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Inter-relationships among alternative definitions of feed efficiency in grazing lactating dairy cows

A. M. Hurley,*† N. López-Villalobos,† S. McParland,* E. Kennedy,* E. Lewis,* M. O'Donovan,* J. L. Burke,† and D. P. Berry*[1]

*Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland
†Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Private Bag 11-222, Palmerston North, New Zealand

ABSTRACT

International interest in feed efficiency, and in particular energy intake and residual energy intake (REI), is intensifying due to a greater global demand for animal-derived protein and energy sources. Feed efficiency is a trait of economic importance, and yet is overlooked in national dairy cow breeding goals. This is due primarily to a lack of accurate data on commercial animals, but also a lack of clarity on the most appropriate definition of the feed intake and utilization complex. The objective of the present study was to derive alternative definitions of energetic efficiency in grazing lactating dairy cows and to quantify the inter-relationships among these alternative definitions. Net energy intake (NEI) from pasture and concentrate intake was estimated up to 8 times per lactation for 2,693 lactations from 1,412 Holstein-Friesian cows. Energy values of feed were based on the French Net Energy system where 1 UFL is the net energy requirements for lactation equivalent of 1 kg of air-dry barley. A total of 8,183 individual feed intake measurements were available. Energy balance was defined as the difference between NEI and energy expenditure. Efficiency traits were either ratio-based or residual-based; the latter were derived from least squares regression models. Residual energy intake was defined as NEI minus predicted energy to fulfill the requirements for the various energy sinks. The energy sinks (e.g., NE_L, metabolic live weight) and additional contributors to energy kinetics (e.g., live weight loss) combined, explained 59% of the variation in NEI, implying that REI represented 41% of the variance in total NEI. The most efficient 10% of test-day records, as defined by REI (n = 709), on average were associated with a 7.59 UFL/d less NEI (average NEI of the entire population was 16.23 UFL/d) than the least efficient 10% of test-day records based on REI (n = 709). Additionally, the most efficient 10% of test-day records, as defined by REI, were associated with superior energy conversion efficiency (ECE, i.e., NE_L divided by NEI; ECE = 0.55) compared with the least efficient 10% of test-day records (ECE = 0.33). Moreover, REI was positively correlated with energy balance, implying that more negative REI animals (i.e., deemed more efficient) are expected to be, on average, in greater negative energy balance. Many of the correlations among the 14 defined efficiency traits differed from unity, implying that each trait is measuring a different aspect of efficiency.

Key words: feed efficiency, dairy, residual energy intake, energy balance, feed conversion

INTRODUCTION

The expanding world human population (FAO, 2009) is contributing to increased global demand for animal-derived energy and protein sources. International interest in sustainable resource use efficiency is therefore intensifying. Although global, national, and even herd resource use efficiency is multi-factorial, affected by animal characteristics such as reproductive performance, longevity, and per lactation energy produced (Berry et al., 2015), individual animal feed intake recording as well as the appropriate definitions of efficiency are also fundamental to achieving the necessary gains in efficiency.

The definition of alternative measures of feed efficiency and their respective utility is the subject of extensive discussion. Since the 1960s, more than 2 dozen definitions of feed efficiency have been presented in the scientific literature (Archer et al., 1999). Feed conversion ratio and feed conversion efficiency are the traditional measures of feed efficiency in growing and lactating animals, respectively. Residual feed intake, used predominately in growing animals as a measure of feed efficiency (Berry and Crowley, 2013), is now also being used in lactating dairy cow populations (Coleman et al., 2010; McParland et al., 2014; Pryce

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[1]Corresponding author: donagh.berry@teagasc.ie

et al., 2014). The definition of residual energy intake (**REI**) in lactating cows does, however, differ among studies (Coleman et al., 2010; McParland et al., 2014; Pryce et al., 2014). Consequently, the applications and benefits of these definitions are different. A plethora of other definitions of feed efficiency also exist in both growing and lactating animals, all with their respective advantages and disadvantages (for review, see Berry and Crowley, 2013). Irrespective of the definition, estimates of feed efficiency in dairy cows must account for different functions involved in energy usage and supply over the entire lactation, for example, lipid and protein body mass changes (Berry et al., 2006). Some currently used definitions of feed efficiency in lactating cows (e.g., feed conversion efficiency) do not fully account for body tissue mobilization patterns. Moreover, the inter-relationships among the alternative definitions of feed efficiency traits have not been fully elucidated.

