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Effects of diet forage proportion on maintenance energy requirement and the efficiency of metabolizable energy use for lactation by lactating dairy cows

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ABSTRACT

The objective of the present study was to examine the effect of dietary forage proportion (FP) on metabolizable energy (ME) requirement for maintenance (ME_m) and the efficiency of ME use for lactation (k_l) in lactating dairy cows. Data used were derived from 32 calorimetric chamber experiments undertaken at our institute between 1992 and 2010, including data from 818 Holstein-Friesian cows (HF), 50 Norwegian Red cows, and 62 crossbred cows (Jersey × HF or Norwegian Red × HF). Animals were offered forage-only rations (n = 66) or forage and concentrate rations (n = 864) with FP ranging from 18 to 100% (dry matter basis). The effect of FP was evaluated by dividing the whole data set into 4 groups according to the FP ranges, categorized as FP <30%, FP = 30 to 59%, FP = 60 to 99%, and FP = 100%. The ME_m for individual cows was calculated from heat production minus energy losses from inefficiencies of ME use for lactation, energy retention and pregnancy, and k_l was obtained from milk energy output adjusted to zero energy balance ($E_{l(0)}$) divided by ME available for production. Increasing FP significantly reduced ME intake and milk energy output ($P < 0.001$), although the differences between the 2 low FP groups were not significant. However, increasing FP significantly increased the ratio of heat production over ME intake and ME_m (MJ/kg$^{0.75}$; $P < 0.001$), with the exception that the increases did not reach significance in heat production/ME intake between FP <30% and FP = 30 to 59%, or in ME_m between FP = 60 to 99% and FP = 100%. However, the FP had no significant effect on the k_l values, which were similar among the 4 groups of cows. The effect of FP was also evaluated using the linear mixed regression technique relating $E_{l(0)}$ to ME intake. The results demonstrated that with a common regression coefficient (slope), the regression constants (intercepts) taken as net energy requirement for maintenance significantly increased ($P < 0.001$) with increasing FP. However, the increase between the 2 high FP groups did not research significance. It is concluded that increasing diet FP had no effects on k_l but significantly increased maintenance energy requirement (MJ/kg$^{0.75}$). These results indicate that using the current energy feeding systems to ration dairy cows managed under low input systems may underestimate their nutrient requirements, because the majority of feeding systems adopted globally do not differentiate the maintenance energy requirements between low and high forage input systems.
Key words: forage proportion, maintenance energy requirement, energy utilization efficiency, lactating dairy cow

INTRODUCTION

Low-input dairy farming is widely adopted in favorable grass-growing areas of the world (e.g., in New Zealand, Australia, and Ireland) or in countries where the economic conditions constrain high-concentrate inputs (e.g., in some developing countries). These low-input systems are increasingly recognized as delivering multi-functional benefits to the agricultural industry and society, in contrast to some higher input systems, which are often linked with fertility, health, and welfare challenges (Seykora and McDaniel, 1983; Ingvartsen et al., 2003; König et al., 2008; Koeck et al., 2014). Dairy cows managed under the low-input systems are normally offered forage-based diets supplemented with no or a small amount of concentrates. However, forages are bulky materials and normally contain less ME than concentrate supplements, although high-quality grass may have a comparable ME concentration to that of concentrates. Therefore, cows offered forage-based diets may need to consume a greater physical quantity of bulky forages than those offered concentrate-based di-

