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Feed conversion efficiency in dairy cows: Repeatability, variation in digestion and metabolism of energy and nitrogen, and ruminal methanogens

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ABSTRACT

The objective was to study repeatability and sources of variation in feed conversion efficiency [FCE, milk kg/kg dry matter intake (DMI)] of lactating cows in mid to late lactation. Trials 1 and 2 used 16 cows (106 to 368 d in milk) grouped in 8 pairs of 1 high- and 1 low-FCE cow less than 16 d in milk apart. Trial 1 determined the repeatability of FCE during a 12-wk period. Trial 2 quantified the digestive and metabolic partitioning of energy and N with a 3-d total fecal and urine collection and measurement of CH_4 and CO_2 emission. Trial 3 studied selected ruminal methanogens in 2 pairs of cows fitted with rumen cannulas. Cows received a single diet including 28% corn silage, 27% alfalfa silage, 17% crude protein, and 28% neutral detergent fiber (dry matter basis). In trial 1, mean FCE remained repeatedly different and averaged 1.83 and 1.03 for high- and low-FCE cows, respectively. In trial 2, high-FCE cows consumed 21% more DMI, produced 98% more fat- and protein-corrected milk, excreted 42% less manure per kilogram of fat- and protein-corrected milk, but emitted the same daily amount of CH_4 and CO_2 compared with low-FCE cows. Percentage of gross energy intake lost in feces was higher (28.6 vs. 25.9%), but urinary (2.76 vs. 3.40%) and CH_4 (5.23 vs. 6.99%) losses were lower in high- than low-FCE cows. Furthermore, high-FCE cows partitioned 15% more of gross energy intake toward net energy for maintenance, body gain, and lactation (37.5 vs. 32.6%) than low-FCE cows. Lower metabolic efficiency and greater heat loss in low-FCE cows might have been associated in part with greater energy demand for immune function related to subclinical mastitis, as somatic cell count was 3.8 fold greater in low- than high-FCE cows. As a percentage of N intake, high-FCE cows tended to have greater fecal N (32.4 vs. 30.3%) and had lower urinary N (32.2 vs. 41.7%) and greater milk N (30.3 vs. 19.1%) than low-FCE cows. In trial 3, *Methanobrevibacter* spp. strain AbM4 was less prevalent in ruminal content of high-FCE cows, which emitted less CH_4 per unit of DMI and per unit of neutral detergent fiber digested than low-FCE cows. Thus lower digestive efficiency was more than compensated by greater metabolic efficiencies in high- compared with low-FCE cows. There was not a single factor, but rather a series of mechanisms involved in the observed differences in efficiency of energy utilization of the lactating cows in this study.

Key words: feed efficiency, energy metabolism, nitrogen utilization, manure, dairy cattle

INTRODUCTION

Worldwide meat and milk demand is projected to increase, especially in emerging economies where livestock systems are generally considered inefficient but have multiple socio-economic functions (Herrero et al., 2013). For the dairy sector, the challenge of providing dairy products to a more affluent and increasing population (FAO, 2009) depends in part on increasing the efficiency of nutrient utilization by lactating dairy cows with limited effect on global cycles of C (Asner and Archer, 2010) and N (Galloway et al., 2010). Feed conversion efficiency (**FCE**; kg of milk/kg of DMI; Berry and Crowley, 2013) and N use efficiency [**NUE**; milk N g/100 g of N intake (**NI**)] are common measures of efficiency of dietary energy and N utilization in lactating dairy cows. In contrast to NUE, which has remained typically low (around 25%) and highly variable (10 to 40%; Calsamiglia et al., 2010), considerable improvement in FCE has been achieved through dilution of maintenance (Bauman et al., 1985) associated with genetic selection for higher milk production (USDA, 2013). However, marginal increases in FCE decrease with increasing milk production and future selection for higher milk production alone will no longer lead to substantial increases in FCE, in part because of the loss of digestible energy associated with high rate of passage in cows with high DMI and milk production (NRC, 2001). Thus, alternative approaches need to be explored to

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further improve FCE. Ruminal methanogens appeared to vary in cattle with different feed efficiency (Zhou et al., 2009). However, altering the proportion of gross energy intake (**GEI**) available for milk production can be achieved theoretically by reducing the energy in any of the following pools: feces, urine, enteric CH_4, maintenance, body gain, or heat. Thus, quantifying variability at each step of energy and N utilization may serve as a guide for future efforts to improve FCE and NUE. For example, if some of the variability is proven heritable, progeny testing or genomic selection could be used to improve FCE (Yan et al., 2010; Woodward et al., 2011). Hence, the objectives of the current study were to determine the repeatability of FCE over time in mid to late lactation (trial 1), to quantify variations in digestive and metabolic partitioning of energy and N (trial 2), and to study selected ruminal methanogens (trial 3) in lactating dairy cows with contrasting FCE.

