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Factors affecting energy and nitrogen efficiency of dairy cows: A meta-analysis

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ABSTRACT

A meta-analysis was performed to explore the correlation between energy and nitrogen efficiency of dairy cows, and to study nutritional and animal factors that influence these efficiencies, as well as their relationship. Treatment mean values were extracted from 68 peer-reviewed studies, including 306 feeding trials. The main criterion for inclusion of a study in the meta-analysis was that it reported, or permitted calculation of, energy efficiency (Eeff; energy in milk/digestible energy intake) and nitrogen efficiency (Neff; nitrogen in milk/digestible nitrogen intake) at the digestible level (digestible energy or digestible protein). The effect of nutritional and animal variables, including neutral detergent fiber, acid detergent fiber (ADF), digestible energy, digestible protein, proportion of concentrate (PCO), dry matter intake, milk yield, days in milk, and body weight, on Eeff, Neff, and the Neff:Eeff ratio was analyzed using mixed models. The interstudy correlation between Eeff and Neff was 0.62, whereas the intrastudy correlation was 0.30. The higher interstudy correlation was partly due to milk yield and dry matter intake being present in both Eeff and Neff. We, therefore, also explored the Neff:Eeff ratio. Energy efficiency was negatively associated with ADF and PCO, whereas Neff was negatively associated with ADF and digestible energy. The Neff:Eeff ratio was affected by ADF and PCO only. In conclusion, the results indicate a possibility to maximize feed efficiency in terms of both energy and nitrogen at the same time. In other words, an improvement in Eeff would also mean an improvement in Neff. The current study also shows that these types of transverse data are not sufficient to study the effect of animal factors, such as days in milk, on feed efficiency. Longitudinal measurements per animal would probably be more appropriate.

Key words: meta-analysis, energy efficiency, nitrogen efficiency, dairy cow

INTRODUCTION

Feed efficiency (**FE**) in dairy production has received increasing attention because it influences not only farm profitability but also losses to the environment. Because feed costs account for more than 50% of total costs of dairy production (Shalloo et al., 2004), any improvement in FE has a direct effect on the profitability of dairy farms (Britt et al., 2003). Moreover, if nutrients consumed are not converted into milk, body reserves, or a newborn calf, they are excreted into the environment, resulting in emissions of, for example, ammonia, methane, or nitrous oxide (Thomassen et al., 2009). Improving FE can, therefore, be beneficial for both farm profitability and the environmental impact of milk production (Wall et al., 2010; Yan et al., 2010).

Feed efficiency is traditionally defined as the ratio of output to input [e.g., milk produced/DMI (kg/kg), energy in milk/energy intake (Mcal/Mcal), or nitrogen in milk/nitrogen intake (g/g); Brody, 1945]. An alternative definition of FE is residual feed intake (**RFI**; kg/d or Mcal/d), which estimates the difference between actual and predicted intake (Koch et al., 1963; Prendiville et al., 2009). In genetic selection, RFI has been preferred to efficiency expressed as ratios, as selection based on ratios carries disadvantages, such as increased error variance as a proportion of total variance and a strong correlation with component traits, for FE and milk yield (Wang et al., 1992). Residual feed intake is, by definition, phenotypically independent of component traits, but suffers from the problem of accumulation of errors in the measurements used (Herd and Arthur, 2009). Richardson et al. (2004), for example, stated that only 73% of the variation in RFI could be explained by biological mechanisms. Despite their obvious importance, in practice, neither FE nor RFI are used extensively due to the difficulties in the field of measuring their components, particularly intake, with a reasonable level of precision (McNaughton and Pryce,

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2007; Moore et al., 2009). A second issue is that FE has commonly been evaluated in terms of energy (or mass), with nitrogen being accounted for only via its energy content (Zamani et al., 2008). However, attention for environmental impact of emissions of NH_3 or N_2O, which are related to N excretion, has increased. Hence, nitrogen efficiency (**Neff**) should also be considered. In this context, a key question is whether Neff and energy efficiency (**Eeff**) are affected by the same factors.

