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# Reducing Crude Protein in Beef Cattle Diet Reduces Ammonia Emissions from Artificial Feedyard Surfaces

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## ABSTRACT

**Concentrated animal feeding operations are major sources of ammonia to the atmosphere. Control methods to reduce emissions include acidifying amendments, urease inhibitors, and absorbents. For beef cattle, decreasing crude protein (CP) in diets may be the most practical and cost-effective method to reduce ammonia emissions. Our objective was to quantify the effect of reducing CP in beef cattle diet on ammonia emissions. Two groups of steers were fed diets with either 11.5 or 13.0% CP and all urine and feces were collected. Manures from the two diet treatments were applied in a replicated laboratory chamber experiment, and ammonia emission was quantified using acid gas washing. In four seasonal field trials, manures from the two diet treatments were applied to two 10-m-diameter, circular, artificial feedyard surfaces, and ammonia emission was quantified using the integrated horizontal flux method. Manure from steers fed 11.5% CP diet had less urine, less urinary N, and a lesser fraction of total N in urine, compared with the 13.0% CP diet. Decreasing crude protein in beef cattle diets from 13 to 11.5% significantly decreased ammonia emission by 44% ($p < 0.01$) in the closed chamber laboratory experiment, and decreased mean daily ammonia flux by 30% ($p = 0.10$), 52% ($p = 0.08$), and 29% ($p < 0.01$) in summer, autumn, and spring field trials, respectively. No difference was observed in winter. On an annual basis, decreasing crude protein reduced daily ammonia flux by 28%. Reducing crude protein in beef cattle diets may provide the most practical and cost-effective way to reduce ammonia emissions from feedyards.**

It is estimated that nitrogen cycling through terrestrial ecosystems has doubled, primarily through anthropogenic activities (Smil, 1990; Vitousek et al., 1997). These include the production and use of nitrogen fertilizers, planting of nitrogen-fixing crops, release of nitrogen from storage reservoirs in soils and plant biomass, and the burning of fossil fuels. Many of these sources are agricultural, and estimates of the agricultural contribution to increased N in global ecosystems range from 50 to more than 90%, with animal husbandry comprising the majority of that contribution (Bouwman et al., 1997; Ferm, 1998; Galloway and Cowling, 2002; Howarth et al., 2002).

Ammonia is the primary basic constituent of the atmosphere; it readily combines with and neutralizes oxidized compounds such as $SO_2$ and $NO_x$, forming secondary particulates. Ammonia and its compounds can be transported long distances, wash out in precipitation, and return to the earth's surface. Nitrogen enrichment of land and water can have varying effects, from the fertilization of cropland, to excessive enrichment and degradation of sensitive ecosystems (Matson et al., 2002; Rabalais, 2002; Todd et al., 2004).

Animal feeding operations, with abundant masses of manure, are major sources of ammonia. Practices to limit the loss of ammonia via volatilization include decreasing pen surface pH by addition of acidifying amendments (Shi et al., 2001), applying urease inhibitors and/or essential oils (Parker et al., 2004; Varel, 1997; Varel et al., 1999, 2004), managing the pen surface (Adams et al., 2004), absorbing ammonia with zeolites (Eng et al., 2003, 2004; Venglovsky et al., 1999), shifting N from urine to feces (Gueye et al., 2003), or decreasing excreted N by modifying cattle diet (McBride et al., 2003). However, the problems of effectively applying pen surface amendments or the poor cost-effectiveness of some practices present challenges that may prohibit the application of otherwise effective methods to reduce ammonia emission.

Modifying diet by decreasing crude protein while maintaining animal performance may be the most practical method. In feedyards, beef cattle are routinely fed diets that contain 12.5 to 14% crude protein (CP), 0.5 to 1.0% urea, and 0.3% P (Galyean and Gleghorn, 2000). Nutrition and management practices can influence the quantity, form, and route (feces, urine, respiration) of nutrient excretion by the animal (Scott, 1972; Tucker and Watts, 1993; National Research Council, 1996, 2001; James et al., 1999; Gueye et al., 2003; McBride et al., 2003; Kebreab et al., 2004) as well as influence transformations and movements of excreted nutrients (Cole et al., 2003; Greene and Cole, 2003). Because nutrient requirements change with the physiological state of an animal, it may be possible to decrease ammonia emissions and nutrient excretion (Cole et al., 2003) by decreasing CP concentrations of beef cattle finishing diets as time on feed increases (phase feeding) without adversely affecting performance (Galyean, 1998; Erickson et al., 2000; Greene and Cole, 2003; Gleghorn et al., 2004; Vasconcelos et al., 2004). Cole et al. (2005) showed, in vitro, that increasing crude protein in beef cattle diet from 11.5 to 13.0% increased ammonia emission from 60 to 200%, due primarily to increased urinary N.

