ABATEMENT MEASURES TO REDUCE AMMONIA EMISSIONS FROM OPEN-LOT FEEDYARDS AND DAIRIES

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Abstract. *Reduction of ammonia emissions from animal feeding operations is important from the perspective of environmental policy and its impact on agriculture. Control measures for the abatement of ammonia from open-lot beef cattle feedyards and dairies can be grouped into pre-excretion and post-excretion strategies. Pre-excretion strategies include developing nutritional strategies to improve the utilization of crude protein (CP). Decreasing CP from 13% to 11.5% at the end of the feeding period did not affect animal performance, but the N:P concentration in the manure was unchanged. Decreasing CP from 13% to 10% increased the N:P concentration in the manure, but adversely affected dry matter intake and gain efficiency. Post-excretion strategies include the use of urease inhibitors and other additives to control ammonium concentrations and manure pH. Additives such as alum which alter manure pH were shown to decrease ammonia emissions by up to 98% in laboratory studies, but cost as much as $63 per animal unit per year. Urease inhibitors have been shown to conserve urea in the manure and reduce ammonia emissions in the laboratory, but based on recent research their effectiveness and economics in the field is still questionable. This paper further discusses the factors affecting ammonia emission rates and effectiveness and economics of pre-excretion and post-excretion BMPs for reducing ammonia emissions from animal feeding operations.*

Keywords. *ammonia, feedyard, dairy, manure, emissions, urease inhibitor, cattle*

INTRODUCTION

Beef cattle producers face many challenges as the result of increased public concerns regarding effects of agricultural practices on the environment. Excessive nutrients accumulate in beef cattle feedlots when imports of elemental nutrients in purchased feeds are greater than nutrient exports in beef cattle products. Significant amounts of nitrogen can be volatilized from manure on the feedlot surface. Scientists have estimated that as much as 50% of feed N is lost as ammonia (Bierman et al., 1999).

Nitrogen loss into the atmosphere results in lower N:P ratios, leads to less-desirable fertilizer value of manure, and contributes to air quality concerns. The need to decrease the emissions of ammonia and other gases produced by livestock and their waste products has grown in recent years. As a result of data indicating that these gases have the potential to contribute to the greenhouse effect, acid rain, and/or stratospheric ozone depletion, many European countries already have regulations limiting ammonia emissions from concentrated animal feeding operations. Moreover, emissions of ammonia and oxides of N and S have been implicated as potential contributors to fugitive dust emissions, especially PM-10 and PM-2.5 particulates (Morse, 1996a; Morse, 1996b).

The nitrogen excreted in the feces is composed of undigested feed residues, microbial cells, endogenous secretions, and sloughed cells from the gastrointestinal tract. Once excreted, most of these nitrogenous residues are degraded slowly and therefore release ammonia-N into the atmosphere at a slow rate. In contrast, urinary N is composed primarily of urea ($CO(NH_2)_2$), which is rapidly hydrolyzed to ammonium and carbon dioxide by microbes in the feces and soil (Mason, 2004). The conversion of urea to ammonium is an enzymatic process, and is catalyzed by the urease enzyme which is present in feces and soil.

Ammonia volatilization is a complex process which is generally related to four factors: 1) ammonium concentration in the manure and atmosphere, 2) temperature of the manure, 3) pH of the manure, and 4) turbulent transport or wind exchange (Harper et al., 2004; Sommer and Hutchings, 1995). Scientists working on control measures have typically focused on reducing ammonium concentrations, controlling pH, and reducing the exposed area and air exchange over the emitting area (Sommer and Hutchings, 1995).

These control measures can be grouped into two primary management strategies: 1) pre-excretion strategies such as altering animal diets, and 2) post-excretion strategies such as altering pH or applying surface additives. Pre-excretion strategists would ask the question "What can we do to reduce the nitrogen excreted in the manure?" while post-excretion strategists would ask "What can we do to reduce ammonia emissions once the manure hits the ground?" Both of these strategies will be discussed in detail with reference to recent research.

PRE-EXCRETION STRATEGIES

Cattle consume nitrogen in the form of crude protein (CP), and convert it into body tissue or byproduct waste (urine and feces). A logical method for controlling the amount of volatized ammonia is to develop nutritional strategies to improve the utilization of CP. Excess N is passed through the animal and excreted in the feces and urine. Reducing these dietary excesses might be the easiest way to reduce nutrients in the manure. In an ideal world, cattle would be fed the exact amount of nutrients that their bodies require for optimum growth. However, because of inherent variation in cattle and feed ingredients, this may not be altogether possible. Nevertheless, identifying methods for altering and controlling inputs is a current focus of research (NRC, 2000).

It is common industry practice for beef cattle to be fed a constant CP concentration (routinely approximately 13 to 13.5%) throughout the entire feeding period (Galyean and Gleghorn, 2000). However, nutrient requirements change as the cattle grow, resulting in animals receiving less than optimum CP early in the feeding period and greater than optimum CP late in the feeding period (Gleghorn et al., 2004). Changing the diet (i.e. the CP concentration) during the feeding period to more closely meet the nutritional requirement is a concept called 'phase feeding.' Studies with cattle fed finishing diets based on dry-rolled corn suggest that CP concentration can be reduced to less than 11% during the latter portion of the feeding period without adversely affecting animal performance

(Erickson et al., 2001). However, when cattle are fed more fermentable finishing diets based on steam-flaked grains, decreasing dietary CP concentrations could potentially lead to an increase in digestive disturbances (Cole, 2003).

