.3	40.2	258	
Thur	1300 to 1600	25.8	(369.2)	(224.9)	496	
Thur	1600 to 1900	44.7	69.2	67.0	573	
T - F	1900 to 0700	26.9	83.5	70.2	566	
Fri	0700 to 1000	24.4	43.1	56.0	775	
Fri	1000 to 1300	31.4	58.7	72.5	650	
Fri	1300 to 1600	62.4	61	54.4	552	
Fri	1600 to 1900	52.9	43	46.5	661	

F-S	1900 to 0700	27.3	75.5	76.3	652	

(Values in parenthesis are highly questionable)

Studies in Nebraska using total N balance methods suggest that atmospheric nitrogen losses during the summer are about 50 to 60% of daily nitrogen intake. Our values were approximately 50 to 60 % of the Nebraska values. If both values are accurate, this suggests a good portion of atmospheric nitrogen losses may be dinitrogen gas and/or nitrous oxide, products of nitrification and denitrification in the soil. Nitrous oxide is a "greenhouse" gas that is a potential concern. However, dinitrogen is a completely innocuous gas that comprises approximately 80% of normal air. Studies indicate that upwards of 50% of atmospheric nitrogen losses from swine lagoons may be as dinitrogen gas.

Ammonia concentrations on the downwind edge of the feedyard varied greatly. When pens were being cleaned upwind, greater ammonia concentrations were noted.

Pond and pen surface chemistry: The temperature of the retention pond averaged 25.3 C (77 F). The pH averaged 8.6. The high pH suggests conditions are conducive to release of ammonia from the retention pond.

Average composition of pen surface sample are present in Table 2. In general, only a small percentage of the total N in the pen surface was as nitrates or ammonia. Assuming the diet contained 13.5% crude protein (ie . 2.16 % N) and 0.32% P, and equal proportions of N and P were deposited in the animals body, the decrease in the N:P ratio between the diet (6.75) and the pen surface (3.36) does suggest that approximately 50% of nitrogen fed was lost to the atmosphere.

Table 2. Pen surface characteristics during trial 1

Characteristic	Pens with cattle		Unoccupied "receiving" pens	
	Surface	Mound	Surface	Mound
pH	7.85	7.61	8.23	8.50
Dry matter,%	57.89	61.29	60.3	67.46
Nitrogen,%	2.36	2.28	2.50	2.34
Phosphorus,%	0.69	0.69	0.71	0.76
Nitrate, ppm	2.81	2.95	2.98	2.71
Ammonia, ppm	1265	1087	826	347

Trial 2, January, 2003:

Tentative ammonia emissions calculated using the box model are presented in Table 3. On average, calculated emissions were approximately 15 to 20% of total daily nitrogen fed or about 65% of losses noted during the summer. As noted during the summer, there was a diurnal pattern in ammonia concentrations and emissions with highest values during the day and lowest values at night.

Table 3. Calculated preliminary ammonia flux determined using the box model of Ashbaugh (micrograms / m**2/ second) and average ammonia concentrations near the center of the feedyard (micrograms/m**3) at a height of 3 meters in January, 2003

Day	Time interval, hours	Box model		Ammonia concentration	Misc. information
		Tower only	Passives		
T-W	1700 to 0900	38	39	418	
Wed	0900 to 1300	(190)	(170)	376	
Wed	1300 to 1700	-	-	-	
W-T	1700 to 0900	41	48	168	Var. wind
Thur	0900 to 1300	41	51	168	Var. wind
Thur	1300 to 1700	51	53	258	Var. wind
T-F	1700 to 0900	-	-	-	Pumps stop
Fri	0900 to 1300	25	27	399	
Fri	1300 to 1700	75	75	355	
F-S	1700 to 0900	54	51	269	
Sat	0900 to 1300	50	51	346	
Sat	1300 to 1700	(160)	(160)	397	
Mon	0900 to 1300	41	35	440	
Mon	1300 to 1700	-	-	490	Poor profile
M-T	1700 to 0900	36	38	251	Var. wind
Tue	0900 to 1300	41	42	247	Var. wind
Tue	1300 to 1700	28	28	269	Var. wind
T-W	1700 to 0900	48	50	358	Var. wind
Wed	0900 to 1300	(90)	(120)	290	Var. wind

Wed	1300 to 1700	37	39	475	
W-T	1700 to 0900	22	17	262	

(Values in parenthesis are highly questionable)

Studies in Nebraska using total N balance methods suggest that atmospheric nitrogen losses during the winter are about 20 to 30% of daily nitrogen intake. Again, our values were approximately 50 to 60 % of the Nebraska values; thus suggesting that appreciable atmospheric losses of nitrogen from the pen surfaces are as dinitrogen gas.

Pond and pen surface chemistry. The temperature of the retention pond averaged 6.5 C (44 F). The pH averaged 7.37. The lower pH, compared to the summer study, could be due to the use of water from the continuous flow waterers that diluted the ammonia and nitrogen in the retention pond. However, the pH was still high enough to be conducive to release of ammonia from the retention pond.

Composition of the pen surface layers are presented in Table 4. Nitrogen and P concentrations were greatest in the loose surface layer, intermediate in the hard-packed manure-soil layer, and lowest in the underlying soil layer. Ammonia concentrations were about 10% of total N content in the surface, hard pack, and mound samples but almost 40 % of total N in the soil layer.