Our objective was to quantify the effect of reducing crude protein in beef cattle diet on ammonia emission by: (i) collecting urine and feces from two groups of steers fed a diet with either 11.5 or 13.0% CP; (ii) applying the manures to artificial feedyard surfaces under ambient conditions during all seasons throughout

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**Abbreviations:** CP, crude protein; CP11, 11.5% crude protein diet; CP13, 13% crude protein diet; DAT, day after treatment.

the year; and (iii) estimating, and then comparing, ammonia emissions from the two treatments.

## MATERIALS AND METHODS

Research was conducted at the USDA-ARS Conservation and Production Research Laboratory, Bushland, Texas (35° N, 102° W). In February 2002, two groups of four steers each were fed diets that varied only in CP (11.5 and 13.0%) for 21 d. Supplemental nitrogen in the diets was provided by urea, which comprised 0.52% of the 11.5% CP diet (CP11) and 1.08% of the 13.0% CP diet (CP13). Additional details of diet compositions are given in Cole et al. (2005). Steers were fed ad libitum and individually in feeding stalls. All urine and feces were collected from steers during the last 7 d of the feeding trial. Urine was collected from each steer using a rubber collar attached to a vacuum system that drew urine immediately after excretion into a sealed container, which was emptied twice a day. Feces were collected by hand from the floor of each feeding stall twice a day. After collection, urine and feces from each steer were weighed, subsampled for analysis, and frozen. A subsample equal to 1% of the urine and feces output of each steer was collected at the same time and frozen, for use in an in vitro laboratory experiment. Steers weighed about 500 kg each at the end of the feeding trial.

### Laboratory Experiment

The in vitro ammonia emission system was described in detail by Shi et al. (2001) and Cole et al. (2005). Briefly, the system consisted of 18 sealed plastic chambers (20 cm × 20 cm × 12 cm deep) each attached to two ammonia trapping bottles containing 100 mL of 0.9 *M* sulfuric acid and a vacuum system to pull air through the chambers and ammonia traps at a rate of 3 L $min^{-1}$. In each chamber, the feces and urine excreted by one steer (four steers per diet treatment) were added on top of air-dry, 2-mm mesh-screened soil (1550 g of Pullman clay loam: fine, mixed, superactive, thermic Torrertic Paleustolls). There were two chambers per steer. The mass of urine and feces added to each chamber was equal to 1% of the daily excretion by the steer during the feeding trial. Two chambers containing soil but no feces or urine were included to correct for ambient atmospheric ammonia. Acid traps were replaced with fresh traps each day for 3 d then at 2-d intervals until Day 7 of collection.

### Field Experiment

We selected a field site where wind flow was unimpeded by barriers and obstructions so that wind, temperature, and ammonia profiles would fully develop, and far enough away from potential ammonia sources so that background ammonia concentrations were minimized. The site was prepared by excavating two circles with a 5-m radius to a depth of 0.2 m. The 80-$m^2$ circle represented the area typically allotted to five cattle in southern High Plains feedyards. Fresh pen surface scrapings from a nearby commercial feedyard were then packed in the excavated circles to create an artificial pen surface. The two artificial feedyard circles were 100 m apart, on an east–west axis. A 2.5-m-tall instrument mast was erected in the center of each circle. A third mast was located 40 m west of the westernmost circle, where background ammonia concentration was measured. On each mast, 250-mL capacity gas washing bottles were installed at 0.15, 0.25, 0.4, 0.6, 1.2, and 2.4 m.

Ammonia was trapped in the gas washing bottles by first drawing air through a Teflon filter to remove particulates, then bubbling it through an impinger in 80 to 120 mL of 0.05 *M* sulfuric acid. Air-flow rate of each gas washing bottle was measured with a precision, calibrated flow meter (Dry-Cal DC Lite; Bios International, Butler, NJ) at the beginning and end of each measurement period. Nominal air flow rate was 6 L $min^{-1}$; flow rate over four trials from all gas washing bottles averaged 5.98 L $min^{-1}$, with a standard deviation of 0.38 L $min^{-1}$. At the beginning of a sampling period, gas washing bottles with fresh acid were sealed and transported to the site, exchanged with the bottles there, and then the sealed bottles with samples were transported back to the laboratory. In the laboratory, each sample was decanted into a 100-mL volumetric flask, the gas washing bottle was rinsed with 10 to 30 mL of 0.05 *M* sulfuric acid, the rinsate decanted into the flask, and then the sample in the flask was diluted to 100 mL by pipetting acid into it. Samples were mixed in the flask, 30 mL were decanted into a sample bottle, and then all samples were refrigerated until analysis. A calibrated flow injection analyzer (QuickChem FIA+ 8000; Lachat Instruments, Milwaukee, WI) was used to quantify ammonium in the samples, with a minimum detection limit of 10 μg $L^{-1}$. This corresponded to atmospheric ammonia concentrations of $<1$ μg $m^{-3}$.

