SURFACE AMENDMENTS TO MINIMIZE AMMONIA EMISSIONS FROM BEEF CATTLE FEEDLOTS

Y. Shi, D. B. Parker, N. A. Cole, B. W. Auvermann, J. E. Mehlhorn

ABSTRACT. *Amendments for reducing ammonia emissions from open–lot beef cattle feedlots were evaluated in the laboratory. A mixture of 1550 g of soil, 133 g of feces, and 267 g of urine was placed into plastic containers that were 20 cm × 20 cm × 12 cm deep. Using a vacuum system, clean air (3.2 L/min) was passed over the soil–manure surface and ammonia was trapped by bubbling the air through dilute sulfuric acid. Treatments were a blank (soil with no manure), control (soil–manure mixture with no amendment), 4500 kg/ha $Al_2(SO_4)_3$ (alum), 9000 kg/ha alum, 375 kg/ha commercial product (CP) for reducing ammonia emissions, 750 kg/ha CP, 4500 kg/ha calcium chloride ($CaCl_2$), 9000 kg/ha $CaCl_2$, 9000 kg/ha brown humate, 9000 kg/ha black humate, 1 kg/ha of the urease inhibitor N–(n–butyl) thiophosphoric triamide (NBPT), and 2 kg/ha NBPT. There were four replications of each treatment. Ammonia emissions were measured for 21 days following application of the amendments. Cumulative ammonia emissions after 21 days, expressed as a percentage of the control, were 0.4% for the blank, 8.5% for 4500 kg/ha alum, 1.7% for 9000 kg/ha alum, 73.6% for 375 kg/ha CP, 68.2% for 750 kg/ha CP, 28.8% for 4500 kg/ha $CaCl_2$, 22.5% for 9000 kg/ha $CaCl_2$, 32.4% for 9000 kg/ha brown humate, 39.8% for 9000 kg/ha black humate, 35.9% for 1 kg/ha NBPT, and 34.4% for 2 kg/ha NBPT. Calculated costs of the amendments ranged from \$0.12 to \$5.53 per application per head. Only one treatment had a benefit/cost ratio greater than 1.0. Results suggest that amendments can reduce ammonia emissions from open feedlots, but the costs may be prohibitive. Site–specific environmental impacts should be evaluated before using these amendments in a commercial setting.*

Keywords. *Ammonia, Air quality, Emissions, Feedlot, Feedyard, Manure, Cattle.*

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 urine and feces on the feedlot surface. Nitrogen loss into the atmosphere results in higher carbon/nitrogen ratios, leads to less–desirable fertilizer value, 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 currently 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). Scientists have estimated that as much as 50% of feed N is lost as ammonia (Bierman, 1995).

MECHANISMS FOR AMMONIA REDUCTION

Several chemical amendments and additives have been studied to reduce ammonia emissions (Cole et al., 1999). Additives rely on several modes of action. Earlier work demonstrated that pH affects losses of inorganic nitrogen in the form of ammonia from cropped fields, with high pH resulting in greater ammonia losses (Harmsen and Kolenbrander, 1965). Chemical amendments such as alum and calcium chloride reduce ammonia emissions first by decreasing pH and second 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 to 10% of the control, whereas 20% alum reduced ammonia emissions to 74% of the control. However, $CaSO_4$ and $MgSO_4$ ineffectively reduced ammonia emissions. Moore et al. (1995) reported that alum

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significantly reduced ammonia volatilization from poultry manure. The direct addition of sulfuric acid to cow and pig slurries reduced ammonia volatilization (Stevens et al., 1989).

Compounds that inhibit the enzymatic breakdown of nitrogenous compounds present in feces and urine can also decrease ammonia production. Much of the nitrogen excreted in the urine is in the form of urea, which is rapidly hydrolyzed to ammonium and eventually ammonia 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 ammonia production.

Nitrogen can be conserved and nitrogen and ammonia 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 ammonia emissions, and found that ammonia volatilization was reduced from 29% to 47% by increasing the carbon/nitrogen ratio of the liquid hog manure.

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 64% to 137% of the control.

