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Performance, digestion, nitrogen balance, and emission of manure ammonia, enteric methane, and carbon dioxide in lactating cows fed diets with varying alfalfa silage-to-corn silage ratios

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ABSTRACT

Two trials were conducted simultaneously to study the effects of varying alfalfa silage (AS) to corn silage (CS) ratio in diets formulated to avoid excess protein or starch on lactating dairy cow performance, digestibility, ruminal parameters, N balance, manure production and composition, and gaseous emissions [carbon dioxide (CO_2), methane (CH_4), and ammonia-N (NH_3-N)]. In trial 1 all measurements, except gas emissions, were conducted on 8 rumen-cannulated cows in replicated 4 × 4 Latin squares. In trial 2, performance and emissions were measured on 16 cows randomly assigned to 1 of 4 air-flow controlled chambers in a 4 × 4 Latin square. Dietary treatments were fed as total mixed rations with forage-to-concentrate ratio of 55:45 [dietary dry matter (DM) basis] and AS:CS ratios of 20:80, 40:60, 60:40, and 80:20 (forage DM basis). Measurements were conducted the last 3 d of each 21-d period. Treatments did not affect DM intake, DM digestibility, and milk/DM intake. However, responses were quadratic for fat-and-protein-corrected milk, fat, and protein production, which reached predicted maxima for AS:CS ratio of 50:50, 49:51, and 34:66, respectively. Nitrogen use efficiency (milk N/N intake) decreased from 31 to 24 g/100 g as AS:CS ratio increased from 20:80 to 80:20. Treatments did not alter NH_3-N/milk-N but tended to have a quadratic effect on daily NH_3-N emission. Treatments had a quadratic effect on daily CH_4 emission, which was high compared with current literature; they influenced CH_4 emission per unit of neutral detergent fiber (NDF) intake and tended to influence CO_2/NDF intake. Ruminal acetate-to-propionate ratio and total-tract NDF digestibility increased linearly with increasing AS:CS ratio. In addition, as AS:CS ratio increased from 20:80 to 80:20, NDF digested increased linearly from 2.16 to 3.24 kg/d, but CH_4/digested NDF decreased linearly from 270 to 190 g/kg. These 2 counterbalancing effects likely contributed to the observed quadratic response in daily CH_4 emission, which may have been influenced also by increasing starch with increasing CS in the diet as reflected by the increased ruminal propionate molar proportion. Overall, production performances were greatest for the intermediate AS:CS ratios (40:60 and 60:40), but daily excretion of urine, manure, fecal N, urinary urea N, and urinary N decreased with increasing proportion of CS in the diet, whereas daily CH_4 emission was reduced for the 2 extreme AS:CS ratios (20:80 and 80:20). However, the proportion of AS and CS in the diet did not affect CH_4/fat-and-protein corrected milk.
Key words: greenhouse gas, rumen fermentation, nitrogen utilization, forage, soybean

INTRODUCTION

The 2 main forages fed to dairy cows in the Midwest of the United States are alfalfa silage (**AS**) and corn silage (**CS**). Compared with CS, AS has greater CP and NPN (NRC, 2001). Thus, feeding increasing AS:CS ratios in the forage portion of a diet often leads to increased dietary CP and NPN, which has been associated with lower N utilization efficiency (**NUE**; g of milk N/100 g of N intake) and greater manure N excretion (Wattiaux and Karg, 2004; Brito and Broderick, 2006), and consequently greater manure NH_3-N emission (Powell et al., 2008; Aguerre et al., 2012) and indirect nitrous oxide (a potent greenhouse gas) emission from the manure (Dijkstra et al., 2013). However, reducing dietary CP (James et al., 1999) and RDP (Monteny et al., 2002) may mitigate NH_3-N emission. In this study we hypothesized that formulating diets with increasing proportion of AS would not alter NH_3-N emission, if CP, RDP, and RUP remained within the general guidelines of the NRC (2001).

Increasing the proportion of AS relative to CS in the diet alters forage NDF composition substantially because at similar NDF content, AS NDF has greater lignin and lower hemicellulose content than CS NDF (NRC, 2001). Similarly, fractional rate of NDF diges-