Profiles of wind speed and air temperature were defined at the same heights as the ammonia gas washing bottles were positioned. Cup anemometers (12102M; R.M. Young, Traverse City, MI) measured wind speed and aspirated, fine-wire (25.4-μm diameter) thermocouples (ASPTC; Campbell Scientific, Logan, UT) measured air temperature. Other meteorological measurements included incoming solar radiation (LI200X; Licor, Lincoln, NE), net radiation (Q7.1; Radiation and Energy Balance Systems, Seattle, WA), relative humidity and air temperature (HMP45; Vaisala, Helsinki, Finland), manure pack temperature (STP1; Radiation and Energy Balance Systems), wind direction (12005; R.M. Young), and precipitation (TE525; Campbell Scientific). Outputs from meteorological instruments were sampled every 5 s and 5-min means were recorded to a data logger (CR23X; Campbell Scientific).

Ammonia flux was estimated using the integrated horizontal flux (IHF) method (Wilson et al., 1982, 1983; Wilson and Shum, 1992). The method assumes that source strength is uniform from the emitting surface, and that air flow is fully turbulent. The vertical flux density, $Q$ (μg $m^{-2}$ $s^{-1}$), was calculated by integrating the horizontal flux densities between the limits $z_0$, the roughness length (m), and $z_b$, the height (m) at which ammonia concentration over a treated circle equals background concentration:

$$Q = \frac{1}{R}\int_{z_0}^{z_b} Q(z)\mathrm{d}z \qquad [1]$$

where $Q(z)$ (μg $m^{-2}$ $s^{-1}$), the horizontal flux at height $z$ (m), is the product of wind speed and ammonia concentration at $z$, and $R$ is the radius of the circle (m). Ammonia concentration of the air at each measurement height was calculated with:

$$C(z) = \frac{c(z)v(z) - M}{f(z)t(z)}K \qquad [2]$$

where $c(z)$ is the acid sample $NH_4$–N concentration (μg $L^{-1}$), $v(z)$ is the acid sample volume (L), $M$ is the mass of $NH_4$–N in field blanks (μg), $f(z)$ is air flow rate through the gas washing bottle ($m^3$ $s^{-1}$), $t(z)$ is the sampling time (s), and $K = 17/14$ is the ratio of the molecular weights of $NH_3$ and N. The field blanks were three gas washing bottles that were handled the same as sampling gas washing bottles except no air was drawn through them. They were used to correct for potential sample contamination during field handling and laboratory processing. Ammonia concentration at each height over manure circles was further corrected by subtracting the background

**Table 1. Mean characteristics of manure collected during 7-d feeding trial from steers fed either 11.5 or 13.0% crude protein (CP) diet; numbers in parentheses are the standard deviation of the mean.**

| | Feces | | | Urine | |
|---|---|---|---|---|---|
| Treatment | Mass collected | Dry matter | N concentration | Volume collected | N concentration |
| | kg head$^{-1}$ d$^{-1}$ | % | g kg$^{-1}$ | L head$^{-1}$ d$^{-1}$ | g L$^{-1}$ |
| 11.5% CP | 4.1 (0.4) | 26.9 (1.5) | 34.5 (1.3) | 7.1 (5.5) | 9.6 |
| 13.0% CP | 3.2 (1.3) | 27.7 (1.2) | 37.5 (2.8) | 7.8 (3.1) | 10.7 |

ammonia concentration at the same height. Profiles of horizontal flux were integrated using the Trapezoidal Rule. The limits of integration were the roughness length, $z_0$, and the height at which ammonia concentration was within 20% of background ammonia concentration, $z_b$. In most cases, ammonia concentration measured over the treated circles was at background concentration at $z$ = 1.2 or 2.4 m. Roughness length was determined from wind speed profiles measured under neutral thermal stability during a preliminary trial; mean $z_0$ was 6.75 mm.

Four trials, in summer, autumn, winter, and spring were completed, each lasting 29 d, except for the summer trial, which was 22 d. For each trial, the sequence was: (i) thaw out a mass of urine and feces from each diet treatment that was equivalent to the mean single-day output from five steers; (ii) apply urine and feces to treated circles once at the beginning of the trial; and (iii) measure ammonia concentration profiles on DAT (day after treatment) 1, 2, 4, 7, 11, 16, 22, and 29 of the trial. Sample integration times varied from 3 to 6 h during the daytime and from 12 to 16 h during nighttime. The sampling schedule was generally maintained, although inclement weather sometimes forced modification of sampling runs. Feces and urine for each treatment were divided into 80 equal increments and then applied to the center of 1-m$^2$ plots gridded on each circle. This application scheme was designed to meet the assumption of the integrated horizontal flux method that source strength is homogenous.

### Statistical Analysis

Treatment differences from the in vitro laboratory experiment were tested using a completely random experimental design, with steer within treatment as the error term in the analysis of variance (SAS Institute, 1999). Treatment differences within each seasonal field trial were tested using paired *t* tests, with each sampling time considered as an observation.