Most previous research on control of ammonia emissions has been conducted with swine, poultry, and dairy manure, and usually in a liquid slurry. Reducing ammonia emissions by open, earthen–surfaced beef cattle feedlots has received little attention. The purpose of this research was to investigate the ability of several amendments to reduce ammonia emissions from simulated beef cattle feedlot surfaces.

Materials and Methods

A mixture of soil, feces, and urine was placed into sealed plastic containers 20 cm × 20 cm × 12 cm deep. There were 12 treatments, with four containers (replications) per treatment, for a total of 48 containers. The first treatment was a blank, in which 1550 g of soil was placed into the container. For the other 11 treatments, 1550 g of soil, 133 g of feces, and 267 g of urine were mixed and placed into containers to simulate feedlot conditions. The soil was a Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustolls) obtained at the West Texas A&M University Nance Ranch located 10 km east of Canyon, Texas. The initial nitrogen concentration in the Pullman clay loam, measured using a Leco CNS–2000 Elemental Analyzer (Leco Corp, St. Joseph, Mich.), was 1864 mg/kg (dry weight basis). Feces were fresh droppings collected at the West Texas A&M University research feedlot. Urine was obtained from feeding stalls at the USDA–ARS laboratory in Bushland, Texas. The initial nitrogen concentration in the soil–feces–urine mixture measured using the LECO CNS–2000 was 2395 mg/kg (dry weight basis).

Amendments were thoroughly mixed with the soil–feces–urine mixture and added to the containers at the rates shown in table 1. Each container was connected to an ammonia collection trap containing 100 ml of 0.9 M sulfuric acid. Each acid trap was connected with plastic tubing to a large plastic container filled with water. The large container was connected to a vacuum pump (0.75 kW ShopVac). Total airflow rate was adjusted to 153 L/min (3.2 L/min per container) by constricting the plastic tubing. 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 24 hours for the first week and every 48 hours for the next two weeks. Acid samples were analyzed for total nitrogen by automated procedures using a Technicon Autoanalyzer (Technicon, 1997).

Soil/manure mixture samples were analyzed for pH, moisture content, carbon, nitrogen, sulfur, and nitrate upon completion of the 3–week period. The pH of the soil–manure mixture was measured in a slurry of two parts water to one part mixture by weight. Moisture content was determined by oven drying at 105° C for 24 h. Carbon, nitrogen, and sulfur were determined using a carbon–nitrogen–sulfur analyzer (Leco Corp. Model CNS–2000, St. Joseph, Mich.). Nitrate was determined by cadmium reduction using flow injection analysis (Perstorp Analytical, Wilsonville, Oregon).

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).

Results and Discussion

Ammonia Emissions

Each of the amendments reduced ammonia emissions (fig. 1, table 2). The two alum treatments were the most effective, reducing the 21–day cumulative ammonia emissions by 91.5% and 98.3%. These were followed by the two calcium chloride treatments, which reduced 21–day cumulative ammonia emissions by 71.2% and 77.5%. Of the two humate treatments, the brown humate was more

Table 1. Amendments and application rates.

Treatment	Amendment	Amount of Amendment Added (g)	Equivalent Application Rate (kg/ha)
1	None (Blank)	0	NA
2	None (Control)	0	NA
3	Aluminum sulfate	18	4500
4	Aluminum sulfate	36	9000
5	Commercial product[a]	1.5	375
6	Commercial product[a]	3.0	750
7	Calcium chloride	18	4500
8	Calcium chloride	36	9000
9	Brown humate[b]	36	9000
10	Black humate[b]	36	9000
11	NBPT[c]	0.004	1
12	NBPT[c]	0.008	2

[a] Ammonia Hold, Lonoke, Arkansas.
[b] HumaTech, Inc., Houston, Texas.
[c] Crescent Technology, Inc., Belle Chasse, Louisiana.

