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Prediction of ammonia emission from dairy cattle manure based on milk urea nitrogen: Relation of milk urea nitrogen to ammonia emissions

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ABSTRACT

The main objectives of this study were to assess the relationship between ammonia emissions from dairy cattle manure and milk urea N (MUN; mg/dL) and to test whether the relationship was affected by stage of lactation and the dietary crude protein (CP) concentration. Twelve lactating multiparous Holstein cows were randomly selected and blocked into 3 groups of 4 cows intended to represent early [123 ± 26 d in milk (DIM)], mid (175 ± 3 DIM), and late (221 ± 12 DIM) lactation stages. Cows within each stage of lactation were randomly assigned to a treatment sequence within a split-plot Latin square design balanced for carryover effects. Stage of lactation formed the main plots (squares) and dietary CP levels (15, 17, 19, and 21% of diet dry matter) formed the subplots. The experimental periods lasted 7 d, with d 1 to 6 used for adjustment to diets and d 7 used for total collection of feces and urine as well as milk sample collection. The feces and urine from each cow were mixed in the proportions in which they were excreted to make slurry that was used to measure ammonia emissions at 22.5°C over 24 h using flux chambers. Samples of manure slurry were taken before and after ammonia emission measurements. The amount of slurry increased by 22% as dietary CP concentration increased from 15 to 21%, largely because of a greater urine volume (25.3 to 37.1 kg/d). Initial urea N concentration increased linearly with dietary CP from 153.5 to 465.2 mg/dL in manure slurries from cows fed 15 to 21% CP diets. Despite the large initial differences, the final concentration of urea N in manure slurries was less than 10.86 mg/dL for all dietary treatments. The final total ammoniacal N concentration in manure slurries increased linearly from 228.2 to 508.7 mg/dL as dietary CP content increased from 15 to 21%. Ammonia emissions from manure slurries ranged between 57 and 149 g of N/d per cow and increased linearly with dietary CP content, but were unaffected by stage of lactation. Ammonia emission expressed as a proportion of N intake increased with percentage CP in the diet from about 12 to 20%, whereas ammonia emission as a proportion of urinary urea N excretion decreased from 67 to 47%. There was a strong relationship between ammonia emission and MUN [ammonia emission (g/d per cow) = 25.0 (±6.72) + 5.03 (±0.373) × MUN (mg/dL); $R^2 = 0.85$], which was not different among lactation stages. Milk urea N concentration is one of several factors that allows prediction of ammonia emissions from dairy cattle manure.

Key words: milk urea nitrogen, urinary urea nitrogen excretion, ammonia emission

INTRODUCTION

Ammonia volatilization is a process in which the N in animal manure (urine and feces) is released into the atmosphere via biochemical and mass transfer reactions. The primary pathway for ammonia volatilization from manure begins with the hydrolysis of urinary urea to NH_3 and CO_2, which is catalyzed by the activity of urease, an enzyme produced by microorganisms that is found in both feces and in soil (Muck and Steenhuis, 1980). Once hydrolyzed, ammonia in aqueous solution is present as both NH_4^+ and NH_3, which are coupled in equilibrium by a dissociation reaction. The equilibrium between the volatile NH_3 and nonvolatile NH_4^+ fractions is temperature and pH dependent. The volatilization of ammonia occurs via convective mass transfer from the boundary layer of the manure slurry to the air above the surface. The equilibrium of ammonia between the manure slurry and the air above the surface is approached by ammonia volatilization and is dependent on the temperature and air velocity at the slurry–air boundary (Monteny and Erisman, 1998).

Because the initial step of ammonia volatilization is irreversible, under normal pH conditions, the amount of ammonia emitted should be determined by its production rate (Muck, 1982). The rate of urea hydrolysis,

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and thus the ammonia production rate, is determined by the amount of urea excreted in urine as well as the urease activity. Urea availability is the limiting factor for ammonia production because urease activity on commercial dairies is high (Monteny and Erisman, 1998). Urea accounts for 50 to 90% of the N in cattle urine (Bristow et al., 1992) and, with the exception of urine ammonia, has the highest ammonia volatilization potential of the N-containing compounds in urine (Bussink and Oenema, 1998). Accordingly, several studies reported that in dairy cattle, ammonia emissions were linearly dependent on urinary urea N (**UUN**) excretion (g/d per cow; Elzing and Monteny, 1997; James et al., 1999; Cassel et al., 2005).