## RESULTS AND DISCUSSION

### Characteristics of Collected and Applied Manure

Steers fed CP11 produced 28% more feces and 9% less urine than those fed CP13 (Table 1). Nitrogen concentration in collected feces and urine was also less for the CP11 diet. Nitrogen in collected manure was partitioned differently in the two treatments, with urinary N comprising 66.2% of total N in the CP11 treatment, compared with 72.7% in the CP13 treatment. Urinary N typically increases as CP in a diet increases, as was observed for dairy heifers (James et al., 1999) and dairy cows (Frank et al., 2002; Frank and Swensson, 2002; Smits et al., 1995).

Applied manure from the CP11 treatment averaged 30 g more N in feces and 102 g less N in urine (Table 2). Fraction of total manure N applied in urine was 64.3 and 76.1% for the CP11 and CP13 treatments, respectively, which compared closely to urine N fractions observed in collected manure. Applied urine N ranged from 240 to 270 g (mean 257 g) for the CP11 treatment, and ranged from 341 to 384 g (mean 359 g) for the CP13 treatment. Total applied manure N ranged from 403 to 427 g (mean 400 g) for the CP11 treatment and ranged from 450 to 492 g (mean 472 g) for the CP13 treatment. More manure N was applied to the CP13 treatment in all trials, with the greater difference ranging from 33 to 104 g (Table 2). The greater mass of N in the CP13 treatment was due primarily to greater urine N in that treatment; from 80 to 131 g more urine N (mean 102 g) was applied with the CP13 treatment, compared with the CP11 treatment.

**Table 2. Mass of nitrogen in manure from steers fed either 11.5 or 13.0% crude protein (CP) diet, and applied to artificial feedyard surfaces.**

| | Feces | | Urine | | Total | |
|---|---|---|---|---|---|---|
| Trial | 11.5% CP | 13.0% CP | 11.5% CP | 13.0% CP | 11.5% CP | 13.0% CP |
| Summer | 133 | 119 | 270 | 366 | 403 | 485 |
| Autumn | 142 | 108 | 240 | 341 | 381 | 450 |
| Winter | 136 | 108 | 253 | 384 | 388 | 492 |
| Spring | 162 | 115 | 265 | 346 | 427 | 461 |
| Mean | 143 | 113 | 257 | 359 | 400 | 472 |
| % of Total | 35.7 | 23.9 | 64.3 | 76.1 | 100 | 100 |

### Laboratory Experiment

Ammonia N emitted from chambers in the laboratory was significantly less ($p < 0.01$) for the CP11 treatment compared with the CP13 treatment, ranging from 39 to 50% less for the days sampled during the experiment (Table 3). Total ammonia N lost after 7 d was 44% less ($p < 0.01$) for the CP11 treatment compared with the CP13 treatment. In a chamber experiment using manure collected from dairy cows, Frank and Swensson (2002) found that as CP in diets in a range from 16.6 to 17% decreased to 13.1 to 13.5%, ammonia release was significantly decreased. The reduction, inferred from treatment differences in chamber outlet ammonia concentration

**Table 3. Daily and total $NH_3$–N loss from chambers in laboratory treated with manure from steers fed either 11.5 or 13.0% crude protein (CP) diet.**

| Day | 11.5% CP | 13.0% CP | SEM† | Prob. > *F*‡ |
|---|---|---|---|---|
| | mg | | | |
| 1 | 3.6 | 6.8 | 0.40 | 0.01 |
| 2 | 5.7 | 11.4 | 0.76 | 0.01 |
| 3 | 5.8 | 9.9 | 0.51 | 0.01 |
| 4, 5 | 6.9 | 11.3 | 0.61 | 0.01 |
| 6, 7 | 5.4 | 9.6 | 0.51 | 0.01 |
| Total | 27.4 | 49.0 | 2.67 | 0.01 |

† Standard error of the mean.
‡ Probability of a larger value of F.

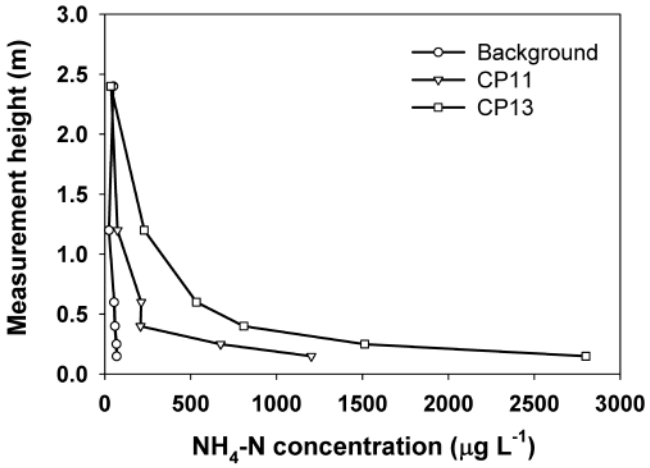


**Fig. 1. The $NH_4$–N concentration of analyte from gas washing bottles over artificial feedyard surfaces treated with manure from steers fed either 11.5 or 13.0% crude protein (CP) diet; summer trial, first day after treatment (DAT 1), 1300–1600 h.**

