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Application Rate and Timing Effects on Urease Inhibitor Performance for Minimizing Ammonia Emissions From Beef Cattle Feedyards

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Abstract. *A laboratory study was conducted to evaluate how rate and timing of urease inhibitor application affects ammonia emissions from simulated beef cattle feedyard surfaces. The urease inhibitor N-(n-butyl)thiophosphoric triamide (NBPT) was applied at rates of 0, 1 and 2 kg/ha, at 8, 16, and 32 day frequencies, and with or without simulated rainfall. Synthetic urine was added every 2 days to the manure surface. Gaseous NH₃ was trapped in a sulfuric acid*

solution using a vacuum system and analyzed for nitrogen using automated procedures. NBPT applied every 8 days was most effective, with the 1 and 2 kg/ha NBPT treatments resulted in 49 and 66% reduction in NH₃ emission rates, respectively. The 8-day, 1 kg/ha NBPT treatment had the most promising cost/benefit ratio of 0.48. Simulated rainfall reduced the NH₃ emission rates slightly as compared to the non-rainfall treatments, though the differences were not statistically different.

Keywords. Ammonia, air quality, odor, nitrogen, urea, manure, beef cattle, feedlot, urease

Introduction

Cattle production is the principal animal agricultural operation in the Texas Panhandle area, with more than seven million beef cattle fed each year (SPS, 1999). There are seventy feedyards in the area with capacities greater than 20,000 head (Parker et al., 1997). Large amounts of manure are produced from these feedyards. The manure is rich in nutrients and is used as fertilizer in crop production. However, large amounts of manure left in the feedyard pens can contribute to water and air pollution if not managed properly.

In open-lot beef cattle feedyards, manure is left in the pen for 120 to 360 days (Parker et al., 1997). During this time, significant amounts of nitrogen can be volatilized from urine and feces on the feedyard surface. Nitrogen loss into the atmosphere results in higher C/N and lower N/P ratios, leads to less desirable fertilizer value, and contributes to air quality concerns. The need to decrease emissions of ammonia (NH₃) 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 currently have regulations limiting NH₃ emissions from concentrated animal feeding operations. Moreover, emissions of NH₃ 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). Scientists have estimated that as much as 50% of feed N is lost via volatilization (Bierman, 1995).

The abatement of NH₃ emissions is necessary due to several environmental, agricultural, social and economic reasons. Intensive livestock operations can create a significant source of NH₃ emissions to the atmosphere. Although some of the NH₃ emitted will be deposited locally, it can also be deposited thousands of kilometers away contributing to trans-boundary air pollution across countries (UNECE, 2001). These emissions may impact the surrounding ecosystem and their use (Arogo et al., 2001). NH₃ emissions are given importance all over the world. Studies in Europe have shown that measures to reduce NH₃ generally reduce odors as well (Xue et al., 1998). Decreasing NH₃ emissions can not only decrease environmental impacts, but also can increase the fertilizer value of the manure.

Several chemical amendments and additives have been studied to reduce NH₃ emissions (Shi et al., 2001; Cole et al., 1999; Miner and Stroh, 1976). Additives rely on several modes of action. Earlier research has shown that pH affects losses of NH₃ from cropped fields, with high pH resulting in greater NH₃ losses (Harmsen and Kolenbrander, 1965). Chemical amendments such as alum and calcium chloride reduce NH₃ emissions by decreasing pH and through cation exchange. Hydrolysis of the Al³⁺ ion in alum frees three H⁺ ions, decreasing pH and reducing NH₃ emissions. Through cation exchange, hydrogen ions are released and replaced by aluminum or calcium ions, again resulting in decreased pH and reduced NH₃ emissions.

Kithome et al. (1999) evaluated the efficacy of the chemical amendments CaCl₂, CaSO₄, MgCl₂, MgSO₄, and Al₂(SO₄)₃ (alum) for reducing NH₃ emissions from composted poultry manure.