The objectives of the present study were (1) to derive alternative definitions of energetic efficiency in lactating Holstein-Friesian dairy cows, and (2) to quantify the inter-relationships among these alternative definitions. Results from this study may be useful in determining the most appropriate definition of energy efficiency in lactating dairy cows, although one definition is unlikely to meet the requirements of all potential stakeholders.

MATERIALS AND METHODS

Data

Data were available from the Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland (50°7′N; 8°16′W) from the years 1988 to 2009, inclusive. All studies were undertaken on 2 adjacent research farms, namely, Curtin's Research Farm and Moorepark Research Farm. Cows originated from studies which evaluated alternative grazing strategies, nutritional strategies, or strain of Holstein-Friesian animals; see O'Neill et al. (2013) for a description of the database. Animals were fed a basal diet of grazed grass. Swards consisted primarily of perennial ryegrass (*Lolium perenne*) and were managed under a rotational grazing system similar to that described by Dillon et al. (1995). Some animals were supplemented sporadically with concentrates, varying from 0.89 to 3.9 kg of DM per cow daily, offered in equal feeds during each milking. All cows were milked twice daily.

Individual cow milk yield was recorded daily; milk fat and protein concentration was determined from successive morning and evening milk samples once per week using mid-infrared spectroscopy (Fos-let instrument, AS/N Foss Electric, Hillerød, Denmark). Net energy requirement for lactation was calculated as (Agabriel, 2007)

$$NE_L = 0.44 + 0.0055 \times (FC - 40) + 0.0033 \times (PC - 31),$$

where FC is fat concentration expressed in grams per kilogram and PC is protein concentration expressed in grams per kilogram.

Individual animal live weight was recorded weekly upon exiting the milking parlor using an electronic scale (Tru-Test Limited, Auckland, New Zealand). Animal BCS (scale 1 = emaciated, 5 = obese) was recorded every 2 to 3 wk in increments of 0.25 (Edmonson et al., 1989). Cubic splines with 6 knot points at 20, 70, 120, 170, 220, and 270 DIM, with a covariance structure fitted among knot points, were fitted through individual live weight and BCS test-day records. Live weight and BCS at each DIM were interpolated from the fitted splines. Forward differencing was used to estimate daily live weight and BCS change for each DIM.

Individual animal grass DMI at pasture was estimated using the n-alkane technique (Mayes et al., 1986) as modified by Dillon and Stakelum (1989). During the intake measurement period, cows were dosed twice daily before milking with paper bungs containing 500 mg of C32-alkane (n-dotriacontane) for 12 d. Fecal samples were collected from each cow twice daily during d 7 to 12. Subsequently, samples were bulked per cow, giving one sample per cow per intake measurement period; this sample was sub-sampled for gas chromatography analysis. Selected herbage samples were taken following close observation of cows grazing both after morning and evening milking on d 6 to 11 of the intake measurement period. The ratio of herbage C33-alkane (tritriacontane) to dosed C32-alkane was used to estimate DMI as outlined in detail by Dillon (1993).

Individual cow daily total DMI (i.e., grazed pasture DMI plus concentrate DMI) was available, on average, 4.5 times per lactation. Energy values of the pasture and concentrate were based on the French Net Energy system where 1 unité fourragère du lait (**UFL**) is the net energy requirements for lactation equivalent of 1 kg of standard air-dry barley (Jarrige et al., 1986) equivalent to 7.11 MJ of net energy or 11.85 MJ of ME. The energy values and energy sinks were also based on the French Net Energy system.

The UFL concentration of the offered herbage was calculated using the ADF and CP concentrations, which were measured in the laboratory (Jarrige, 1989). Concentrate UFL value was also calculated from the chemical composition of the feed. The net energy content of the concentrate fed was calculated for each day;