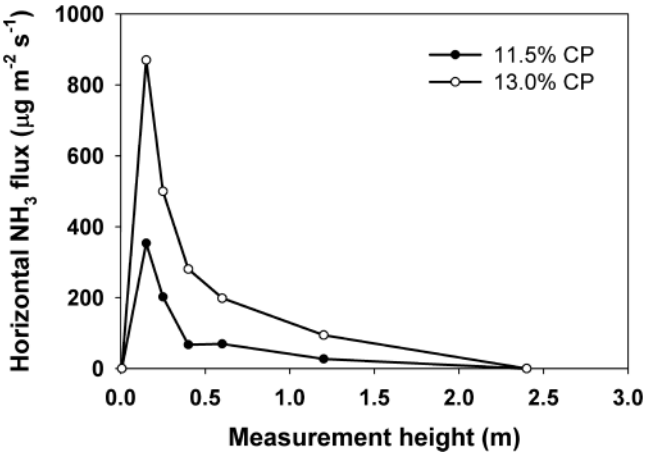


**Fig. 2. Horizontal ammonia flux over artificial feedyard surfaces treated with manure from steers fed either 11.5 or 13.0% crude protein (CP) diet; summer trial, first day after treatment (DAT 1), 1300–1600 h.**

averaged 50%. A similar in vitro experiment (Frank et al., 2002) found that when dairy cow diet CP decreased from 19 to 14%, ammonia flux decreased 64%. Manure (feces and urine) from the 19% CP diet was wetter and had greater N content, suggesting that there was more urine in it, compared with the 14% CP diet.

## Field Experiment

### Gas Washing Sample and Air: Concentrations and Profiles

A sampling period from the summer trial (22 July 2002, DAT 1, 1215–1600 h) was selected to illustrate the range of sample and air concentrations and profiles encountered in the field study. In this case (Fig. 1), background analyte $NH_4$–N concentration changed little with height and averaged 55 μg $L^{-1}$ (SD = 16 μg $L^{-1}$). This case was typical of background profile shapes and in the lower range of background analyte concentrations. Analyte $NH_4$–N concentrations over the treated circles ranged as high as 2800 μg $L^{-1}$ for the CP13 treatment at 0.15 m in this case (Fig. 1). Analyte concentrations as high as 5357 μg $L^{-1}$ were occasionally measured during nighttime under stable atmospheric conditions.

Background $NH_3$ concentrations were almost always near-constant with height, with mean profile (0.15 to 2.4 m) concentrations ranging from <1 to 39 μg $m^{-3}$ (Table 4). Ammonia concentration over manure-treated circles decreased with height, except when concentration approached background concentration. Greatest $NH_3$ concentration (257 μg $m^{-3}$) was measured during the summer trial (Table 4). Maximum $NH_3$ concentrations measured over the treated circles during other seasons ranged from 43 to 59 μg $m^{-3}$ (Table 4).

Typical profiles of horizontal flux, using the same data as in Fig. 1, are presented in Fig. 2. Vertical $NH_3$ flux is the area beneath each curve. In this case, $NH_3$ concentration over the treated circles reached background $NH_3$ concentration at $z$ = 2.4 m (Fig. 2), and this height was used as the upper bound of integration. Some profiles did not reach background concentration at $z$ = 2.4 m, so that horizontal flux at that height was greater than zero. The upper bound of integration was still set at 2.4 m, so that flux in those instances was underestimated by a small percentage. Frequency of sampling periods when this happened ranged from 8% in summer to 17% in spring. Lower bound of integration in all cases was $z_0$.

### Ammonia Flux

Decreasing crude protein in steer diets from 13.0 to 11.5% decreased ammonia flux 36% in summer ($p$ = 0.09), 44% in autumn ($p$ = 0.04), and 26% in spring ($p < 0.01$), but not in the winter (Table 5). Ammonia fluxes estimated from the artificial feedyard circles were within the range of those from one-time applied urea (Wilson et al., 1983), sewage sludge (Beauchamp et al., 1978), swine manure (Gordon et al., 1988), dairy cattle manure (Beauchamp et al., 1982), green manure (Rana

**Table 4. Atmospheric ammonia concentrations measured at a background tower or measured over artificial feedyard surfaces treated with manure from steers fed either 11.5 or 13.0% crude protein (CP) diet.**

| Trial | Background mean | Background maximum | 11.5% CP maximum | 13.0% CP maximum |
|---|---|---|---|---|
| | μg $m^{-3}$ | | | |
| Summer | 8 | 24 | 129 | 257 |
| Autumn | 7 | 18 | 43 | 56 |
| Winter | 9 | 36 | 43 | 43 |
| Spring | 8 | 39 | 54 | 59 |