Urea is produced mainly in the liver as a means of detoxification of ammonia present in the systemic circulation, which is produced by AA catabolism and ruminal microorganisms as they metabolize dietary N compounds consumed by ruminants (DePeters and Ferguson, 1992). Blood urea rapidly equilibrates with milk (Gustafsson and Palmquist, 1993) so that its concentration in blood and milk are closely associated (Broderick and Clayton, 1997). Blood urea is then filtered by the kidneys for excretion in urine. Dietary factors that affect the efficiency of N utilization by ruminal microorganisms, such as ruminal degradability of carbohydrate and protein sources, may influence UUN excretion (Sannes et al., 2002; Broderick et al., 2008). The amount of urea excreted in urine may also be affected by factors that influence urine volume, such as N, Na, and K intake (Bannink et al., 1999). Milk urea N has emerged as a potentially useful tool to predict N excretion in urine and N utilization efficiency in lactating dairy cows (Jonker et al., 1998; Kauffman and St. Pierre, 2001). We recently examined the relationship between MUN and UUN excretion over a wide range of dietary CP levels and found that UUN excretion was linearly related to MUN when its concentration was $\leq$25 mg/dL (Burgos et al., 2007).

We hypothesized that UUN excretion is proportional to MUN and that, under conditions in which urease activity is not limiting and environmental conditions in which ammonia dissociation and mass transfer (i.e., temperature, pH, and air velocity) remain relatively constant, ammonia emissions from dairy cattle manure slurry is proportional to UUN excretion. The overall objective of the study was to evaluate the potential of MUN as a predictor of ammonia emissions from dairy cattle manure. The specific objectives of the experiment described herein were to assess the relationship between ammonia emissions with UUN excretion and MUN to test whether these relationships, as well as manure slurry composition and ammonia emissions, were affected by stage of lactation or dietary CP content.

MATERIALS AND METHODS

Cows, Experimental Design, and Diets

Twelve lactating multiparous Holstein cows were randomly selected and blocked into 3 groups of 4 cows intended to represent (mean $\pm$ SD) early (123 $\pm$ 26 DIM), mid (175 $\pm$ 3 DIM), and late (221 $\pm$ 12 DIM) lactation stages. Cows within each stage of lactation were randomly assigned to a treatment sequence within a split-plot Latin square design balanced for carryover effects. Stage of lactation formed the main plots, and dietary CP levels (15, 17, 19, and 21% diet DM) formed the subplots. The ingredient and nutrient composition of the experimental diets are shown in Table 1. The experimental periods lasted 7 d, with d 1 to 6 used for adjustment to diets and d 7 used for total collection of urine and feces as well as milk sample collection.

Cows were milked daily at approximately 0630 and 1830 h and fed at 0700 and 1900 h throughout the experiment. Cows were housed in individual pens measuring 6.1 $\times$ 4.6 m during d 1 to 6 of the experimental period. On d 7, cows were moved to individual pens fitted with rubber mats modified to create a tie-stall arrangement. All experimental procedures were approved by the Institution Animal Care and Use Committee at the University of California, Davis.

Sample Collection

Sample collection procedures were described in detail elsewhere (Burgos et al., 2007). Briefly, amounts of feed offered and orts were measured daily for each cow throughout the experiment and daily samples were pooled by period. Proportional milk samples from consecutive evening and morning milkings were composited by cow and analyzed for urea. Urine was collected using indwelling Foley catheters draining into plastic jugs embedded in ice-cold water tubs. Urine volume was measured for 4 consecutive intervals of approximately 6 h. Before each milking, feces were manually cleared from cows' rectum and collected. Cows were then stimulated to urinate and urine was collected. Catheters were then clamped shut and cows were led to the milking parlor, milked, and immediately returned to their stalls; the tubing was reconnected to the catheters. From each collection interval, an aliquot was kept at 4°C and used to create a weighted composite sample to represent the 24-h period. The 24-h urine collection period is short but was selected because the urine was needed immediately for the collection of ammonia and a longer collection time would require urine to be stored for longer periods of time before the measurement of ammonia, further increasing the risk of a degraded sample. Also,