Vasconcelos et al. (2004a, 2004b) evaluated the effects of phase feeding on the performance of beef steers fed steam flaked corn based diets (Table 1). All cattle were fed a 90% concentrate finishing diet that contained 13% CP until they weighed approximately 477 kg. At that time, the diet was either maintained at 13% CP or switched to 11.5% CP or 10% CP. Decreasing dietary CP to 11.5% did not affect performance; however, decreasing the CP to 10% adversely affected dry matter intake and gain efficiency. Decreasing dietary CP to 11.5% did not significantly affect the N:P ratio of pen surface manure but decreasing dietary CP to 10% increased ($P < 0.05$) the manure N:P ratio.

In a larger study, with more extensively processed steam flaked corn, Gleghorn et al. (2005, unpublished data) noted similar overall results. However, they also noted that switching diets during the last 56 days on feed caused a decrease in dry matter intake ($P <0.05$).

We evaluated the effects of dietary CP concentration (11.5, 13 or 14.5%), ruminal degradability of dietary CP (supplemental sources were urea, cottonseed meal or a mixture), and days fed on potential ammonia losses using an in vitro system (Cole et al., 2005). Feces and urine excreted were collected from 54 steers fed nine diets in a factorial arrangement (3 concentrations and 3 supplemental sources). Increasing dietary CP concentration increased in-vitro ammonia losses primarily due to increased urinary N excretion. Ammonia losses increased ($P < 0.01$) as days on feed increased (Table 2), suggesting that decreasing dietary CP concentration will have its greatest effect on ammonia losses late in the feeding period.

Ammonia losses may also be decreased by shifting N excretion from the rapidly degraded urinary urea N to more slowly degraded fecal N. Using a total N balance technique, Bierman et al. (1999) and Erickson et al. (2003) reported that increasing dietary fiber decreased total N volatilization; apparently by shifting N excretion to the feces. Because cattle have the ability to recycle N from one section of the gut to another via the blood stream, feeding methods that shift digestion to the lower gut may increase fecal N excretion while decreasing urinary N excretion. However, these methods can potentially decrease animal performance and increase overall ammonia losses.

Table 1. Effect of phase feeding of crude protein on performance of finishing steers and on the N:P ratio of collected pen manure (Vasconcelos et al., 2004b)

Item	13.0% CP[a]	11.5% CP[a]	10.0% CP[a]	SEM	P
Daily gain, kg					
Before switch	2.01	2.05	1.98	1.26	0.91
After switch	1.63	1.72	1.53	0.07	0.21
Overall	1.78	1.87	1.69	0.05	0.09
Dry matter intake, kg/d					
Before switch	10.27	10.23	10.37	0.109	0.62
After switch	11.13	10.83	10.12	0.186	0.01
Overall	10.80	10.66	10.20	0.164	0.06
Gain:feed ratio, g/kg					
Before switch	190	201	196	6.0	0.83
After switch	151	159	146	4.0	0.29
Overall	166	175	162	2.0	0.07
Manure N:P	3.56	3.45	3.87	0.10	0.04

[a] CP concentration of diet after switched from 13% CP finishing diet.

Table 2. Cumulative ammonia-N, and total N losses during the 7-d in vitro incubation period (overall LS means; n = 54/day: Cole et al., 2005)

Item	Collection period (days on feed)			SEM
	< 30[a]	75	>120	
NH_3-N lost, mg	13.26 b	26.66 c	41.04 d	1.19
NH_3-N lost, % of urine N	2.76 b	3.82 c	5.60 d	0.11
Total N lost, mg	137.8 b	161.2 bc	177.6 c	10.4
N lost, % added N	15.3	13.2	15.6	0.88
N lost, % urine N	37.6	25.0	27.7	2.14
NH_3-N lost, % N lost	38.1 b	46.3 c	45.0 c	2.17

[a] Approximate days on feed when feces and urine were collected.
b,c,d Means in same row without a common letter differ ($P < 0.05$).

Nitrogen excretion can also be shifted away from the urine via feeding a protein source with a lower ruminal degradability. Increasing the urea concentration of the diet can increase urinary N excretion and thus increase ammonia losses (Cole et al., 2005).

POST-EXCRETION STRATEGIES

Several post-excretion applied chemical amendments and additives have been studied to reduce ammonia emissions (Cole et al., 1999). In open lot feedyards and dairies, temperature and turbulent transport (i.e. wind) are difficult to control, making the controlling of ammonium concentration and pH the best means available for controlling post-excretion ammonia volatilization. Additives rely on several modes of action to control pH and ammonium concentration.

CONTROL OF pH

The ammonium concentration in manure is dependent on the rate of hydrolysis of urea (CO(NH2)2). Urea is initially converted to ammonium carbonate (Eq. 1), then to ammonium ions, carbon dioxide gas, and water (Eq. 2). The hydrolysis reaction consumes H+, increasing the pH (Sawyer and McCarty, 1978). The resultant increase in pH then drives the ammonium-ammonia balance (Eq. 3) to the right, increasing ammonia volatilization.

$$CO(NH_2)_2 + 2H_2O \quad \overbrace{\Rightarrow}^{\text{urease enzyme}} \quad (NH_4)_2CO_3 \tag{1}$$

$$(NH_4)_2CO_3 + 2H^+ \Rightarrow 2NH_4{}^+ + CO_2 \uparrow + H_2O \tag{2}$$

$$NH_4{}^+ + OH^- \Leftrightarrow NH_3 \uparrow + H_2O \tag{3}$$

Ammonium predominates at lower pH while ammonia gas predominates at high pH. At a pH of approximately 9.5, equal amounts of ammonia and ammonium are present. Nearly 10 times more ammonia is present when the pH is 8.0 than when the pH is 7.0. Thus, decreasing the pH has been shown to reduce ammonia losses (Harmsen and Kolenbrander, 1965).