**Table 5. Ammonia flux from artificial feedyard surfaces treated with manure from steers fed either 11.5 or 13.0% crude protein (CP) diet.**

| Trial | 11.5% CP | 13.0% CP | SD of mean difference | $n$ | Prob. > $t$† |
|---|---|---|---|---|---|
| | μg $m^{-2}$ $s^{-1}$ | | | | |
| Summer | 10.1 | 15.8 | 3.1 | 18 | 0.09 |
| Autumn | 0.9 | 1.6 | 0.3 | 22 | 0.04 |
| Winter | 2.0 | 2.1 | 0.4 | 21 | 0.77 |
| Spring | 2.5 | 3.4 | 0.2 | 26 | <0.01 |

† Probability of a larger value of $t$.

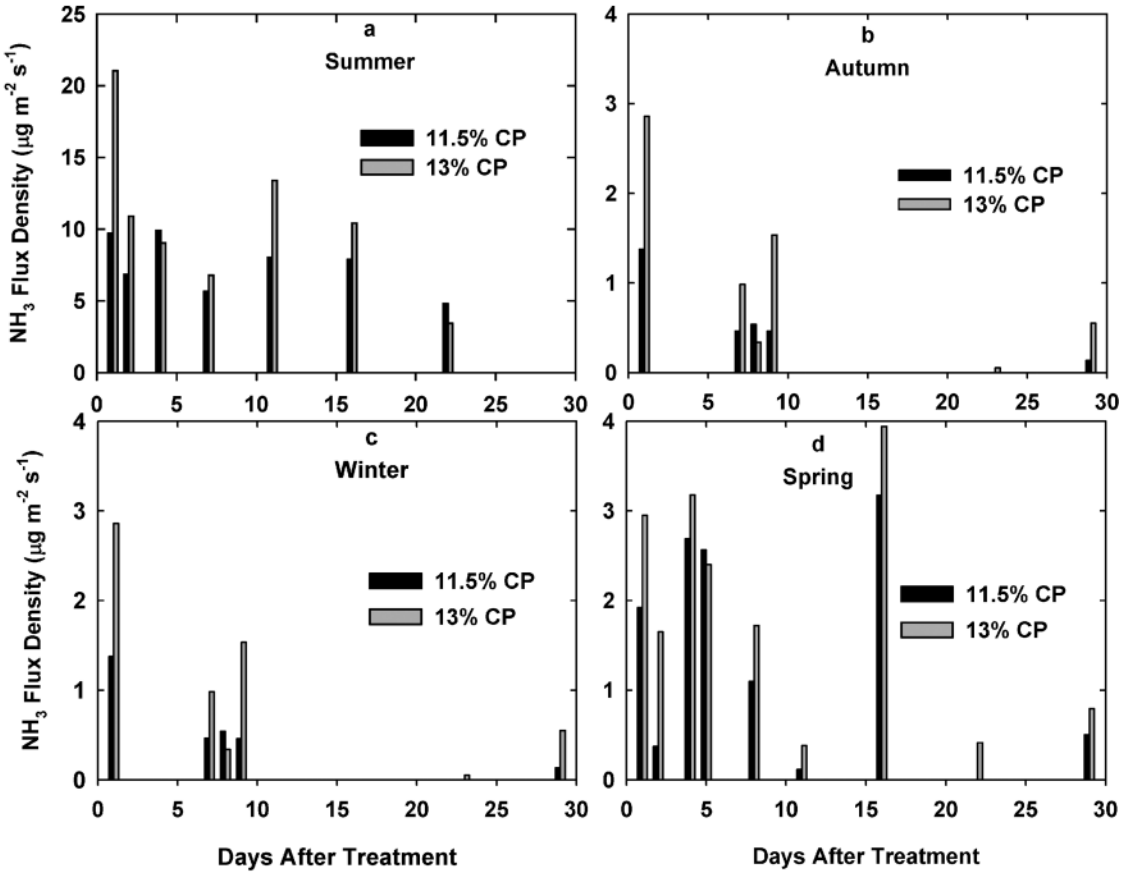


**Fig. 3. Mean daily ammonia flux density from artificial feedyard surfaces treated with manure from steers fed either 11.5 or 13.0% crude protein (CP) diet. The summer trial began on 22 July 2002; autumn trial on 21 Oct 2002; winter trial on 10 Feb 2003; and spring trial on 14 Apr 2003.**

and Mastrorilli, 1998), and at a commercial beef cattle feedyard (Hutchinson et al., 1982). Maximum ammonia flux occurred during the summer trial in the afternoon of the first day after treatment, when the CP13 flux was 76.4 $\mu g\ m^{-2}\ s^{-1}$. Summer fluxes generally decreased with time after treatment, though increased flux was sometimes observed following precipitation.

