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Analysis of Nitrogen Utilization and Excretion in Growing Dairy Cattle[1]

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ABSTRACT

Literature data on utilization of dietary N were analyzed by using meta-analytic procedures for growing milk-fed dairy calves and weaned dairy heifers. The objective was to statistically assess N utilization and excretion in growing dairy cattle when dietary N was altered in otherwise balanced rations at various stages of growth. Studies meeting the selection criteria included data from 16 published papers encompassing 94 distinct observations made on 217 animals. Of these, 6 studied calves were fed milk or milk protein-based milk replacer [milk-fed; 30 to 81 kg of body weight (BW)] with 37 different dietary treatments, and 10 experiments studied heifers receiving diets based on forage, concentrates, or a combination of forage and concentrates (weaned; 56 to 472 kg of BW) with 57 different dietary treatments. Mixed model and fixed effect regression analyses were used to evaluate responses to additional dietary N. True digestibility of dietary N was 100.4% for milk-fed calves and 96.4% for weaned heifers, with corresponding basal fecal N excretion values of 3.05 and 6.51 g of N/kg of dry matter intake. Urinary N (g of N/kg of $BW^{0.75}$) was consistently greater for milk-fed calves, but the response to increasing N intake was parallel to the response for weaned heifers. Whether using a mixed model approach or a fixed effect approach to account for metabolizable energy intake, BW, and dry matter intake, milk-fed calves retained more N per kilogram of $BW^{0.75}$ than weaned heifers. However, marginal efficiency of N utilization responded as a continuous function of BW, as opposed to a bimodal response associated with diet type. Gross N efficiency (GNE) responded quadratically to N intake and was greater for milk-fed calves than for weaned heifers. Linear and quadratic coefficients of this function did not differ between diet types, indicating that the response in gross N efficiency to additional N intake was not different between diet groups; rather, the absolute level obtainable differed. Dietary CP concentrations of 18.9% for milk-fed calves and 14.2% for weaned heifers were found to maximize GNE; 22.5% MJ of crude protein/MJ of ME was found to maximize GNE for both groups. Equations are discussed relative to the requirements to replace basal N losses and efficiency of N utilization.
Key words: nitrogen utilization, dairy calf, dairy heifer

INTRODUCTION

The importance of protein nutrition in dairy cattle has made it the subject of significant research effort (NRC, 2001). The overwhelming majority of this effort has been directed toward lactating dairy cows because of their central importance to the economic stability of the dairy operation. Protein nutrition of the growing dairy heifer, especially postweaning, has been subject to relatively less investigation. Although protein nutrition of the dairy heifer has been reviewed several times in the past (Blaxter and Mitchell, 1948; Lofgreen et al., 1951; Roy, 1980), the subject has received continued study. Considering the economic burden associated with feeding dairy heifers (Gabler et al., 2000) and the environmental costs associated with overfeeding protein (Kohn et al., 1997), the protein and N nutrition of dairy heifers assumes added importance for whole-farm sustainability.

Two factors that must be considered when addressing protein requirements of growing animals are that growth occurs on a continuum and that individual tissues can grow at a different rate than the body as a whole. Thus, the growth rate of the whole body and the size, growth rate, and nutrient requirements of an individual tissue may differentially affect nutrient requirements at different stages of growth. These relationships pose a difficulty when attempting to meet nutritional requirements during growth, because an experiment conducted at one phase on the growth curve has absolute validity only at that point. General relationships may emerge, however, from conducting or analyzing numerous experiments at several points along the growth curve. An added difficulty posed by the growing ruminant is the discontinuous mode of digestion and source of nutrients derived from advancing devel-

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opment of the rumen. Proteins from milk are generally of high biological value (Roy, 1970) and can contribute to very high levels of growth. Microbial protein is also a high-quality protein source (Storm et al., 1983) and can meet a significant quantity of the AA requirements in the functional ruminant.

