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Characteristics of feed efficiency within and across lactation in dairy cows and the effect of genetic selection

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ABSTRACT

The objective of the present study was to investigate the phenotypic inter- and intra-relationships within and among alternative feed efficiency metrics across different stages of lactation and parities; the expected effect of genetic selection for feed efficiency on the resulting phenotypic lactation profiles was also quantified. A total of 8,199 net energy intake (NE_I) test-day records from 2,505 lactations on 1,290 cows were used. Derived 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 NE_I minus predicted energy requirements based on lactation performance; residual energy production (REP) was defined as net energy for lactation minus predicted energy requirements based on lactation performance. Energy conversion efficiency was defined as net energy for lactation divided by NE_I. Pearson phenotypic correlations among traits were computed across lactation stages and parities, and the significance of the differences was determined using the Fisher r-to-z transformation. Sources of variation in the feed efficiency metrics were investigated using linear mixed models, which included the fixed effects of contemporary group, breed, parity, stage of lactation, and the 2-way interaction of parity by stage of lactation. With the exception of REI, parity was associated with all efficiency and production traits. Stage of lactation, as well as the 2-way interaction of parity by stage of lactation, were associated with all efficiency and production traits. Phenotypic correlations among the efficiency and production traits differed not only by stage of lactation but also by parity. For example, the strong phenotypic correlation between REI and energy balance (EB; 0.89) for cows in parity 3 or greater and early lactation was weaker for parity 1 cows at the same lactation stage (0.81), suggesting primiparous cows use the ingested energy for both milk production and growth. Nonetheless, these strong phenotypic correlations between REI and EB suggested negative REI animals (i.e., more efficient) are also in more negative EB. These correlations were further supported when assessing the effect on phenotypic performance of animals genetically divergent for feed intake and efficiency based on parental average. Animals genetically selected to have lower REI resulted in cows who consumed less NE_I but were also in negative EB throughout the entire lactation. Nonetheless, such repercussions of negative EB do not imply that selection for negative REI (as defined here) should not be practiced, but instead should be undertaken within the framework of a balanced breeding objective, which includes traits such as reproduction and health.
Key words: estimated breeding value, feed intake, residual energy intake, energy balance, heritability

INTRODUCTION

Improving feed efficiency is a well-established goal in many species and is highly relevant given current international concerns regarding greenhouse gas emissions, nutrient losses, and water quality (Leip et al., 2015). Therefore, identifying more efficient animals that produce the same quantity of product using fewer resources is highly desirable. Feed efficiency in some species has improved substantially in recent decades although this trend has not been as rapid in other species, especially ruminants. The ratio of energy ingested versus energy output in usable product for dairy cows is much worse than both pigs and poultry (Havenstein et al., 1994; Losinger, 1998). Therefore, improving feed efficiency in ruminants is particularly important. It is also important to unravel the correlation structure of feed efficiency across the productive life of the cow and to understand the repercussions of genetic selection for the feed intake complex on the resulting lactation

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profiles of feed efficiency and related traits (e.g., energy balance; **EB**).

The contribution of breeding to improvements in feed efficiency is well recognized (Cahaner and Siegel, 1986; Havenstein et al., 1994, 2003). In poultry, the kilograms of feed required to produce a kilogram of meat (i.e., feed conversion ratio) was predicted to have decreased by 50% and growth rate increased by over 400%, between the years 1960 and 2005 (Zuidhof et al., 2014). Also, in broilers, Sherwood (1977) and Havenstein et al. (2003) showed that approximately 85 to 90% of the improvements in feed efficiency are due to genetics. Although response to selection for a trait can be predicted using selection index theory (Smith, 1936), accurate predictions require a large population of phenotyped animals to accurately estimate the necessary genetic parameters. Nonetheless, in the absence of precise estimates of genetic parameters, especially the necessary genetic (co)variances, it is possible to elucidate the response to selection through examination of phenotypic performance of animals divergent in genetic merit for the trait of interest (which does not include their own phenotypic information). Such a strategy could be useful in lactating dairy cows where data to estimate precise genetic parameters are limited.

The focus of the present study was, therefore, to accurately quantify the phenotypic inter- and intra-relationships among alternative feed efficiency metrics and other performance traits across parities and lactation stages in lactating dairy cows; the expected effect of genetic selection for efficiency on the resulting phenotypic lactation profiles was also quantified.

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. Cows that participated in the current study originated from several controlled experiments that evaluated alternative grazing strategies, nutritional experiments, or strains of Holstein-Friesian animals; see O'Neill et al. (2013) for a full description of the database. The Holstein-Friesian animals consisted of differing genotypes originating from different populations (Kennedy et al., 2003; Buckley et al., 2007; McCarthy et al., 2007; Coleman et al., 2010). All experiments were performed on 2 adjacent research farms in southern Ireland (latitude 52°9′ N, longitude 8°16′ W). Grass DMI for each cow at pasture was periodically estimated using the n-alkane technique (Mayes et al., 1986). Procedures used to gather and analyze fecal samples are described in Kennedy et al. (2008). All cows were offered a basal diet of grazed grass. Swards consisting primarily of perennial ryegrass (*Lolium perenne*) were managed under a rotational grazing system comparable to that detailed by Dillon et al. (1995). Some animals were supplemented with concentrate feed (depending on feeding protocol), varying from 0.89 to 4.0 kg of DM per cow daily, offered in equal feeds during each milking.

Cows were milked twice daily. Individual cow milk yield was recorded daily, whereas milk fat, protein, and lactose concentration was determined from successive morning and evening milk samples once per week using mid-infrared spectroscopy (FT6000, Foss, Hillerod, Denmark). Net energy requirement for lactation was calculated using the following formula according to Agabriel (2007):

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

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

Individual animal BW was largely measured weekly following morning milking using electronic scales (Tru-Test Limited, Auckland, New Zealand). The scales were calibrated weekly against known loads. Body condition score on a scale of 1 (emaciated) to 5 (obese) was assessed by trained scorers every 2 to 3 weeks in increments of 0.25 (Edmonson et al., 1989). Cubic splines were fitted through individual BW and BCS test-day records as described elsewhere (Hurley et al., 2016).

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 lait (**UFL**) is the net energy requirement for lactation equivalent to 1 kg of standard air-dried barley (Jarrige et al., 1986), equivalent to 7.11 MJ of net energy or 11.85 MJ of ME. The offered herbage UFL concentration was calculated using the ADF and CP concentration, which were quantified in the laboratory (Jarrige, 1989). Concentrate UFL value was determined from the chemical composition of the feed. Where the net energy content of the offered herbage (UFL/kg of DM) was not available (i.e., 10% of test-day records), the year-month average was assumed. Where the net energy content of the offered concentrate (UFL/kg of DM) was not available (i.e., 20% of test-day records), the year-month average was assumed. The sum of pasture and concentrate $\mathrm{NE_I}$ were used to define total net energy intake (**$\mathrm{NE_I}$**).