Mean daily ammonia flux was greatest during the summer trial, when maximum mean daily flux was 21.1 $\mu g\ m^{-2}\ s^{-1}$ (CP13, DAT 1; Fig. 3a). Mean daily flux in autumn, winter, and spring did not exceed 4 $\mu g\ m^{-2}\ s^{-1}$ (Fig. 3b, 3c, and 3d). Decreasing crude protein in steer diets from 13.0 to 11.5% decreased mean daily ammonia flux by 30% ($p = 0.10$) in summer, 53% ($p = 0.08$) in autumn, and 29% ($p < 0.01$) in spring (Fig. 3). Assuming these reductions were typical of the seasons, decreasing crude protein in steer diets from 13.0 to 11.5% reduced mean daily ammonia flux by 28% on an annual basis.

## Ammonia Nitrogen Loss

Urea in urine is rapidly hydrolyzed under favorable conditions of warmer temperature and urease enzyme, readily present in feces (Varel, 1997; Arogo et al., 2001). Petersen et al. (1998) found that maximum ammonia loss from urine patches measured in wind tunnels was within 1 to 2 d after application, and that hydrolysis of urinary urea in soil was almost complete within 24 h. In this study, $NH_3$–N loss during the first 2 d after manure application tended to be greater for the CP13 treatment during summer ($p = 0.11$), autumn ($p = 0.07$), and spring ($p = 0.12$), but not during the winter trial (Table 6). Ammonia N loss during subsequent days was significantly greater ($p \leq 0.04$) for the CP13 treatment during winter and spring trials, but not summer or autumn trials (Table 6). For the spring trial, warmer temperatures during the latter part of the trial probably contributed to the difference. During the first 2 d after manure application in the summer, $NH_3$–N loss was 28.3% of applied urine N for the CP11 treatment and

**Table 6. Mean $NH_3$–N loss from artificial feedyard surfaces treated with manure from steers fed either 11.5 or 13.0% crude protein (CP) diet.**

| Trial | 11.5% CP | 13.0% CP | SD of mean difference | *n* | Prob. > *t* † |
|---|---|---|---|---|---|
| | g | | | | |
| | DAT‡ 1 and 2 | | | | |
| Summer | 13.4 | 26.0 | 5.9 | 7 | 0.11 |
| Autumn | 2.1 | 4.5 | 1.0 | 5 | 0.07 |
| Winter | 3.5 | 2.1 | 1.0 | 6 | 0.24 |
| Spring | 1.9 | 3.7 | 1.0 | 7 | 0.12 |
| | DAT > 2 | | | | |
| Summer | 18.8 | 22.3 | 3.1 | 11 | 0.28 |
| Autumn | 1.0 | 1.5 | 0.4 | 17 | 0.20 |
| Winter | 1.7 | 3.1 | 0.6 | 15 | 0.04 |
| Spring | 3.0 | 3.7 | 1.0 | 19 | <0.01 |

† Probability of a larger value of *t*.
‡ Day after treatment.