Chemical amendments such as alum and calcium chloride reduce ammonia emissions by decreasing pH and through cation exchange. Hydrolysis of the Al^{3+} ion in alum frees three H^+ ions, decreasing pH and reducing ammonia emissions. Through cation exchange, hydrogen ions are released and replaced by aluminum or calcium ions, again resulting in decreased pH and reduced ammonia emissions.

Kithome et al. (1999) evaluated the efficacy of the chemical amendments $CaCl_2$, $CaSO_4$, $MgCl_2$, $MgSO_4$, and $Al_2(SO_4)_3$ (alum) for reducing ammonia emissions from composted poultry manure. Mixing 20% $CaCl_2$ with compost reduced ammonia emissions by 90%, whereas 20% alum reduced ammonia emissions by 26%. However, $CaSO_4$ and $MgSO_4$ were ineffective in reducing ammonia emissions. Moore et al. (1995) reported that alum significantly reduced ammonia volatilization from poultry manure. The direct addition of sulfuric acid to cow and pig slurries has also been shown to reduce ammonia volatilization (Stevens et al., 1989).

In a laboratory experiment, Shi et al. (2001) evaluated several amendments which used pH adjustment for the control of ammonia emissions from simulated open-lot feedyards (Table 3, Figure 1). Alum was effective at reducing ammonia emissions by as much as 98%. There was a strong curvilinear relationship between pH and ammonia emissions, with ammonia emissions increasing rapidly between pH 6 and 8 (Figure 2).

Figure 1. Photograph of the ammonia emission apparatus consisting of Tupperware® air emission chambers and acid traps connected to a vacuum pump.

CONTROL OF AMMONIUM CONCENTRATION

Ammonia emissions can be decreased by altering the carbon/nitrogen ratio of the pen surface. Subair et al. (1999) evaluated the ability of paper products added to liquid hog manure to reduce ammonia emissions, and found that ammonia volatilization was reduced from 29% to 47% by increasing the carbon/nitrogen ratio of the liquid hog manure.

Table 3. Total ammonia-N volatilized from simulated open-lot beef cattle feedyard surfaces over a 21-day period in the laboratory (adapted from Shi et al., 2001). Each mean was calculated from three replications. Costs include materials and shipping, but do not include spreading costs.

Treatment	Mean NH_3-N Emisson Rate (μg m^{-2} min^{-1})	% Reduction as Compared to Control	Final pH	Cost if Applied Every 21 Days (\$ animal $unit^{-1}$ yr^{-1})
Blank (soil only)	14 a	NA	6.83	NA
Control (soil-manure, no amendment)	3307 e	NA	7.55	NA
Alum (4500 kg/ha)	281 a	91.5	5.98	31.50
Alum (9000 kg/ha)	56 a	98.3	4.20	63.00
Calcium chloride (4500 kg/ha)	952 bc	26.4	6.99	25.75
Calcium chloride (9000 kg/ha)	743 b	22.5	6.85	51.68
Brown humate (9000 kg/ha)	1071 bcd	32.4	7.06	96.22
Black humate (9000 kg/ha)	1314 d	39.8	7.10	96.22
NBPT (1 kg/ha)	1186 cd	35.9	7.52	1.45
NBPT (2 kg/ha)	1138 cd	34.4	7.58	2.90

Means in a column without common letters are significantly different using Tukey's HSD test ($P<0.05$).

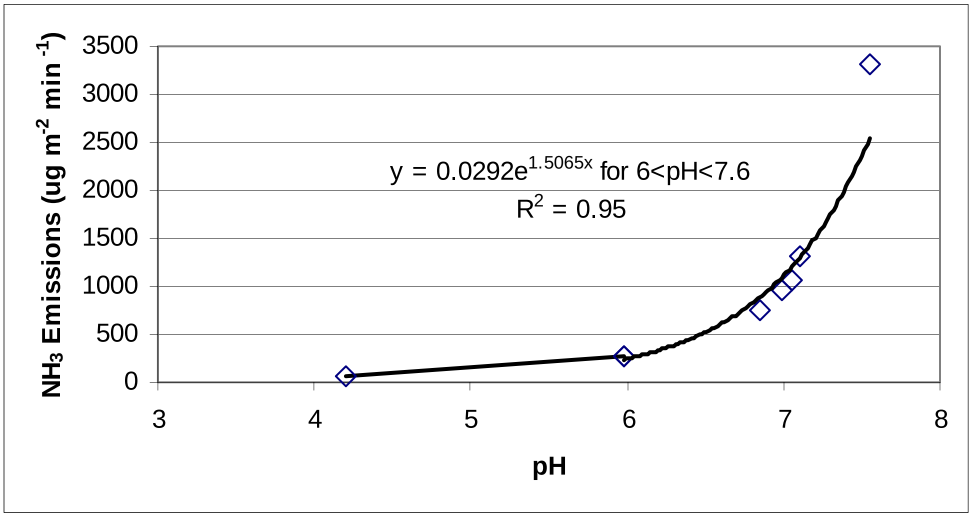

Figure 2. Graph showing the relationship between ammonia emissions and pH for the simulated beef cattle feedyard data from Table 3 (adapted from Shi et al., 2001)

In addition to chemical and enzymatic amendments, several commercial products are now marketed for reducing ammonia emissions. Zhu et al. (1997) evaluated several commercial additives for reducing ammonia emissions from swine lagoons. Ammonia emissions ranged from a 37% increase to a 36% reduction.