Mixing 20% CaCl₂ with compost reduced NH₃ emissions to 10% of the control, whereas 20% alum reduced NH₃ emissions to 74% of the control. However, CaSO₄ and MgSO₄ ineffectively reduced NH₃ emissions. Moore et al. (1995) and DeLaune et al. (2004) reported that alum significantly reduced NH₃ volatilization from poultry manure. Lowering the pH by direct addition of sulfuric acid to cow and pig slurries has been shown to reduce NH₃ volatilization (Stevens et al., 1989).

Compounds that inhibit the enzymatic breakdown of nitrogenous compounds present in feces and urine can also decrease NH₃ production. Much of the nitrogen excreted in the urine is in the form of urea, which is rapidly hydrolyzed to ammonium and eventually NH₃ gas by the urease enzyme produced by soil and fecal microbes. Urease inhibitors can block the hydrolysis of urea to ammonium (Varel, 1997; Varel et al., 1999) and thereby decrease NH₃ production.

Nitrogen can be conserved and nitrogen and NH₃ emissions decreased by altering the carbon/nitrogen ratio. Subair et al. (1999) evaluated the ability of paper products added to liquid hog manure to reduce NH₃ emissions, and found that NH₃ volatilization was reduced from 29% to 47% by increasing the C/N ratio of the liquid hog manure.

In addition to chemical and enzymatic amendments, several commercial products are now marketed for reducing NH₃ emissions. Zhu et al. (1997) evaluated several commercial additives for reducing NH₃ emissions from swine lagoons. NH₃ emissions ranged from 64% to 137% of the control.

Shi et al. (2001) evaluated several amendments for reducing NH₃ emissions from beef cattle manure under laboratory conditions. Several amendments showed promise in reducing NH₃ emissions including alum (92 to 98% reduction), calcium chloride (71 to 79% reduction), humate (60 to 68% reduction), and the urease inhibitor N-(n-butyl)thiophosphoric triamide (NBPT) (65 to 66% reduction). NBPT was the only amendment that had a benefit/cost ratio greater than 1.0.

The purpose of this research was to investigate the ability of the urease inhibitor NBPT to reduce NH₃ emissions from simulated beef cattle feedyard surfaces under a variety of simulated field conditions.

Objectives

The specific objectives of this research were to:

- 1) Determine how often NBPT must be applied to minimize NH₃ emissions in simulated feedyard conditions,
- 2) Determine how precipitation affects the effectiveness of NBPT, and
- 3) Estimate the economic effectiveness of using NBPT.

Materials and Methods

Experimental Design

The experiment design included the following three factors:

1. NBPT application rate (0, 1 or 2 kg/ha)
2. NBPT application interval (applied every 8, 16, or 32 days)
3. Simulated rainfall (no water added or 0.6 cm water added every 4 days)

The design consisted of 14 treatments, including 12 treatments resulting from combinations of the three factors above and an additional two treatments consisting of a blank (no soil/manure) and a control as shown in Table 1. There were three replications per treatment for a total of 42 experimental units.

Table 1. Treatments used in the experiment.

TRT	NBPT Application Rate (kg/ha)	NBPT Application Interval (days)	Simulated Rainfall*
1	Blank (no soil/manure)	None	No
2	Control (soil/manure only)	None	No
3	1	8	No
4	1	8	Yes
5	1	16	No
6	1	16	Yes
7	1	32	No
8	1	32	Yes
9	2	8	No
10	2	8	Yes
11	2	16	No
12	2	16	Yes
13	2	32	No
14	2	32	Yes

* Treatments with simulated rainfall received 0.6 cm water every four days.

Emission Apparatus

A total of 36 Tupperware containers (16.7 x 16.7 x 17 cm deep) were used as air emission chambers (Fig. 1). Treatments 3, 4, 9 and 10 were performed for 16 days total. Six chambers were used for treatments 3 and 4 for the first 16 days and the same chambers were used for treatment 9 and 10 for the remainder of the experiment.