Table 4.. Pen surface characteristics during trial 2.

Characteristic	Loose surface	Packed layer	Soil	Mound
pH	7.95	7.94	8.44	7.79
Dry matter, %	79.75	74.21	83.36	68.73
Nitrogen, %	2.564	1.956	0.28	2.566
Phosphorus, %	0.67	0.588	0.063	0.740
Nitrate, ppm	4.21	0.89	4.55	1.63
Ammonia, ppm	2144	1597	1121	2601

Trial 3, Ammonia losses from simulated feedlot surfaces:

Results from the simulated surfaces indicated that dietary protein content could significantly affect ammonia losses. Ammonia losses from the circle treated with manure from calves fed a 13% crude protein diet were approximately 30% greater than values from calves fed 11.5% crude protein. Emissions were also highly dependent upon temperature with greater losses during the summer than during the winter. Ammonia losses were greatest immediately after application of the manure then decreased with time. However, if a rain occurred, a second burst in ammonia losses was noted. This data will be presented at the ASAE sponsored Third

International Conference on Air Pollution from Agricultural Operations, Raleigh, NC, October 11-14, 2003.

Trial 4: Ammonia losses from experimental retention ponds:

In general, acidifying the retention pond solutions decreased ammonia emissions (Table 5). However, if urea was added to the solution the decrease lasted for approximately 3 days then emissions increased to values equal to those of unacidified water. This may have been due to the fact that the pH of acidified water increased. The urea may have broken down to ammonium which would have stayed in solution until the pH increased, then would be released as ammonia. Diluting the retention pond water by 50% (and thus decreasing the ammonia concentration) decreased ammonia losses by approximately 50%. Adding urea greatly increased ammonia losses. Ammonia losses from retention pond water at feedyard A were about 50% of those from feedyards B and C which were similar. The primary difference between these yards is that feedyard A uses a settling basin before runoff enters the retention pond. Chemical analyses of the samples is in progress.

Table 5. Cumulative approximate ammonia losses (milligrams) from artificial retention ponds.

Treatment	Day 2	Day 6	Day 9	Day 13
Undiluted, pH 9.5	16.8	34.4	44.7	57.1
Undiluted pH 8.0	3.7	11.7	18.7	28.2
Undiluted, pH 6.5	3.2	11.1	17.5	26.7
Diluted, pH 9.5	10.9	18.6	22.3	26.1
Diluted, pH 8.0	2.4	3.8	11.7	16.0
Diluted, pH 6.5	0.6	3.1	5.3	7.6
Added urea, pH 9.5	16.2	95.3	194.5	302.6
Added urea, pH 8.0	6.7	126.6	187.7	265.4
Added urea, pH 6.5	4.0	120.7	184.3	269.6
Feedyard A	21.4	62.9	104.0	167.1
Feedyard B	7.3	25.1	40.1	57.8
Feedyard C	23.0	65.2	101.8	154.9

Trial 5: Methane and nitrous oxide losses from a feedyard.

Air quality data are not yet available.

The pH of the retention pond increased from an average of 8.3 on the first day of sampling to 8.8 on the last day. This was probably due to a significant decrease in pond volume due to evaporation and subsequent increase in solute and solids concentrations. The temperature of retention pond samples ranged from 18.5 to 25.5 C and averaged approximately 23 C (73 F).

Trial 6. Downwind ammonia concentrations.

Ammonia concentrations at the north property line (10 meters downwind) when the wind was from the southeast, south or southwest ranged from approximately 500 to 1000 micrograms/cubic meter (Table 6). In general, during the day, concentrations decreased rapidly on the downwind side. During the night, or at other times when air conditions were more stable, concentration decreased at a slower rate.

Table 6. Some "typical" changes in ammonia concentrations downwind of the yard at a height of 3 meters (Background = 5 to 8 micrograms / cubic meter).

Day and time	Meters down wind of yard						
	10	25	50	100	200	400	800
7/14: 1200 to 1800	745	756	707	561	224	155	40
7/14: 1800 to 0600	855	720	700	567	433	331	181
7/15: 0600 to 1200	810	569	466	325	187	120	36
7/15: 1800 to 0600	702	612	643	454	358	222	172
7/16: 1200 to 1800	670	625	316	169	54	34	8
7/16: 1800 to 0600	588	569	539	236	212	126	86
7/17: 0600 to 1200	876	747	586	346	217	88	23
7/17: 1200 to 1800	774	709	615	410	263	114	41
7/17:1800 to 0600	765	785	744	557	484	282	166
7/18: 0600 to 1200	926	831	590	363	211	72	8
7/18:1200 to 1800	936	733	597	444	250	118	57

Conclusions:

Portions of the research will be presented at the ASAE sponsored Third International Symposium on Air Quality from Agricultural Operations to be held in Raleigh, NC on October 11 to 14, 2003 and published in the proceedings. After additional scrutiny, the research will also be presented at other scientific meetings and published in refereed journals. An amended final report, including any published articles, will be presented when the data are available.

These data are still preliminary and we wish to evaluate the data more before we attempt to make any firm conclusions. However, these data indicated that ammonia emissions from feedyards are difficult to measure and are greatly affected by environmental conditions. Thus the use of a single emission factor for ammonia emissions from feedyards is probably not warranted.