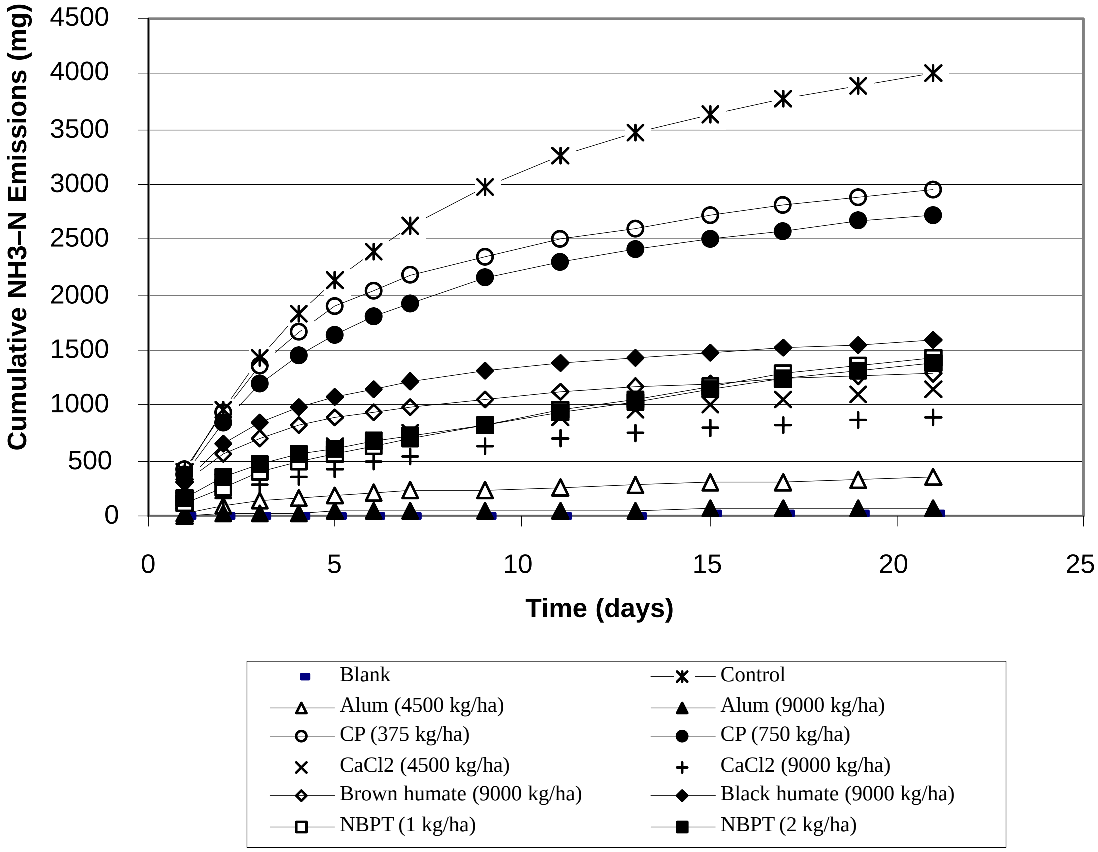

Figure 1. Cumulative ammonia emissions from manure–soil mixtures with amendments. Each data point is the mean of four replications.

Table 2. Total ammonia–N volatilized over a 21–day period.

Treatment	Ammonia–N (mg) Mean[a]	Ammonia–N (mg) Std. Error	% of Control	Rank
Blank (soil only)	17.2 a	0.75	0.4	
Control (soil–manure, no amendment)	4000 f	133.5	100	
Alum (4500 kg/ha)	340.2 a	120.5	8.5	2
Alum (9000 kg/ha)	67.2 a	13.4	1.7	1
Commercial product (375 kg/ha)	2946 e	56.0	73.6	10
Commercial product (750 kg/ha)	2728 e	102.0	68.2	9
Calcium chloride (4500 kg/ha)	1151 bc	29.0	28.8	4
Calcium chloride (9000 kg/ha)	899 b	49.5	22.5	3
Brown humate (9000 kg/ha)	1296 bcd	117.0	32.4	5
Black humate (9000 kg/ha)	1590 d	84.5	39.8	8
NBPT (1 kg/ha)	1435 cd	45.5	35.9	7
NBPT (2 kg/ha)	1376 cd	148.5	34.4	6

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

effective, reducing cumulative ammonia emissions by 67.6% as compared to 60.2% for the black humate, but there was no significant difference between the two humates.