Feed efficiency can be measured at metabolizable, digestible, and gross levels of nutrient intake (Veerkamp and Emmans, 1995; Tolkamp, 2010), which we would then call metabolic, digestible, and gross efficiency, respectively. These different measures of FE may lead to different biological or economic interpretations (Blake and Custodio, 1984). Variation in metabolic efficiency indicates primarily differences in partitioning of nutrients between milk production and other life functions. Environmentally speaking, it does not include losses in feces, gases, and urine being excreted. At the other extreme, gross efficiency includes the part of feed that is not available to animals and, as such, it is of limited value for quantifying the variability between animals in efficiency. Efficiency of use of digestible energy (**DE**) and nitrogen does not consider fecal losses but includes losses in gases, urine, and animal differences in partitioning of nutrients. Digestible efficiency, therefore, makes it possible to not only evaluate the environmental impact of milk production, but also to compare efficiency between animal genotypes in using feed to produce milk. Fecal losses can be estimated easily using feed chemical characteristics or in vitro degradation data (Nousiainen et al., 2009).

Feed efficiency for milk production depends not only on diet composition but also on animal genotype and physiological state (Blake and Custodio, 1984). Genetic potential for milk production and stage of lactation differences modify partition of absorbed nutrients into milk and other life functions. Feed efficiency should, therefore, be studied from both the nutritional and genetic points of view. A better understanding of how nutrients are partitioned has been recognized as being central to maximizing FE and minimizing environmental impact (Friggens et al., 2011). However, it has become clear later that the available data did not allow the exploration of effect of animal factors on FE. In addition, insight into how Eeff and Neff are correlated and how this correlation changes in different conditions would provide a basis for maximizing or predicting FE of animals in both energy and nitrogen terms. Using a meta-analysis approach, the current study study explored the correlation between Eeff and Neff, and examined common nutritional factors affecting Eeff and Neff, and their relationships.

MATERIALS AND METHODS

Literature Search

A literature search using the Web of Science (http://thomsonreuters.com/web-of-science/), ScienceDirect (http://www.sciencedirect.com/), and Google Scholar (http://scholar.google.com/) search engines was conducted to create a database for this study. The following keywords were used in different combinations: Eeff, Neff, dairy cows, nutrient utilization, and dairy cow performance. The inclusion criteria in the database were a feed description in terms of ingredients (%); proportion of concentrate (%); DMI (kg/d); milk yield (kg/d); milk fat, protein, and lactose yield (%); BW (kg); and DIM (d). The chemical composition of the diets in publications was either obtained from the reported laboratory analysis or estimated from NRC (2001), with exceptions of DE and digestible protein, which will be mentioned later in this section.

Only full studies published in peer-reviewed journals were selected (abstracts, conference papers, and review articles were not considered). Eventually, 68 studies (listed in the Appendix) consisting of 306 treatment means that satisfied the above criteria were kept for further analysis.

Efficiency Derivations

As indicated, FE was defined as the ratio of nutrient output in milk to nutrient input in feed, with a focus on energy and nitrogen (subsequently termed Eeff and Neff). Additionally, inputs were expressed as DE or digestible protein.

Energy efficiency was calculated as the ratio between energy in milk (Mcal/d) and DE intake (Mcal/d):

$$\text{Eeff (\%)} = \frac{\text{MY (kg/d)} \times \text{E milk (Mcal/kg of milk)}}{\text{DMI (kg/d)} \times \text{DE diet (Mcal/kg of DM)}}, \quad [1]$$

where **MY** is milk yield of an animal per day, DE diet is the DE content of the diet, and E milk is the energy content of milk, which is the sum of energy of all milk components including fat, protein, and lactose using the equations suggested by NRC (2001) as follows:

$$\begin{aligned}\text{E milk} &= \text{milk fat content (kg/kg of milk)} \times 9.29 \\ &+ \text{milk protein content (kg/kg of milk)} \times 5.47 \\ &+ \text{milk lactose content (kg/kg of milk)} \times 3.95,\end{aligned}$$

where 5.47, 9.29, and 3.95 are the amounts of energy released from the combustion of 1 kg of protein, fat, and lactose, respectively (Mcal/kg; NRC, 2001).