Probably the best way to reduce ammonia production is to slow or stop the conversion of urea to ammonium. Compounds that inhibit the enzymatic breakdown of nitrogenous compounds present in feces and urine can decrease ammonia production. Urease inhibitors can block the hydrolysis of urinary urea to ammonium and thereby decrease ammonia production.

Urease Inhibitors - Lab Studies

Varel (1997) evaluated the urease inhibitors cyclohexylphosphoric triamide (CHPT) and phenyl phosphorodiamidate (PPDA) on one-liter manure slurries composed of equal parts of beef cattle feces and urine. With an initial urea concentration of 3.3 g/l, and an initial urease inhibitor concentration of 10 mg/l, both inhibitors prevented hydrolysis of urea for 4 to 11 days. The weekly addition of 10, 40, or 100 mg/l of PPDA to cattle manure with an initial urea concentration of 5.6 g/l prevented 38, 48, and 70% of the urea from being hydrolyzed after 28 days.

In a laboratory experiment to simulate open-lot beef cattle feedyards, Shi et al. (2001) applied the urease inhibitor N-(n-butyl)thiophosphoric triamide (NBPT) to mixtures of 1550 g soil, 133 g feces, and 267 g urine. The mixtures were placed into plastic containers and, using a vacuum system, air was passed over the soil-manure surface and ammonia was trapped by bubbling the air through dilute sulfuric acid (Figure 1). Shi found that application of 1 and 2 kg/ha of NBPT resulted in 36 and 34% reduction in ammonia emissions, respectively (Table 3).

Parker et al. (2005) conducted a laboratory experiment to further evaluate the urease inhibitor NBPT and how moisture and application frequency affect ammonia emissions . Soil (1200 g) was placed into plastic containers and fresh feces (400 g) were spread evenly over the top of the soil. The NBPT was sprayed on the manure surface at rates of 0, 1 and 2 kg/ha, at 8, 16, and 32 day frequencies, and with or without simulated rainfall. To simulate feedyard conditions, 23 mL of synthetic urine was added to each chamber every two days (equal to 6 L of daily excretion over a 14 m^2 area). The synthetic urea was prepared by mixing 21.4 g urea, 23.1 g $KHCO_3$, 3.8 g KCl and 1.9 g K_2SO_4 together in 1 L of water. Gaseous ammonia was trapped by bubbling through a sulfuric acid solution using a vacuum system and analyzed for nitrogen using automated procedures similar to Shi et al. (2001) (Figure 1). The 8-day application frequency was most effective, with the 1 and 2 kg/ha treatments resulting in 49% to 69% reduction in ammonia emission rates (Table 4). Simulated rainfall reduced the ammonia emission rates as compared to the non-rainfall treatments, though the differences were not statistically different. Parker et al. (2005) determined that NBPT must be applied at a frequency less than 16 days in order to effectively reduce NH_3 emissions, as application at 16 or 32 day frequencies was not significantly different than the control.

Table 4. Mean NH_3-N emission rates ($\mu g\ m^{-2}\ min^{-1}$) for three NBPT application rates, three application frequencies, and with or without simulated rainfall. Each mean is calculated from three replications (adapted from Parker et al., 2005). Costs include materials and shipping, but do not include spreading costs.

NBPT Rate (kg/ha)	NBPT Application Frequency (days)	Simulated Rainfall*	Mean NH_3-N Emisson Rate ($\mu g\ m^{-2}\ min^{-1}$)	% Reduction as Compared to Control	Cost by Treatment (\$ animal unit^{-1} yr^{-1})
0 (Blank)	Na	no	6 a	NA	NA
0 (Control)	Na	no	1570 d	NA	NA
1	8	no	790 bc	49	3.80
1	8	yes	590 b	62	3.80
1	16	no	1510 d	3	1.90
1	16	yes	1330 d	15	1.90
1	32	no	1590 d	-1	0.95
1	32	yes	1570 d	0	0.95
2	8	no	530 b	66	7.60
2	8	yes	490 ab	69	7.60
2	16	no	1540 d	1	3.80
2	16	yes	1230 cd	22	3.80
2	32	no	1400 d	11	1.90
2	32	yes	1190 cd	24	1.90

Means in a column without common letters are significantly different using Tukey's HSD test ($P<0.05$).
* Treatments with simulated rainfall received 0.6 cm water added every four days.