The enzymatic amendment NBPT treatments reduced cumulative ammonia emissions by 64.1% and 65.6%. Because NBPT catalyzes biochemical reactions, there is a minimum amount of enzyme required to reduce urease activity, and application above this rate will give no further benefit. Both NBPT treatments had similar ammonia emissions, suggesting that the amount of enzyme at the lower application rate (1 kg/ha) was sufficient to maximize inhibition of urease activity. This is also evident in figure 2, which shows that daily ammonia emissions were similar after the third day for both NBPT treatments. It is possible that NBPT can be applied at less than 1 kg/ha with the same effect. The commercial product treatments least effectively reduced ammonia emissions, although they reduced cumulative ammonia emissions by 26.4% and 31.8% at the low and high application rates, respectively.

The two alum treatments had the lowest soil pH at the completion of the experiment (table 3). Calcium chloride, humates, and the commercial product also had a lower pH than the control. The NBPT treatments had a pH similar to the control group, indicating that pH was not a factor in ammonia emissions for the NBPT.

The final moisture contents varied between 6.0% and 9.2%, as compared to 8.5% for the control (table 3). Mean moisture contents were not significantly different from the control for any of the treatments, indicating that moisture was not a primary reason for differences in ammonia emissions.

The 21–day average NH_3–N flux of the control treatment was 3307 ug/(m^2·min). This compares favorably to measured NH_3–N fluxes of 37 to 6000 ug/(m^2·min) in the undisturbed manure in an open dairy lot in California (Lester, 1996). Thus, the ammonia fluxes were within the broad range typically found in field conditions, even though the experiment was conducted in a laboratory.

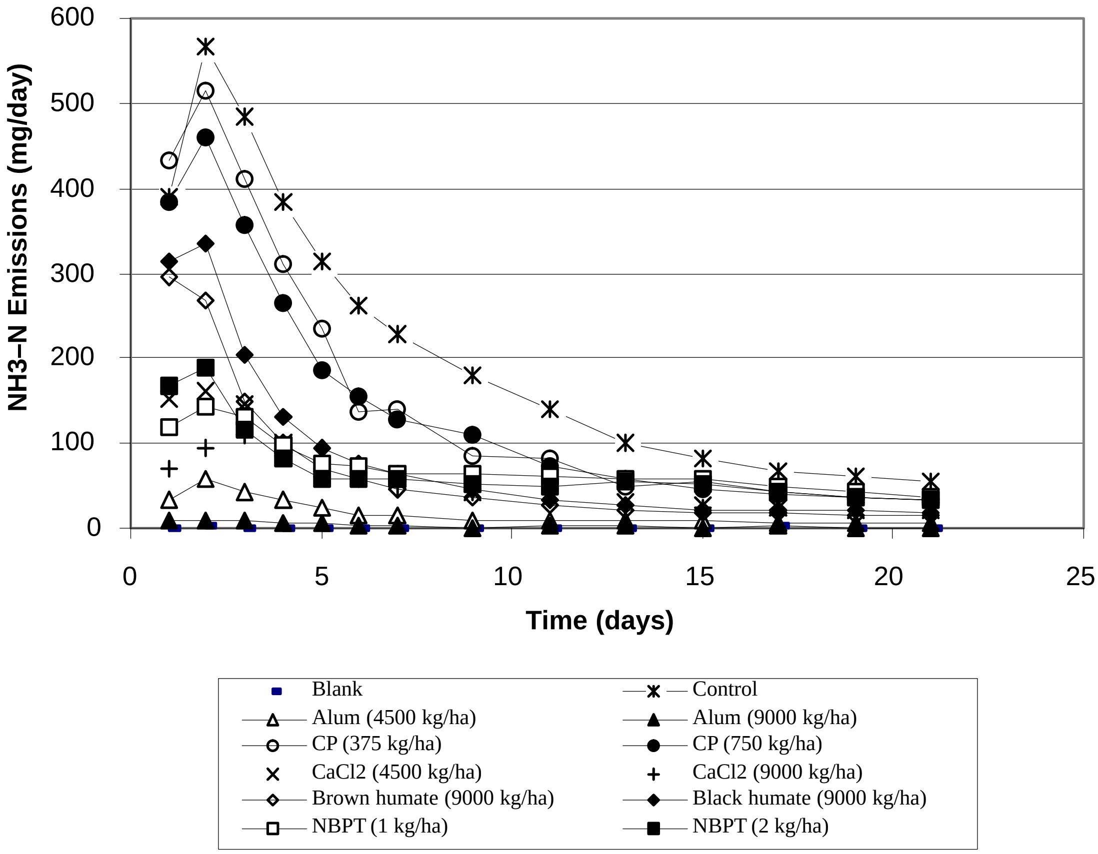

Figure 2. Daily ammonia emissions from manure–soil mixtures with amendments. Each data point is the mean of four replications.