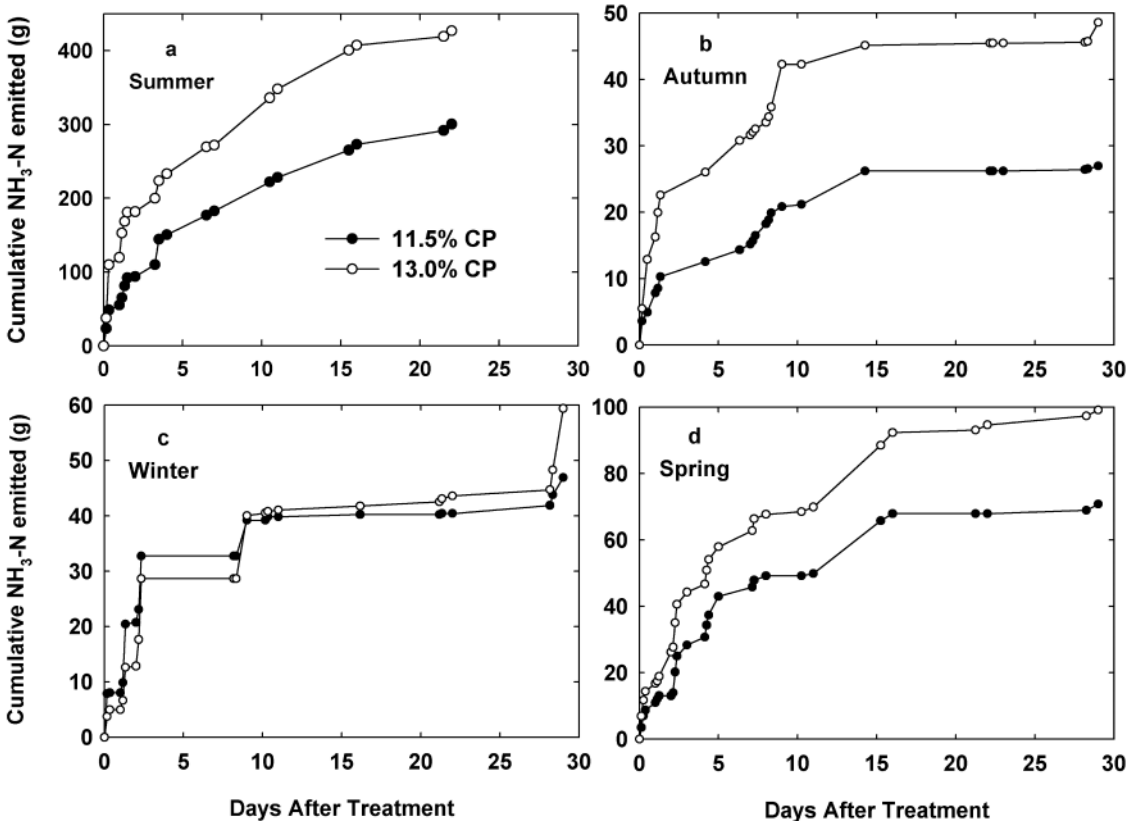


**Fig. 4. Cumulative measured $NH_3$–N emitted from artificial feedyard surfaces treated with manure from steers fed either 11.5 or 13.0% crude protein (CP) diet. The summer trial began on 22 July 2002; autumn trial on 21 Oct 2002; winter trial on 10 Feb 2003; and spring trial on 14 Apr 2003.**

43.5% for the CP13 treatment. During autumn, winter, and spring, $NH_3$–N loss as fraction of applied urine N was small, ranging from 3 to 6%. Measured cumulative $NH_3$–N loss was greatest during the summer trial, when the CP11 treatment lost 300 g of $NH_3$–N and the CP13 treatment lost 427 g (Fig. 4a). Other seasonal measured $NH_3$–N losses for the CP11 treatment ranged from 27 to 71 g, and for the CP13 treatment ranged from 49 to 99 g (Fig. 4b, 4c, and 4d). Autumn losses were least, spring losses were greatest, and winter losses were intermediate. Greatest losses during summer are explained by much warmer temperatures than in other seasons, which enhanced $NH_3$ volatilization (Table 7). Though winter temperatures were coldest, $NH_3$–N losses were least in autumn because greater precipitation during that season suppressed ammonia volatilization.

## CONCLUSIONS

Feeding less crude protein to beef cattle steers reduced total nitrogen in manure and changed the partitioning of N between urine and feces. Manure from steers fed an 11.5% CP diet had less urine, less urinary N concentration, and a lesser fraction of total N in urine compared with manure from steers fed a 13% CP diet. Fecal N was greater in manure from the 11.5% CP diet. On average, the CP11 diet had 28% less urinary N and 27% more fecal N. Urinary N comprised 64.3% of total N for the 11.5% CP treatment and 76.1% for the 13% CP treatment.

Decreasing crude protein in beef cattle diets from 13 to 11.5% decreased ammonia flux. The reduction was 44% ($p < 0.01$) in the closed chamber laboratory experiment. In the field experiment, decreasing dietary crude protein reduced mean daily ammonia flux in summer by 30% ($p = 0.10$). In autumn and spring, decreasing dietary crude protein reduced mean daily ammonia flux by 53 and 29%, respectively ($p \leq 0.08$). No difference was observed in winter. Decreased ammonia emissions from the 11.5% CP diet manure were most likely due to less urinary N.

Estimated annual reduction in daily ammonia flux provided by decreasing crude protein was 28%. For a

**Table 7. Meteorological conditions during experiment. All values are means for days within a trial when ammonia flux was estimated, except precipitation, which is the total for all days within a trial.**

| Trial | Air temperature | Manure pack temperature | Relative humidity | Wind speed | Solar radiation | Total precipitation |
|---|---|---|---|---|---|---|
| | °C | | % | m s$^{-1}$ | W m$^{-2}$ | mm |
| Summer | 25.3 | 27.3 | 56 | 3.7 | 301 | 16 |
| Autumn | 9.3 | 11.2 | 74 | 3.4 | 181 | 40 |
| Winter | 3.3 | 6.1 | 61 | 3.7 | 195 | 2 |
| Spring | 17.0 | 17.2 | 45 | 5.7 | 298 | 14 |

median-sized commercial feedyard located on the southern High Plains, with mean ammonia N emission of 3.2 Mg $d^{-1}$ (Todd et al., 2005) reducing dietary crude protein from 13 to 11.5% could potentially reduce ammonia N loss by 327 Mg $yr^{-1}$. The magnitude of reduction would depend on many factors, such as the ability to precisely formulate and feed rations, genetic variation in cattle, environmental variability, the maintenance of cattle performance, and manure management. In spite of these uncertainties, reducing crude protein in beef cattle diets may provide the most practical and cost-effective way to reduce ammonia emissions from feedyards.

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