Soil (1200 g) was placed into each container and fresh feces (400 g) were spread evenly over the top of the soil. Both the soil and feces layers were about 5 cm thick. The soil was Amarillo fine sandy loam (*fine-loamy, mixed, thermic Aridic Paleustalfs*) obtained near the WTAMU Research Feedyard located 10 km east of Canyon, TX. Fresh feces were collected from the WTAMU Research Feedyard and frozen prior to use in the experiment. The feces were thawed one day before being placed into the chambers.

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 m² area) after the acid was changed out. Synthetic urine was prepared fresh before each application. The synthetic urine preparation was adapted from Shand et al. (2000) and prepared as follows: Urea (21.4 g) was dissolved in 500 mL of water. KHCO₃ (23.1 g), KCl (3.8 g) and K₂SO₄ (1.9 g) were dissolved together in 500 mL of water. The two solutions (1 L total) were mixed immediately before application. In the treatments with simulated rainfall, an additional 173 mL (0.6 cm) of water was sprinkled over the manure surface at four-day intervals. The chambers were maintained at 25°C.

The NBPT, which was in a white crystalline form, was dissolved in a small amount of water and sprayed on the manure surface at the rates and intervals described above. Because a small amount of water was added to the manure whenever NBPT was sprayed on the surface, an equal amount of water was added to all treatments to avoid differences in manure moisture contents between those treatments that received different amounts of NBPT.



Figure 1. Photo of the NH₃ emission apparatus used in the experiment.

Each container was connected to an NH₃ collection trap containing 100 ml of 0.9 M sulfuric acid. Each acid trap was connected with plastic tubing to a common plastic container to ensure an equal airflow from all the chambers (Fig. 1). The common container was connected to a vacuum pump (Marathon Electric, Model 80M48S17D1180JP, 1/3 hp, 75L/min max). The ambient air above the manure was pulled through the acid traps by the vacuum pump. The total airflow was adjusted to obtain a flowrate of 1.4 L/min in each container. Flow rates were measured using an Omega Model FL-105 glass rotameter with stainless steel float (Omega Engineering, Inc., Stamford, Conn.). Acid was changed every 48 hrs. Acid samples were analyzed for total nitrogen by automated procedures at the USDA Laboratory in Bushland, TX using a Lachat flow injection analyzer.

Results for each treatment were compared to test the effects of different amendments. Statistical analyses were performed using Tukey's Honestly Significant Difference (HSD) comparisons within the SPSS Version 7.0 software package. Tukey's test controls the family-wise error rate rather than the individual error rate (Berthouex and Brown, 1994).

Economic Analysis

Costs associated in applying NBPT for each treatment were calculated. NBPT costs were based on the cost of Agrotain®, a commercially available product with 20% active ingredient (NPBT), at a cost of \$11.90/L. The NH₃ emissions of the treatment were compared with the control to obtain reduction in emission for each treatment. Only benefits that had a monetary value, i.e. the increase in fertilizer value of the manure, were used in calculating the benefits, as environmental air quality benefits are difficult to assign a monetary value. A fertilizer value of \$0.32 per kg of N was adapted from the studies of Parker et. al. (1997). Benefits associated with each treatment were calculated from the price of N saved in the manure. The B/C analysis was

performed based on the surface area in which the NBPT was applied, assuming a stocking density of 14 m² per animal.

Results and Discussion

The NH₃ emissions for the 8-day interval application were less than all other application frequencies (Table 2). None of the 16-day or 32-day applications were significantly different from the control (Table 2). None of the simulated rainfall treatments were statistically different than their respective non-rainfall treatment. The 1 kg/ha and 2 kg/ha treatments were not statistically different at any of the frequency application periods.

Table 2. Mean NH₃-N emission rates ($\mu\text{g m}^{-2} \text{min}^{-1}$) for three NBPT application rates, three application intervals, and with or without simulated rainfall. Each mean is calculated from three replications.