Table 3. Mean pH and moisture content of soil–manure mixtures at the completion of the experiment.

	pH		Moisture Content (% dry weight basis)	
Treatment	Mean[a]	Std. Error	Mean[a]	Std. Error
Blank (soil only)	6.83 c	0.21	1.9 a	0.03
Control (soil–manure, no amendment)	7.55 de	0.13	8.9 b	0.98
Alum (4500 kg/ha)	5.98 b	0.18	9.2 b	0.75
Alum (9000 kg/ha)	4.20 a	0.03	8.9 b	0.98
Commercial product (375 kg/ha)	7.12 cde	0.11	6.9 b	1.12
Commercial product (750 kg/ha)	7.39 cde	0.12	9.0 b	1.24
Calcium chloride (4500 kg/ha)	6.99 cd	0.10	8.2 b	0.63
Calcium chloride (9000 kg/ha)	6.85 c	0.09	8.3 b	0.57
Brown humate (9000 kg/ha)	7.06 cde	0.14	6.7 b	0.45
Black humate (9000 kg/ha)	7.10 cde	0.04	7.2 b	0.67
NBPT (1 kg/ha)	7.52 de	0.04	6.0 b	0.31
NBPT (2 kg/ha)	7.58 e	0.09	7.3 b	0.67

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

Economics

The costs of amendments delivered to the feedlot are presented in table 4. These costs do not include labor or related expenses for spreading materials on the feedlot surface. Costs were based on two scenarios to give a range of costs. The first scenario assumes one application at the beginning of the feeding period. The second scenario assumes application every 21 days, or six applications in a 120–day feeding period. The costs of the NBPT treatments were considerably lower than the other treatments.

We also compared the benefit–to–cost (B/C) ratios for all amendments. Benefit per unit feedlot area was calculated as the equivalent value of commercial nitrogen fertilizer saved using the amendment. We used a commercial anhydrous ammonia fertilizer value of $0.19/kg ($175/ton). Amendment cost per unit feedlot area was calculated as the amendment cost per head divided by the typical cattle spacing of 14 m^2/head (150 ft^2/head).

The only treatment that had a B/C ratio greater than 1.0 was the 1 kg/ha NBPT treatment, which had a B/C ratio of 1.75 (table 4). With the exception of the 2 kg/ha NBPT treatment (B/C = 0.89), all other B/C ratios ranged from 0.036 to 0.165, indicating that costs for reducing ammonia emissions were considerably higher than the economic benefits that would be realized from fertilizer savings.

Environmental and Land Application Considerations

Characteristics of manure on the feedlot surface is of environmental concern for two reasons: 1) runoff from the feedlot surface during a precipitation event can carry contaminants to surface and/or ground waters; and 2) most manure produced in feedlots is harvested and applied to cropland, where the manure can indirectly affect water quality through runoff or percolation. Concentrations of

Table 4. Treatment costs and benefit–to–cost ratios for the various amendments. Values include cost of materials and shipping to the feedlot, but do not include spreading costs.

Treatment	Amendment	Rate (kg/ha)	Cost if Applied Once at Beginning of Feeding Period ($/head)	Cost if Applied Six Times During the Feeding Period ($/head)	B/C Ratio
1	None (Blank)	NA	NA	NA	NA
2	None (Control)	NA	NA	NA	NA
3	Aluminum sulfate	4500	1.81	10.86	0.165
4	Aluminum sulfate	9000	3.62	21.72	0.089
5	Commercial product	375	0.72	4.32	0.120
6	Commercial product	750	1.44	8.64	0.072
7	Calcium chloride	4500	1.48	8.88	0.157
8	Calcium chloride	9000	2.97	17.82	0.085
9	Brown humate	9000	5.53	33.18	0.040
10	Black humate	9000	5.53	33.18	0.036
11	NBPT	1	0.12	0.72	1.75
12	NBPT	2	0.24	1.44	0.89

Table 5. Mean[a] carbon, nitrogen, sulfur, and nitrate concentrations in soil–manure mixtures at completion of 21–day period (dry weight basis).