Urease Inhibitors - Field Studies

Varel et al. (1999) conducted two experiments to evaluate the urease inhibitors CHPT and NBPT when applied to open-lot beef cattle feedlot pens. In the first experiment, CHPT and NBPT were applied to an 18 m^2 subarea within each pen in a single application at rates of 45.6 and 22.8 kg ha^{-1}, respectively. Urea accumulation peaked on day 4 at 2 g urea per kg dry manure for CHPT, and disappeared by day 11. Urea accumulation peaked on day 9 at 3.5 g/kg for NBPT and disappeared by day 14. In the second experiment, NBPT was applied every 7 days for 6 weeks at 22.8 kg ha^{-1}. Urea accumulated to a peak concentration of 17 g urea per kg dry manure at day 31 and stabilized at this concentration until week 6 when NBPT application was halted. Urea concentration then decreased to about 10 g/kg one week later and 5 g/kg two weeks later.

In Spring 2004 we conducted a study at the West Texas A&M University Research Feedyard to evaluate how rate of urease inhibitor application affects ammonia emissions from beef cattle feedyard surfaces under field conditions (Parker et al., 2005, unpublished data). The NBPT (sold in aqueous form with 20% active ingredient under the trade name Agrotain®) was applied over a six-week study period to six pens (6 by 26 m), each containing 10 beef cattle. The steers were weighed (avg. weight 485 kg) and randomly assigned to each pen. A schematic of the pen layout is shown in Figure 3. The earthen-surfaced pens were constructed six months earlier as part of a recent feedlot addition, and cattle had been fed in the pens for about three months prior to the initiation of our experiment. Those cattle were removed, and a new set of steers were placed in the pens 20 days prior to the first NBPT application.

NBPT was applied to pens 53-55 every seven days for six weeks at treatment rates of 0, 1 and 2 kg/ha. The NBPT was mixed with water and applied using a tractor-mounted, 3.9 m wide, 415 L commercial sprayer equipped with nine nozzles spaced 0.5 m apart (Wylie Mfg. Co, Petersburg, TX). Pens 49-51 were initially applied NBPT at 0, 1, and 2 kg/ha, but were subsequently increased to 4 and 8 kg/ha on day 14 because of our inability to detect statistical differences in ammonia emission rates between the 0, 1, and 2 kg/ha treatments. Pen 50 was subsequently increased to 40 kg/ha on day 18. Table 5 shows the dates and application rates of the NBPT throughout the experiment.

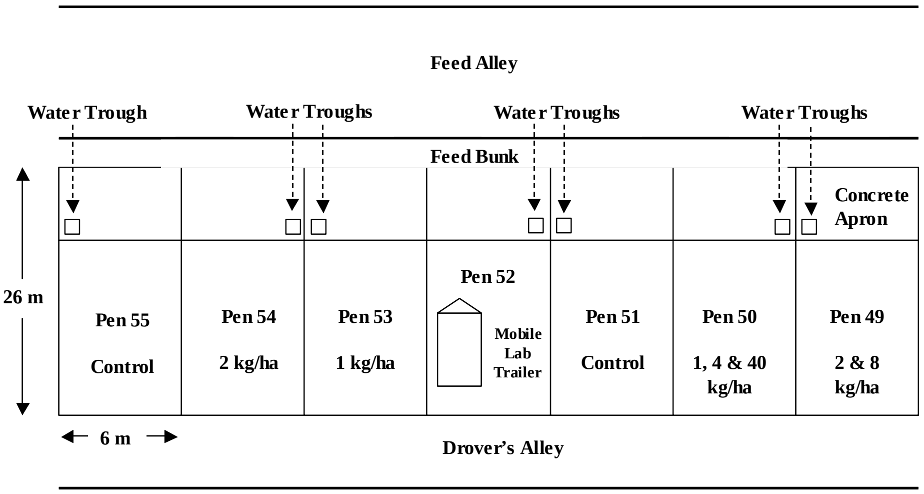

Figure 3. Schematic of the field NBPT study.

Table 5. Dates and rates of NBPT application in the field experiment.

Day	Date	Action
0	04/26/04	Applied 0, 1, 2 kg/ha to all pens
7	05/03/04	Applied 0, 1, 2 kg/ha to all pens
14	05/10/04	Applied 0, 1, 2 kg/ha to pens 53-55 Applied 0, 4, 8 kg/ha to pens 49-51
18	05/14/04	Applied 40 kg/ha to pen 50
21	05/17/04	Applied 0, 1, 2 kg/ha to pens 53-55
28	05/24/04	Applied 0, 1, 2 kg/ha to pens 53-55
35	05/31/04	Applied 0, 1, 2 kg/ha to pens 53-55
42	06/0704	End of Experiment

Ammonia fluxes were measured using a 26.5 cm inside diameter flux chamber connected with tubing to a TEI 17C chemiluminescence NH_3 analyzer (Franklin, MA) housed within a mobile laboratory. Six manure samples were collected from each pen on day 0, 28, and 42 and analyzed for TKN, organic N, NH_4-N, NO_3-N, moisture content and volatile solids by Servi-Tech Laboratories, Dodge City, KS. We were unable to detect statistically significant differences in ammonia fluxes between the different NBPT application rates (Table 6) because of high variability within pens. For example, 27 individual NH_3-N flux measurements within Pen 53 on May 13, 2004 ranged from 512 to 14,990 ug m^{-2} min^{-1} (Koziel et al., 2005).

The mean TKN concentration for the 2 kg/ha treatment was slightly higher than the 0 and 1 kg/ha treatments, indicating that the urease inhibitor was only somewhat effective in retaining nitrogen within the manure pack at the application rates tested (Table 7, Figure 4). At the completion of the six-week experiment, the 2 kg/ha and 40 kg/ha NBPT treatments retained 9 and 20% more total nitrogen in the manure than the control.