NBPT Rate (kg/ha)	NBPT Application Interval (days)	Simulated Rainfall*	Mean $\mu\text{g m}^{-2} \text{min}^{-1}$	Std. Dev.	Minimum	Maximum	Percent of Control
0 (Blank)	na	no	6 a	0.4	5	6	0.4
0 (Control)	na	no	1570 d	220	1430	1820	100
1	8	no	790 bc	80	710	880	51
1	8	yes	590 b	70	520	650	38
1	16	no	1510 d	2105	1300	1720	97
1	16	yes	1330 d	140	1220	1480	85
1	32	no	1590 d	250	1300	1770	101
1	32	yes	1570 d	2500	1290	1760	100
2	8	no	530 b	20	510	550	34
2	8	yes	490 ab	90	420	600	31
2	16	no	1540 d	1700	1400	1730	99
2	16	yes	1230 cd	1902	1020	1370	78
2	32	no	1400 d	160	1240	1570	89
2	32	yes	1190 cd	1701	1070	1390	76

Means within a column with different letters are significantly different using Tukey's HSD test ($\alpha=0.05$).

* Treatments with simulated rainfall received 0.6 cm water added every four days.

Although the average emission rates in Table 2 suggest that NBPT applied every 8 days will decrease NH₃ emissions, the graph of NH₃ emissions with time for the non-rainfall treatments shows that the 1 kg/ha treatment was not much different than the control after the first 8 days, and became greater than the control on day 16 (Fig. 2). The 2 kg/ha non-rainfall treatment decreased noticeably when NBPT was reapplied on the 8th day, yet, like the 1 kg/ha treatment, the emissions were slightly greater than the control on day 16 (Fig. 2). These results suggest that an application interval of slightly less than 8 days may be needed, and also that a higher NBPT application rate may be needed with time as more urea is accumulated on the simulated feedyard surface.

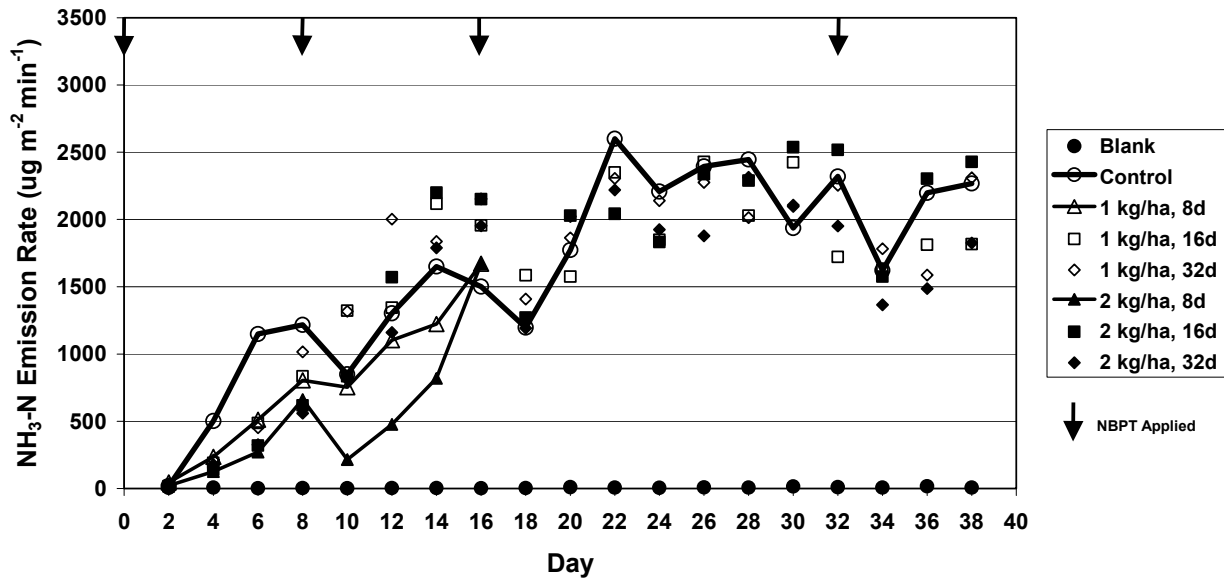


Figure 2. Graph showing how average daily $\text{NH}_3\text{-N}$ emission rates varied over the 38-day study period in the treatments without simulated rainfall. Each data point is the mean of three replications.