Treatment	Carbon (%)	Nitrogen (mg/kg)	Sulfur (mg/kg)	Nitrate (mg/kg)
Blank (soil only)	1.10 a	833 a	44 a	9.8 ab
Control (soil–manure, no amendment)	1.33 abc	1817 bc	73 a	54.8 d
Alum (4500 kg/ha)	1.36 abc	2027 c	266 b	48.8 cd
Alum (9000 kg/ha)	1.39 abcd	1974 c	989 c	28.7 bc
Commercial product (375 kg/ha)	1.34 abc	1533 b	63 a	55.5 d
Commercial product (750 kg/ha)	1.38 abc	1725 bc	69 a	50.4 cd
Calcium chloride (4500 kg/ha)	1.26 ab	1900 bc	68 a	8.4 ab
Calcium chloride (9000 kg/ha)	1.81 d	2002 c	40 a	2.6 a
Brown humate (9000 kg/ha)	1.65 bcd	1834 bc	36 a	57.0 d
Black humate (9000 kg/ha)	1.51 abcd	1963 c	59 a	57.4 d
NBPT (1 kg/ha)	1.31 ab	1808 bc	63 a	44.6 cd
NBPT (2 kg/ha)	1.76 cd	2021 c	77 a	43.6 cd

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

carbon, nitrogen, sulfur, and nitrate in soil–feces–urine mixtures measured upon completion of the experiment are shown in table 5.

Carbon concentrations were highly variable among treatments, and no trends were observed. Carbon concentrations in the two calcium chloride treatments varied from 1.26% to 1.81%, which encompassed the range among treatments. Though not statistically different, mean carbon concentrations of the two humate treatments were higher than most other treatments, which was expected because humate is a carbon–based product. Most Texas Panhandle soils that have been tilled for many years need additional organic matter, so higher carbon concentrations are a benefit to area soils.

A negative correlation was observed between total ammonia emissions over the 21–day period and total nitrogen remaining in the soil–manure mixture at the completion of the experiment (r = –0.69), indicating that reducing ammonia emissions resulted in increased nitrogen retention in manure.

Mean sulfur concentrations were similar among treatments with the exception of the two alum treatments, which were approximately 4 to 14 times higher than the other treatments. Because alum contains sulfur, it is logical that the alum treatments had greater sulfur concentrations. Excessive sulfur concentrations could be a concern to feedlot operators, especially those operations located in areas of high precipitation, because sulfur is a reactant for the production of many odorous gases.

Nitrate concentration of the soil–manure mixture is an environmental consideration because nitrate is soluble, can be transported in water that can run off the feedlot surface during a precipitation event, and is regulated by U.S. EPA drinking water regulations. The highest alum treatment reduced nitrate concentrations to approximately half that of the control, whereas the two calcium chloride treatments reduced nitrate concentrations to about 5% to 15% of the control. All other treatments had nitrate concentrations similar to the control.

Conclusions

A laboratory study demonstrated that ammonia emissions from simulated open–lot earthen feedlot surfaces can be reduced from 26.4% to 98.3% using amendments. Costs for the amendments applied once at the beginning of the feeding period ranged from $0.12 per head per application for the urease inhibitor NBPT to as much as $5.53 per head per application for other amendments. Only the 1 kg/ha NBPT amendment had a benefit–to–cost ratio greater than 1.0, indicating that costs for reducing ammonia emissions exceed the benefits in potential fertilizer savings. Nitrate concentrations in the manure mixture were reduced about 50% by the highest alum treatment, and from 85% to 95% by the two calcium chloride treatments, indicating that these amendments could have other environmental benefits besides reducing ammonia emissions.

This research provides initial information on amendments that can reduce ammonia emissions from open–lot, earthen beef cattle feedlot surfaces. Additional research is necessary to determine: 1) optimum frequency of application in a field setting, 2) potential adverse environmental effects from using the additives in a feedlot setting, and 3) potential adverse effects on animal health or performance.

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