MATERIALS AND METHODS

The lactating dairy cows used in our study, which was conducted at the US Dairy Forage Research Center, Prairie du Sac, Wisconsin (43°19′ N, 89°44′ W), were cared for and handled according to protocols approved by the University of Wisconsin-Madison College of Agricultural and Life Sciences Institutional Animal Care and Use Committee. The study was composed of 3 trials. Trial 1 investigated the FCE repeatability of 16 cows during a 12-wk period (February 27 to May 21, 2011). In trial 2, cows of trial 1 were adapted to chambers (n = 4) before a 3-d total fecal and urine collection, and CH_4 and CO_2 emission measurements were conducted in blocks of 2 pairs of cows staggered on wk 6, 8, 10, and 12 because of chamber availability. In trial 3, rumen samples were collected during wk 10 from 4 cows that were fitted with a rumen cannula (before their first lactation). All cows were housed in tiestalls and received bST (Posilac, Elanco Animal Health, Greenfield, IN) on the same day every 2 wk during the cow selection process and the trials.

Cow Selection and Diet Composition

Feed conversion efficiency was measured on a group of 140 cows with DIM ranging from 106 to 368 in a 14-d period before the start of the study (Asher et al., 2014). The 8 cows with the highest and the 8 cows with the lowest FCE were selected and paired based on parity (4 first and 4 second lactation pairs), and the additional selection constraint was that cows within a pair be less than 16 DIM apart from each other. This protocol resulted in a high-FCE group (n = 8) and a low-FCE group (n = 8) with DMI of (LSM ± SD) 24.0 ± 2.2 and 21.2 ± 3.0 kg/d, milk production of 44.9 ± 6.5 and 24.3 ± 5.4 kg/d, and FCE of 1.87 ± 0.22 and 1.14 ± 0.20, respectively.

The same ration was offered throughout the entire study starting 4 wk before the selection period. It included (DM basis) 28.2% corn silage, 26.7% alfalfa silage, 23.2% high-moisture corn, 7.1% distillers dried grains, 3.6% soybean meal, 8.8% roasted soybeans, and 2.4% vitamin and mineral premix, which contained monensin (373 mg/kg of DM). From wk 4 to 12, feed ingredients were sampled once a week, stored at −20°C, and dried at 60°C (in a forced-air oven) for 48 h. Weekly samples were composited in a single sample using equal weight either before grinding (nonforage samples) or after grinding (forage samples) through a 1-mm Wiley mill screen (Arthur H. Thomas Co., Philadelphia, PA). Ground samples were analyzed for total N content (Leco FP-2000 N Analyzer, Leco Instruments Inc., St. Joseph, MI), analytical DM at 100°C for 24 h, ash content (AOAC, 1996; method 942.05), and NDF content using α-amylase (Ankom Technology, Macedon, NY) with sodium sulfite and corrected for ash concentration according to Van Soest et al. (1991), adapted for Ankom200 Fiber Analyzer (Ankom Technology, Fairport, NY). Ether extract (**EE**) was determined using the Soxtec System Application Note AN390 with acid hydrolysis followed by AOAC method 920.39 (AOAC, 1996) using petroleum ether, which determines the total level of fat including fat that is present as fecal soaps (Johnson and McClure, 1973). Total C was determined by combustion assay (Elementar VarioMax CN analyzer; Elementar Vario, Hanan, Germany), and gross energy (**GE**) was measured using Parr 6400 adiabatic bomb calorimeter (Parr Instrument Company, Moline, IL). Nonfiber carbohydrate was calculated according to NRC (2001). Dietary chemical composition was calculated based on chemical analysis of feed samples and dietary feed ingredient composition.

Feed Conversion Efficiency (Trial 1)

DMI. The amount of TMR offered daily at 0800 h was adjusted to allow for 10% refusals from the previous day, and adjustments of diet ingredient mixes were made 3 times per week for change in forage DM content. Amounts offered and refused were recorded daily. Samples of TMR and next morning refusals were collected in 3 consecutive days each week of the study. Weekly samples were stored at −20°C and dried at 60°C (in a forced-air oven) for 48 h. Dry matter intake was calculated on a 100°C basis using the analytical composition of each ingredient offered (see above) and 100°C DM of refusals. Cows had free access to water.

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