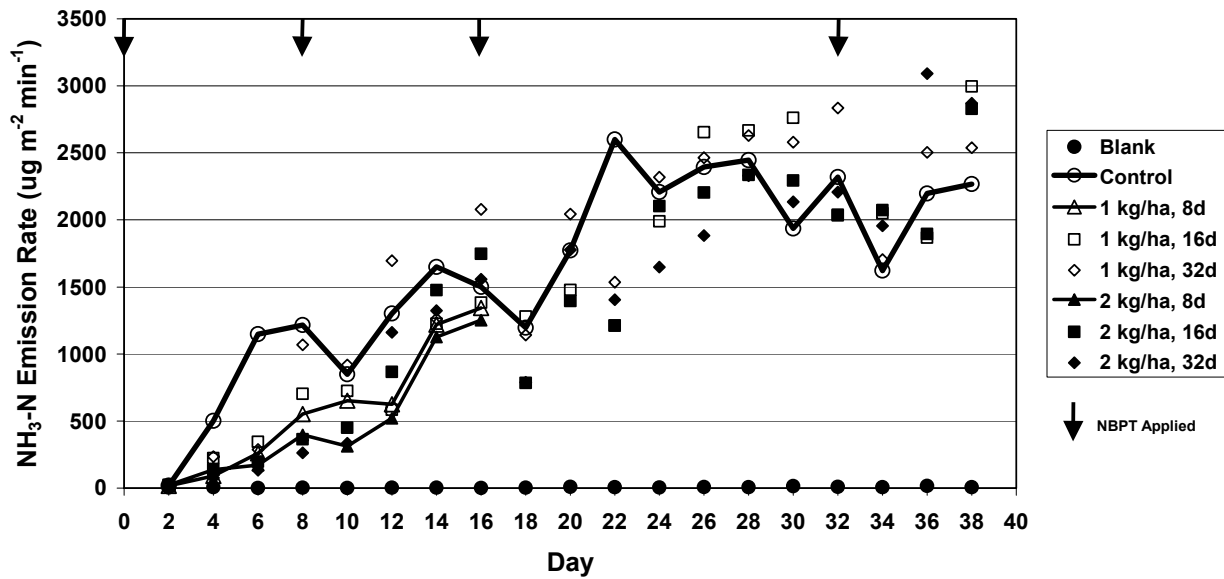


Figure 3. Graph showing how average daily $\text{NH}_3\text{-N}$ emission rates varied over the 38-day study period in the treatments with simulated rainfall. Each data point is the mean of three replications.

With the exception of the 8 day interval application treatments, after day 8 most of the other non-rainfall treatments had NH₃ emissions equal to or greater than the control (Fig. 2). This indicates that NH₃ emissions may be suppressed for a short time, but if NBPT is not continually applied, the buildup of urea will eventually result in a higher NH₃ emission rate than would have occurred had no NBPT been applied. Most of the rainfall treatments remained lower than the control for about 14 days, an indication that moisture plays a small role in the effectiveness of the NBPT (Fig. 3).

When NBPT was added on day 16 and day 32, there was little effect on NH₃ emissions for the non-rainfall treatments (Fig. 2), however, for the rainfall treatments the 2 kg/ha applications exhibited a drop in NH₃ emissions for a few days. It is possible that the NBPT application rate was not high enough due to the buildup of urea from application every 2 days over the study period. Further research is warranted to study this phenomenon and determine the optimum NBPT application rate for feedyard conditions.