Table 6. Mean ammonia emission rates (μg m^{-2} min^{-1}) for the different NBPT application rates (each mean calculated from six individual flux measurements per pen).

Emissions comparing 0, 1, and 2 kg/ha treatments								
Date	Days after applying 1 or 2 kg/ha	Pen 55 0 kg/ha Control		Pen 53 1 kg/ha		Pen 54 2 kg/ha		
		mean	std dev	mean	std dev	mean	std dev	P*
05/06/04	10	1400 a	695	906 a	438	1054 a	507	0.32
05/07/04	11	702 a	180	987 a	558	795 a	186	0.39
05/10/04	14	1082 a	397	933 a	370	1035 a	623	0.86
06/03/04	38	1575 a	362	1569 a	555	2089 a	755	0.24
Emissions comparing 0, 4, and 8 kg/ha treatments								
Date	Days after applying 4 or 8 kg/ha	Pen 51 0 kg/ha Control		Pen 50 4 kg/ha		Pen 49 8 kg/ha		
05/11/04	1	2037 a	1493	1720 a	777	1682 a	996	0.84
05/12/04	2	1504 a	314	1540 a	626	1812 a	331	0.44
05/13/04	3	482 a	179	492 a	107	516 a	119	0.91
05/14/04	4	1256 a	931	910 a	325	731 a	161	0.31
Emissions comparing 0 and 40 kg/ha treatments								
Date	Days after applying 40 kg/ha	Pen 51 0 kg/ha Control		Pen 50 40 kg/ha				
05/17/04	3	1424	1122	1023	349	--	--	0.25
05/18/04	4	783	238	695	148	--	--	0.23
05/20/04	6	2086	1280	1915	720	--	--	0.66
Means in a row without a common letter are significantly different using Tukey's HSD test (P<0.05). *P values from one-way ANOVA or independent samples t-test comparing treatments on a given date.								

Table 7. Mean chemical characteristics of manure samples at the times denoted for the field study. Each mean was calculated from six individual manure samples from each pen.

Description	Day	Pen No.	TKN (%)	Organic N (%)	NH_4-N (%)	NO_3-N (mg/kg)	Moisture Content (%)	Volatile Solids (%)
Start of experiment (Control)	0	55	0.87 a	0.81 a	0.057 abc	0.33 a	19.0 b	37.7 ab
Start of experiment (1 kg/ha)	0	53	0.78 a	0.72 a	0.056 abc	0.20 a	18.3 b	35.6 a
Start of experiment (2 kg/ha)	0	54	0.79 a	0.74 a	0.050 ab	0.08 a	17.0 b	35.8 a
3 d after applying 40 kg/ha	21	50	1.50 b	1.46 b	0.040 a	1.67 bc	8.0 a	44.1 abcd
After 4 weeks (Control)	28	55	1.92 de	1.84 ef	0.075 cd	2.90 de	7.0 a	53.8 e
After 4 weeks (1 kg/ha)	28	53	1.88 de	1.80 def	0.083 d	3.35 e	5.9 a	48.9 de
After 4 weeks (2 kg/ha)	28	54	2.01 e	1.94 f	0.073 bd	2.83 cde	5.8 a	51.1 de
10 d after applying 40 kg/ha	28	50	1.75 cd	1.71 cde	0.040 a	1.60 b	3.5 a	42.2 abcd
End of experiment (Control)	42	55	1.61 bc	1.58 bcd	0.035 a	2.58 bcde	6.7 a	44.9 bcde
End of experiment (1 kg/ha)	42	53	1.59 bc	1.54 bc	0.048 a	2.83 cde	4.7 a	38.4 abc
End of experiment (2 kg/ha)	42	54	1.75 cd	1.70 cde	0.049 a	2.58 bcde	6.8 a	49.8 de
End of experiment (40 kg/ha)	42	50	1.94 de	1.88 ef	0.057 abc	2.12 bcd	6.7 a	47.3 cde

Means in a column without common letters are significantly different using Tukey's HSD test (P<0.05).