Given the nutritional importance of protein in the growing dairy heifer and the limited information related to N partitioning, this investigation statistically examined responses to varying amounts of dietary N. Changes that may be related to BW and ME also were assessed. Outcome variables of interest in these analyses were measures of N partitioning as assessed in nutrient digestibility or balance trials, specifically, apparently digestible N (**ADN**), fecal N (**FN**), urinary N (**UN**), N retained (**NR**), and N efficiency. The objective was to statistically evaluate N retention and excretion in growing dairy cattle in response to increasing levels of dietary N intake (**NI**) in otherwise balanced rations fed across various growth stages. A secondary objective was to evaluate N utilization for basal purposes by extrapolations to zero NI and to compare these estimates between cattle fed liquid, milk protein-based diets and cattle that have been weaned.

MATERIALS AND METHODS

To accomplish these objectives, a literature search was conducted to identify published reports eligible for analysis. The search was conducted by using two databases for all years available: PubMed (1950 to 2007) and ISI Web of Knowledge/Web of Science (Thomson Scientific; 1900 to 2007). References within published manuscripts identified from the database search were also searched in an attempt to find as many candidate papers for analysis as possible. Books relating to this subject (Roy, 1980; Davis and Drackley, 1998; NRC, 2001) and the references therein were also evaluated. Manuscripts citing the papers found in the database search and reference list search were then evaluated by using the Web of Science. Thus, potential papers were identified from an individual manuscript's own references and papers that referred to it. This process was continued until no further new papers were identified as eligible.

To enter the analysis, the experimental objective must have been to study the effects of differing levels of dietary NI in an otherwise balanced ration. At a minimum, trials had to report NI, FN, BW, and DMI to be included; data were not excluded for not reporting UN or NR. It was also considered acceptable if these responses could be calculated reasonably from other information given in the paper. Data must have been derived from total collection of feces and urine, with adequate procedures in place to minimize N loss by volatilization. Adequacy of collection procedures was evaluated statistically for FN and UN excretion by a regression of the mean within-trial response against the mean within-trial NI. A trial was removed as an outlying trial if the Studentized residual associated with this analysis was >3 standard deviations. Results from slaughter balance-growth trials were not included in the analysis unless results from a total collection trial were also presented.

Given the significance of Holstein-Friesian genetics in the North American dairy industry, the original intention was to analyze the N balance of only Holstein-Friesian heifers. However, several early studies on the protein nutrition of calves were conducted with other breeds, and implementing this restriction severely limited the number of experiments and animals eligible for analysis. Although there are substantial differences in mature size between large-framed breeds of dairy cattle, before cattle reach 100 kg there are relatively small differences between breeds in weight and height (Heinrichs and Hargrove, 1994; Heinrichs and Losinger, 1998). Furthermore, Brisson et al. (1957) indicated in an experiment that included Holstein and Ayrshire calves that there were no statistical differences between these 2 breeds in N utilization. Therefore, large-breed dairy calves were considered eligible for analysis if studied before reaching 100 kg if all other criteria were met (only experiments with Ayrshire and Holstein-Friesian calves met all criteria and were analyzed). After 100 kg, only dairy cattle of Holstein or Friesian genetics were eligible for analysis. Steers and bulls were considered eligible for analysis provided they were studied before reaching 200 kg of BW, because at greater BW effects of sex may become more significant in N retention (Fortin et al., 1980).

Applying these restrictions allowed data from 16 published papers to be used. Of these, 6 studied calves were fed milk or milk protein-based milk replacer (milk-fed group) with 37 different dietary treatments, with animals ranging from 30 to 81 kg of BW (Blaxter and Wood, 1951b; Brisson et al., 1957; Roy et al., 1970; Raven, 1972; Donnelly and Hutton, 1976; Blome et al., 2003). For animals in the milk-fed group, all nutrition was derived from the milk or milk replacer and no additional feed was offered (either starter grain or hay). Ten published papers studied cattle receiving diets based on forage, concentrates, or a combination of forage and concentrates (weaned group) with 57 different dietary treatments, with animals ranging from 56 to 472 kg of BW (Whitelaw et al., 1961; Broster et al., 1963; Bowers et al., 1965; Bines and Balch, 1973; Stobo and Roy, 1973; Veira et al., 1980; Bagg et al., 1985; Hoffman et