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ets to achieve a given level of ME intake. However, evidence indicates that high intakes of bulky forage could increase maintenance metabolic rates of cows (Dong et al., 2015). The greater physical intake required with a forage-based diet to achieve similar levels of ME intake are likely to result in greater gut fill, an increased energy expenditure on rumination and digestion, and a greater production of acetic acid in the rumen. All of these factors can contribute to an increase in gut mass, an increase in the size of other internal organs (Reynolds, 1996), and a higher metabolic rate. The protein metabolism in gut, liver, and other internal organs can produce much more heat per unit of weight than that of muscle (Baldwin et al., 1985; Johnson et al., 1990). Indeed, an earlier calorimeter chamber study involving lactating dairy cows found that ME requirement for maintenance (**ME_m**) increased from 0.59, 0.68, to 0.74 MJ/$kg^{0.75}$ when cows were offered diets containing forage levels of less than 50%, 50 to 99%, and 100% (Yan et al., 1997). However, energy rationing systems for dairy cows currently adopted in North America and Europe do not consider the effects of diet forage proportion on basal metabolic rates. Indeed, many of these systems were developed using data from animals offered diets with a low forage proportion (**FP**). Using these systems to ration dairy cows managed within systems with a high FP may result in an underestimation of their maintenance energy requirement.

In recognition of the need to optimize the competiveness of low-input and organic dairy farming, the European Union funded a research project in 2012 to evaluate measures to improve the efficiency and welfare of animals within low-input and organic dairy systems. The present study was part of this project and was designed to address the knowledge gap described previously. Therefore, the objectives of the present study were to use a large calorimeter data set of lactating dairy cows collated at this institute to investigate the influence of diet FP on energetic efficiency, and to quantify any differences in ME_m and the efficiency of ME use for lactation (**k_l**) for lactating dairy cows offered diets containing low and high proportions of forage.

MATERIALS AND METHODS

Animals and Diets

Data used were collated from 32 individual experiments involving lactating dairy cows undertaken at this institute from 1992 to 2010, including data from 818 Holstein-Friesian cows (**HF**), 50 Norwegian Red cows, and 62 crossbred cows (Jersey × HF or Norwegian Red × HF, F_1 hybrid). The majority of these studies have been published in peer-reviewed scientific journals, and their references are presented in the Appendix. The HF cows had a range of Profitable Lifetime Index (£) from −93 to 145, based on the calculation of Predicted Transmitting Ability 2010 proof under the UK genetic evaluation system. The crossbred animals were the offspring of a crossbreeding program undertaken within the Agri-Food and Biosciences Institute Hillsborough herd. The cows were at different stages of lactation when housed in the calorimeter chambers, with a mean DIM of 159 for HF cows, 158 for Norwegian Red cows, 179 for Jersey × HF cows, and 247 for Norwegian Red × HF cows. Parity of the cows was as follows: 258 first parity, 206 second parity, and 466 between parities 3 and 9.

All diets were offered ad libitum, with cows offered either forage-only diets (n = 66), or a mixture of forage and concentrates (n = 864), according to protocols within individual experiments. The forages offered included grass silage (n = 623), mixtures of grass silage and maize silage (n = 155), mixtures of grass silage and whole crop wheat silage (n = 4), mixtures of fresh grass and straw (n = 4), maize silage (n = 6), whole crop wheat silage (n = 6), straw (n = 36), fresh grass (n = 42), dried grass (n = 20), and dried lucerne (n = 34). The grass silages were produced from primary growth, primary regrowth, and secondary regrowth material, with grass either unwilted or wilted before ensiling, and ensiled with or without application of silage additives. Grass (fresh and dried) and grass silages offered were produced from predominantly perennial ryegrass swards containing a range of varieties (e.g., Aberstar, Aberzest, Fetione, Magella, Menna, Merbo, Merlinda, and Spelga). The concentrates offered included a mineral-vitamin supplement and some of the following ingredients: cereal grains (barley, wheat, or maize), by-products (maize gluten meal, molassed or unmolassed sugar-beet pulp, citrus pulp, or molasses), and protein feeds (soybean meal or rapeseed meal). Diets were either 100% forage (n = 66) or contained varying proportions of concentrate, from 13 to 82% (n = 864).

Digestibility and Calorimeter Measurements

Energy intake and output data used in the present study were measured in digestibility trials and by indirect open-circuit respiration calorimeter chambers. Before the commencement of nutrient utilization measurements, all dairy cows were offered their experimental diets for at least 3 wk in group-housed cubicle accommodation with free access to water. Afterward, animals were transferred to a tie-stall facility and remained in individual stalls for between 5 to 8 d, with

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