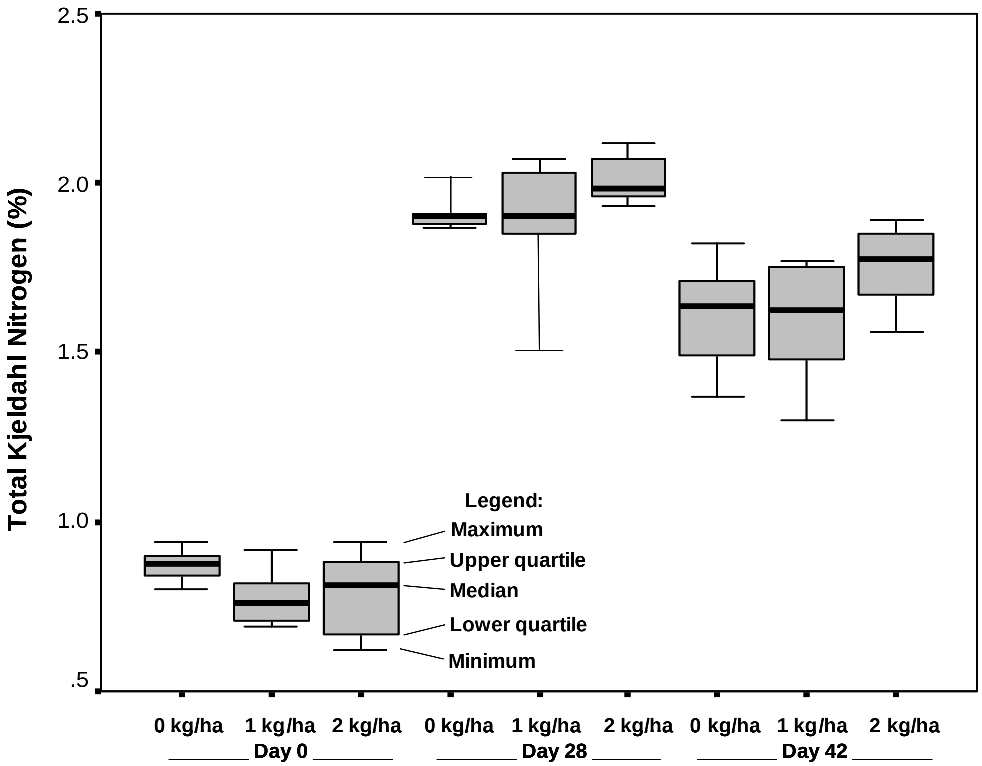

Figure 4. Boxplots comparing TKN concentrations in the manure at days 0, 28, and 42 after first NBPT application. NBPT was applied every seven days.

Potential Concerns with Urease Inhibitors

Urease inhibitors have been very successful in farming applications where slowing the conversion of urea to ammonium provides extra time for the crops to take up the ammonium. However, the use of urease inhibitors in feedyard conditions is entirely different, as the ammonium is not consumed by plants but will eventually convert to ammonia gas and volatilize. Because urease inhibitors have a finite life of about 7 to 10 days, additional urease inhibitor must be added if one wishes to keep the N in urea form. As more urea is deposited daily on the feedyard surface, it seems logical that additional urease inhibitor would also be needed if the goal is to control all or most of the ammonia emissions. Theoretically, if a given amount of urease inhibitor were applied at the beginning of the feeding period, then in week two the same amount of urease inhibtor would be needed plus additional urease inhibitor to account for the recently added urea (i.e 2X that of the first week). In the third week, then 3X that of the first week would be required. If urease inhibitor application were ceased prior to removal of the manure, then based on previous research results, it would appear that the existing urea would be hydrolyzed rapidly resulting in a large flush of ammonia gas. An analogy would be a balloon in which additional air is added each day. If the balloon were ever untied, then all of the air would rush out at once. In the case of ammonia, this would probably not be a desirable situation. Ongoing research with urease inhibitors will continue to provide valuable information on the long-term effectiveness of urease inhibitors for open-lot feeding operations. It may be that urease inhibitors have the most value when applied near the end of the feeding period prior to manure being removed from the feedyard.

CONCLUSIONS

In this paper, several pre-excretion and post-excretion strategies have been identified for minimizing ammonia emissions from open-lot feedyards and dairies. Decreasing the crude protein concentration in the diet at the end of the feeding period appears to have promise for reducing the amount of nitrogen excreted to the atmosphere, but additional research will likely be necessary to make sure that animal performance is not compromised. The use of surface-applied additives and urease inhibitors also appear to have promise in retaining the nitrogen in the manure once it is excreted, thereby reducing ammonia emissions. The long-term effectiveness of these additives under actual field conditions will continue to be a topic of research in coming years. It is likely that a combination of pre-excretion and post-excretion strategies will provide the most economical and environmentally friendly control technologies for reducing ammonia emissions from open-lot feedyards.

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REFERENCES

Bierman, S., G. E. Erickson, T. J. Klopfenstein, R. A. Stock, and D. H. Shain. 1999. Evaluation of nitrogen and organic matter balance in the feedlot as affected by level and source of dietary fiber. *J. Anim. Sci.* 77:1645-1653.

Cole, N.A. 2003. Precision nutrition - opportunities and limitations. In *Proc. Plains Nutrition Council Spring Conference.* TAES publication # AREC 03-13:1-19.

Cole, N. A., D. B. Parker, and L. W. Greene. 1999. Atmospheric emissions of nutrients from feedyards and potential control measures. In *Proc. High Plains Beef Conference on Health, Nutrition, and Environment*, 84-94. 18-19 August 1999. Amarillo, Texas: Texas Agricultural Extension Service.

Cole, N. A., R. N. Clark, R. W. Todd, C. R. Richardson, A. Gueye, L. W. Greene, and K. McBride. 2005. Influence of dietary crude protein concentration and source on potential ammonia emissions from beef cattle manure. *J. Anim. Sci.* 83; (in press).

Erickson,G. E., J. R. Adams, T. B. Farran, C. B. Wilson, C. N. Macken, and T.J. Klopfenstein. 2003. Impact of cleaning frequency of pens and carbon to nitrogen (C:N) ratio as influenced by the diet or pen management on N losses from outdoor beef feedlots. In *Proc. 9th Inter. Symp. on Animal, Agricultural and Food Processing Wastes*, Raleigh, NC, Oct. 12-15, 2003. ASAE, St. Joseph, MI. p 397-404.

Erickson, G. E., and T. J. Klopfenstein. 2001. Nutritional methods to decrease N losses form open-dirt feedlots in Nebraska. The Scientific World Journal 1(S2):836-843. Available: http://www.thescientificworld.com. Accessed on Nov. 5, 2003.