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tion is likely to be greater because fractional rate of NDF digestion is greater for alfalfa compared with CS (Herrick et al., 2012). Recent findings indicated that the amount of NDF digested in the digestive tract of lactating dairy cows increased with increasing AS:CS ratio (Brito and Broderick, 2006; Spanghero and Zanfi, 2009). More NDF digestion may result in more methane (CH_4) and carbon dioxide (CO_2) emission because these greenhouse gases are produced during enteric fermentation of fiber. Although, Doreau et al. (2014) reported lower daily CH_4 emission with CS compared with grass silage in the diet, the difference waned when expressed per kilogram of OM digested. Changes in NDF composition associated with plant maturity (Boadi and Wittenberg, 2002) and plant species (Chaves et al., 2006) have been shown to alter enteric CH_4 emission under grazing conditions. However, the hypothesis that the difference in NDF composition between AS and CS affects CH_4 emission remain to be fully explored. Hassanat et al. (2013) reported no change in daily CH_4 emission and CH_4/FCM when replacing AS with CS; however, dietary ether extract (**EE**), which is known to have an inhibitory effect on CH_4 emission (Mores et al., 2013), decreased substantially as the proportion of CS increased in the diet. Thus our main objectives were to study the effects of AS:CS ratio in the forage portion of diets balanced for RDP and RUP and a constant level of EE on lactating dairy cow performance; apparent total-tract digestibility; ruminal fermentation characteristics; N balance; manure production and composition; and emission of CH_4, CO_2, and NH_3-N.

MATERIALS AND METHODS

Cows and Experimental Design

The experiments were conducted with cows from the herd of the US Dairy Forage Research Center, at Prairie du Sac, Wisconsin. Cows were housed in tie stalls bedded with rubber mats and wheat straw (except in trial 2). Care and handling of the animals were conducted as outlined in the guidelines of the Research Animal and Resource Committee at the University of Wisconsin–Madison. Two trials were conducted simultaneously with the same experimental diets and basic experimental design: 4 × 4 Latin squares with 21-d periods and treatment sequences balanced for carryover effects. Trial 1 measured performance, rumen parameters, apparent digestibility, and N balance of 8 rumen-cannulated lactating Holstein cows. One Latin square included 4 primiparous cows of (means ± SD) 536 ± 41 kg of BW and 136 ± 4 DIM, whereas the other Latin square included 4 multiparous cows (683 ± 27 kg of BW and 37 ± 17 DIM) that were randomly assigned to dietary treatments. Trial 2 measured performance and gaseous emission from 16 multiparous cows (653 ± 83 kg of BW and 85 ± 34 DIM). Cows were randomly assigned to 1 of 4 air-flow controlled chambers, and chambers were randomly assigned to 1 of 4 dietary treatment sequences.

Trials 1 and 2: Diets and Performance Measurements

Each of the 4 experimental dietary treatment had a forage-to-concentrate ratio of 55:45 (DM basis) but a different AS:CS ratio in the forage portion of the diet: 20:80, 40:60, 60:40, and 80:20 (DM basis; Table 1). Aside from AS and CS, few feed ingredients were used in constructing the treatments in an attempt to minimize confounding effects. Ingredient composition of the concentrate portion of the diet was adjusted to maintain NRC (2001) predicted RDP and RUP above 10 and 6% of dietary DM, respectively, and to avoid excess CP or starch in the diet. Thus, as AS increased and CS decreased, solvent soybean meal (**SBM**) was replaced with expeller SBM, and the proportion of ground corn grain increased at the expense of the soybean by-products (Table 1). Diets were offered to each cow individually as TMR once daily at 0800 h allowing for 10% orts (as-fed basis). Also, the as-fed proportions of concentrate mix, mineral and vitamin premix, and forages in the TMR were adjusted weekly based on forage DM analysis.

During the last 4 d of each period, daily samples of approximately 0.5 kg of AS, CS, corn grain, solvent SBM, expeller SBM, soy hulls, and feed refusals were collected and stored at −20°C. Individual feed ingredients were composited by period on an equal-weight basis (as fed), dried at 60°C (forced-air oven) for 48 h, and ground to pass a 1-mm Wiley mill screen (Arthur H. Thomas, Philadelphia, PA). Feed-refusal samples were composited by period according to daily as-fed refusal weights for each individual cow (trial 1) or chamber (trial 2). The composite samples were dried at 60°C for 48 h and ground to pass a 1-mm screen of a Wiley mill (Arthur H. Thomas). Ground feed samples and refusal samples were analyzed for total N (Leco FP-2000 Nitrogen Analyzer, Leco Instruments Inc., St. Joseph, MI), analytical DM at 100°C for 24 h, ash (AOAC International, 1996; method 942.05), and NDF using α-amylase (Sigma no. A3306: Sigma Chemical Co., St. Louis, MO) with sodium sulfite and corrected for ash according to Van Soest et al. (1991) and adapted for Ankom^{200} Fiber Analyzer (Ankom Technology, Fairport, NY), and ADF was analyzed using AOAC method 973.18 (AOAC International, 1996). Fatty acid content was determined with the procedure of Sukhija and Palmquist (1988), and starch was determined with