The application of water at 4-day intervals did not result in statistically different NH₃-N emissions (Table 2), though there was some evidence that water played a role in the effectiveness of the NBPT (Fig. 3). It is possible that the water helped spread the NBPT through the manure surface, thereby increasing its effectiveness.

The addition of synthetic urine every 2 days resulted in a continuous increase in emission rates until about day 20. In similar previous studies, fresh feces and urine were added at the onset of the experiment, and no additional urine or manure was added during the experiment (Shi et al., 2001). In Shi's research, emissions were highest initially and decreased rapidly with time. The mean daily emission rates of the present study were about half of the emission rates reported by Shi et al. (2001).

The NBPT was mixed into the manure in Shi's experiments, whereas the urease inhibitor was sprayed over the manure surface in this experiment. NBPT applied by spraying over the manure produced similar results of the incorporated applications. In practical conditions, incorporation requires additional labor, and it is probable that cattle hoof action would be adequate for mixing the NBPT into the manure. Spraying also requires additional labor, however, it might be possible for NBPT to be applied through sprinklers already in place to minimize dust emissions in some feedyards.

Varel et al. (1999) reported that a feedyard containing 50,000 head could release 10,000 kg of NH₃ nitrogen per day. Based on the NH₃ emission rate of the control in this experiment and assuming 14 m² pen space per animal, an estimated 1570 kg of NH₃ nitrogen would be released per day.

The mean NH₃ emission rate for the control in this experiment was 1570 μg m⁻² min⁻¹, which compares to 3307 μg m⁻² min⁻¹ as reported in the 21-day laboratory study of Shi et al. (2001). Reported NH₃ emissions measured in field studies in West Texas have been reported as 289, 1,816, and 1,666 μg m⁻² min⁻¹ for winter, spring and summer seasons, respectively (Koziel et al., 2004). In the present study, the mean emission rate in the control very close to that reported by Koziel et al. for spring and summer feedyard conditions.

Economics

The benefits derived from the urease inhibitor such as decrease in emissions and increase in fertilizer value must be sufficient to justify the cost of the amendment. Because only the 8-day application intervals had significantly lower NH₃ emissions, the benefit cost analysis was performed on these two treatments. The economic analysis using area-based extrapolation indicated a B/C ratio of 0.48 for the 1 kg/ha treatment as compared to 0.30 for the 2 kg/ha

treatment. NH₃ emissions were lower in the 2 kg/ha treatment, though the B/C ratio was lower. With the highest B/C of 0.48, the analysis indicates that application of NBPT is not economical based solely on the increased N content in the manure (Table 3). However, other air quality and environmental benefits may make NBPT a viable option in the future.

Table 3. Economics of using NBPT at the rates shown. Benefits equal the additional nitrogen value in the manure, while costs equal the NBPT cost only and no application costs included.

	1 kg/ha NBPT applied at 8-day interval	2 kg/ha NBPT applied at 8-day interval
Decrease in NH ₃ emissions (kg/animal unit/yr)	5.7	7.2
Increase in fertilizer value of manure (\$/animal unit/yr)	1.82	2.30
Cost of NBPT (\$/animal unit/yr)	3.80	7.60
Benefit to cost ratio	0.48	0.30

Conclusions

The following conclusions were drawn from this laboratory research project:

- 1) When applied every 8 days and without simulated rainfall, NH₃ emissions were reduced by 49.4 and 66.0% at NBPT application rates of 1 kg/ha and 2 kg/ha, respectively.
- 2) NBPT must be applied at an interval no greater than 8 days in order to be effective at reducing NH₃ emissions. Application at 16 or 32 day intervals was not significantly different than the control.
- 3) Simulated rainfall reduced the NH₃ emission rates slightly as compared to the non-rainfall treatments, though the differences were not statistically different..
- 4) The use of NBPT for reducing NH₃ emissions from beef cattle feedyards looks promising based on the results of this and other laboratory studies. However, this research suggest that a buildup of urea may require an increased amount of added NBPT with time. Additional research should be performed to evaluate the performance of the urease inhibitor in actual field conditions.

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