Galyean, M. L., J. F. Gleghorn. 2000. Summary of the 2000 Texas Tech university consulting nutritionist survey. Available at http://www.asft.ttu.edu/burnett_center/progress_reports/bc12.pdf.

Gleghorn, J. F., N. A. Elam, M. L. Galyean, G. C. Duff, N. A. Cole, and J. D. Rivera. 2004. Effects of crude protein concentration and degradability on performance, carcass characteristics, and serum urea nitrogen concentration in growing and finishing beef steers. *J. Anim. Sci.* 82:2705-2717.

Gleghorn, J. F., P. Defoor, M. L. Galyean, G. C. Duff, and N. A. Cole. 2005. Effects of phase feeding on performance of finishing beef steers (unpublished data)

Harmsen, G. W., and G. J. Kolenbrander. 1965. Soil inorganic nitrogen. In Soil Nitrogen: ASA Monograph Series No. 10, 43-92. Madison, Wisconsin: American Society of Agronomy.

Harper, L.S., N.A. Cole, T.K. Flesch, R.R. Sharpe, R.W. Todd and J.D. Wilson. 2004. Ammonia from livestock operations: Measurement technologies and emissions. In *Proceedings of the Plains Nutrition Council Spring Conference,* San Antonio, TX, April 15-16, 2004. TAES AREC04-14:27-51.

Kithome, M., J. W. Paul, and A. A. Bomke. 1999. Reducing nitrogen losses during simulated composting of poultry manure using adsorbents or chemical amendments. *J. Environ. Qual.* 28(1): 194-201.

Koziel, J. A., D. B. Parker, B. H. Baek, J. Bush, M. B. Rhoades, and Z. Perschbacher-Buser. 2005. Ammonia and hydrogen sulfide flux from beef cattle pens: implications for air quality measurement methodologies and evaluation of emission controls. To be presented at the Seventh International Livestock Environment Symposium, ASAE, May 18 - 20, 2005, Beijing, China.

Mason, A. 2004. Nitrogen distribution in pen surface layers of beef cattle feedyards. M.S. Thesis. West Texas A&M University, Canyon, TX.

Moore, P. A., T. C. Daniel, D. R. Edwards, and D. M. Miller. 1995. Effect of chemical amendments on ammonia volatilization from poultry litter. *J. Environ. Qual.* 24(2): 293-300.

Morse, D. 1996a. Understanding fugitive dust and ammonia emissions. In *Proc. 1996 Nat. Poultry Waste Management Symposium*, 19-23. Harrisburg, Pennsylvania: National Poultry Waste Management Symposium Committee.

Morse, D. 1996b. Impact of environmental regulations on cattle production. *J. Animal Science* 74(12): 3103-3111.

NRC. 2000. Nutrient Requirementss of Beef Cattle: Update 2000 of 7th Ed. Natl. Acad. Press, Washington, DC.

Parker, D.B., S. Pandrangi, L. W. Greene, L. K. Almas, N. A. Cole, M. B. Rhoades, J. A. Koziel. 2005. Rate and frequency of urease inhibitor application for minimizing ammonia emissions from beef cattle feedyards. *Transactions of the ASAE.* In Press.

Sawyer, C.N. and P.L. McCarty.1978. Chemistry for environmental engineering. 3rd Ed. McGraw-Hill, Inc., New York, NY.

Sommer, S.G. and N. Hutchings. 1995. Techniques and strategies for the reduction of ammonia emission from agriculture. *Water, Air and Soil Pollution* 85:237-248.

Shi Y., D. B. Parker, N. A. Cole, B. W. Auvermann, and J. E. Mehlhorn. 2001. Surface amendments to minimize ammonia emissions from beef cattle feedlots. *Transactions of the ASAE* 44(3):677-682.

Stevens, R. J., R. J. Laughlin, and J. P. Frost. 1989. Effect of acidification with sulfuric acid on the volatilization of ammonia from cow and pig slurries. *J. Agric. Science* 113(3): 389-395.

Subair, S., J. W. Fyles, and I. P. O'Halloran. 1999. Ammonia volatilization from liquid hog manure amended with paper products in the laboratory. *J. Environ. Qual.* 28(1): 202-207.

Varel, V. H. 1997. Use of urease inhibitors to control nitrogen loss from livestock waste. *Bioresource Tech.* 62(1): 11-17.

Varel, V. H., J. A. Nienaber, and H. C. Freetly. 1999. Conservation of nitrogen in cattle feedlot waste with urease inhibitors. *J. Animal Science* 77(5): 1162-1168.

Vasconcelos, J. T., L. W. Greene, N.A. Cole, F. T. McCollum, and J. C. Silva. 2004a Effects of phase feeding of protein on performance, blood urea nitrogen and carcass characteristics of finishing beef cattle: I. Individually fed steers. *2004 Beef Cattle Research in Texas.* Pp 129-133. Texas A&M Univ.

Vasconcelos, J. T., L. W. Greene, N.A. Cole, F. T. McCollum, and J. C. Silva. 2004b. Effects of phase feeding of protein on performance, blood urea nitrogen and carcass characteristics of finishing beef cattle: I. Group fed steers. *2004 Beef Cattle Research in Texas.* Pp 135-139. Texas A&M Univ.

Zhu, J., D. S. Bundy, X. Li, and N. Rashid. 1997. Controlling odor and volatile substances in liquid hog manure by amendment. *J. Environ. Qual.* 26(3): 740-743.