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Genetics of alternative definitions of feed efficiency in grazing lactating dairy cows

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ABSTRACT

The objective of the present study was to estimate genetic parameters across lactation for measures of energy balance (EB) and a range of feed efficiency variables as well as to quantify the genetic inter-relationships between them. Net energy intake (NEI) from pasture and concentrate intake was estimated up to 8 times per lactation for 2,481 lactations from 1,274 Holstein-Friesian cows. A total of 8,134 individual feed intake measurements were used. Efficiency traits were either ratio based or residual based; the latter were derived from least squares regression models. Residual energy intake (REI) was defined as NEI minus predicted energy requirements [e.g., net energy of lactation (NE_L), maintenance, and body tissue anabolism] or supplied from body tissue mobilization; residual energy production was defined as the difference between actual NE_L and predicted NE_L based on NEI, maintenance, and body tissue anabolism/catabolism. Energy conversion efficiency was defined as NE_L divided by NEI. Random regression animal models were used to estimate residual, additive genetic, and permanent environmental (co)variances across lactation. Heritability across lactation stages varied from 0.03 to 0.36 for all efficiency traits. Within-trait genetic correlations tended to weaken as the interval between lactation stages compared lengthened for EB, REI, residual energy production, and NEI. Analysis of eigenvalues and associated eigenfunctions for EB and the efficiency traits indicate the ability to genetically alter the profile of these lactation curves to potentially improve dairy cow efficiency differently at different stages of lactation. Residual energy intake and EB were moderately to strongly genetically correlated with each other across lactation (genetic correlations ranged from 0.45 to 0.90), indicating that selection for lower REI alone (i.e., deemed efficient cows) would favor cows with a compromised energy status; nevertheless, selection for REI within a holistic breeding goal could be used to overcome such antagonisms. The smallest (8.90% of genetic variance) and middle (11.22% of genetic variance) eigenfunctions for REI changed sign during lactation, indicating the potential to alter the shape of the REI lactation profile. Results from the present study suggest exploitable genetic variation exists for a range of efficiency traits, and the magnitude of this variation is sufficiently large to justify consideration of the feed efficiency complex in future dairy breeding goals. Moreover, it is possible to alter the trajectories of the efficiency traits to suit a particular breeding objective, although this relies on very precise across-parity genetic parameter estimates, including genetic correlations with health and fertility traits (as well as other traits).
Key words: random regression model, heritability, energy, residual energy intake, feed intake

INTRODUCTION

The gross efficiency of converting feed energy to milk in dairy cows has more than doubled over the past century, largely as the indirect consequence of increased milk output per cow (Oltenacu and Broom, 2010). Reducing feed intake, without repercussions for the other performance traits, is important to maintain dairy sector competitiveness while also meeting projected consumer demands for animal protein within the realm of constrained resources. Improving feed efficiency is also desirable because of its potential benefits toward reducing both nutrient and greenhouse gas emissions per animal. The importance of feed efficiency to the dairy industry is well recognized and has led to a large-scale global effort to improve this animal characteristic (Berry et al., 2014; de Haas et al., 2015).

Genetic selection for feed efficiency is common in pigs and poultry (Emmerson, 1997; Lonergan et al., 2001), but it is not explicitly considered in most dairy

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cow breeding objectives. Its omission from the dairy cow breeding objective is due to both a lack of available feed intake data from which to estimate net feed efficiency, but also the lack of a consensus on the most appropriate definition of net feed efficiency in dairy cows. Several feed efficiency definitions have been proposed and have been the subject of extensive discussion. Hurley et al. (2016) described the phenotypic (co)variances among a range of different definitions of feed efficiency in grazing lactating dairy cows. Less well known, however, is the genetic (co)variance among these alternative definitions of feed efficiency. Most of the studies on the genetics of the feed intake complex have been derived from dairy cows in confined production systems, and assumed feed efficiency was genetically the same trait throughout lactation (Manzanilla-Pech et al., 2014; Manafiazar et al., 2016). The existence of genetic variation in alternative definitions of feed efficiency, as well as the estimation of precise intra- and intertrait genetic correlations, needs to be quantified before consideration in genetic evaluations and subsequent inclusion in breeding objectives. The objective of the present study was to estimate genetic parameters across lactation for a range of alternative measures of feed efficiency in grazing lactating Holstein-Friesian dairy cows, and quantify the genetic intra- and interrelationships among these alternative definitions.

MATERIALS AND METHODS

Data

Data were collected from the Animal and Grassland Research and Innovation Centre, Teagasc Moorepark, Fermoy, Co. Cork, Ireland, between the years 1995 to 2014, inclusive. All studies were undertaken on 2 adjacent research farms, namely Curtin's Research Farm and the Moorepark Research Farm located in southern Ireland (latitude 52°9′N; longitude 8°16′W). The majority of cows used in the present study originated from several controlled experiments, which evaluated alternative grazing strategies, nutritional strategies, or strains of Holstein-Friesian animals; a description of the database is provided by Hurley et al. (2016). Individual animal grass DMI at pasture was periodically estimated using the n-alkane technique (Mayes et al., 1986). Details on the procedures used to collect and analyze fecal grab samples have been provided elsewhere (Kennedy et al., 2008). The procedure provides a measure of DMI averaged across 6 d of sampling. All cows were offered a basal diet of grazed grass. Perennial ryegrass (*Lolium perenne*) was the predominant pasture species at both research farms, and pastures were managed under a rotational grazing system comparable to that detailed by Dillon et al. (1995). Some animals were supplemented with concentrates (depending on feeding protocol), varying from 0.89 to 3.9 kg of DM per cow daily, offered in equal feeds during each milking.

Cows were milked twice daily at 0700 and 1500 h and individual cow milk yield was recorded daily; milk fat, protein, and lactose concentration was determined from successive evening and morning milk samples once per week using mid-infrared spectroscopy (FT6000, FOSS, Hillerod, Denmark). Net energy requirement for lactation was calculated as follows (Agabriel, 2007):

$$NE_L = (0.054 \times FC + 0.031 \times PC + 0.028 \times LC - 0.015) \times \text{milk kg},$$

where FC is fat concentration (%), PC is protein concentration (%), and LC is lactose concentration (%).

Individual animal live weight (BW) was generally measured weekly following morning milking using an electronic scale (Tru-Test Limited, Auckland, New Zealand). The scales were calibrated weekly against known weights. Body condition score on a scale of 1 (emaciated) to 5 (obese) was assessed by trained scorers 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 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 at each DIM. Individual cow daily total DMI (i.e., grazed pasture DMI plus concentrate DMI) was available up to 8 times (average of 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 standard air-dry barley (Jarrige, 1989) equivalent to 7.11 MJ of net energy or 11.85 MJ of ME. The UFL concentration of the offered herbage was calculated using the ADF and CP concentration, 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 offered was calculated for each day; where UFL content of concentrate was not available (i.e., 26% of test-day records), the year-month average was assumed. Where the net energy content of the offered herbage (UFL/kg of DM) was not available (i.e., 8% of test-day records), the year-month average was assumed. Total net energy intake (**NEI**) was defined as the sum of pasture and concentrate NEI.