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The association between genetic merit for live-weight and phenotypic energy intake and efficiency in grazing dairy cows

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Introduction

Existing technologies to measure individual animal feed intake, especially at pasture, are costly, labor-intensive, and unsuitable for routine use at scale (Williams et al., 2021). Cow live-weight, on the other hand, is inexpensive to record resulting in it being widely used in genetic evaluations. In the absence of (genetic evaluations) for feed intake, live-weight is used in many dairy cow breeding objectives to reflect (genetic) differences in feed intake. The economic value associated with differences in feed intake is simply applied to the animal's genetic merit for live-weight. The appropriateness of this strategy has not actually been explored in a large dataset – in other words does phenotypic feed intake increase with genetic merit for live-weight, and is this association linear across the trajectory of genetic merit for live-weight. The objective, therefore, of the present study was to quantify the mean phenotypic energy intake and energy efficiency of grazing Holstein-Friesian cows stratified into deciles on genetic merit for live-weight, testing the hypothesis that feed intake does increase as cows get genetically heavier.

Materials & Methods

Net energy intake data. Records of individual cow daily pasture dry matter intake (DMI) estimates, concentrate DMI, live-weight, body condition score, and milk production, collected between the years 1998 and 2022, inclusive, were available from five Irish research farms. These records were collected as part of experimental studies evaluating different genotypes of Holstein-Friesians and alternative grazing and nutritional strategies. Individual cow grass DMI was estimated using the n-alkane technique and DMI was calculated as the sum of grass DMI and concentrate DMI; each cow received between 0 and 6.2 kg of concentrate DMI per day in the milking parlor. A full description of the n-alkane procedure used to estimate DMI at pasture has been described by Dillon and Stakelum (1989), and details of the animal management, milk yield and composition estimation, body weight and body condition score recording and the quality control edits have been described in detail by Williams et al. (2026). Cow parity was categorized as 1, 2, 3,4, or ≥ 5 and days in milk were categorized into approximately 30-day intervals; DMI records were divided into early (≤90 days), mid (91-180 days), and late lactation (>180 days) datasets. Contemporary group was defined as experimental treatment by year; contemporary group with less than 5 DMI records were discarded. After editing, the early lactation dataset comprised of 3,163 DMI records from 2,201 lactations on 1,220 Holstein-Friesian cows, the mid lactation dataset comprised of 3,703 DMI records from 2,500 lactations on 1,368 Holstein-Friesian cows, and the late lactation dataset comprised of 2,758 DMI records from 2,234 lactations on 1,175 Holstein-Friesian cows.

Daily net energy intake (NEI) was calculated as the sum of grass and concentrate energy intake while accounting for the impact of concentrate intake on the digestibility of the ingested pasture. The energy values of concentrate and pasture were based on the French Net Energy system (Williams et al., 2026). In addition to NEI, an efficiency trait was defined as the residual of NEI after adjusting for energy sinks (NEI_{adj}):

$$NEI_{adj}=NEI-[NEL+BW^{0.75}+BCS+\Delta BW^{+}+\Delta BW^{-}+\Delta BCS^{+}+BCS^{-}] \quad (1)$$

where NEI is net energy intake, NEL is the net energy requirement for lactation, and $BW^{0.75}$ is metabolic live-weight. The energy required for a 1 kg gain in live-weight is higher than the

energy generated from a 1 kg loss in live-weight; therefore, piecewise regression was applied to BCS change (ΔBCS) and live-weight change where ΔBW^{+} describes a cow gaining live-weight and ΔBW^{-} describes a cow losing live-weight. Similarly, ΔBCS^{+} describes a cow gaining BCS and ΔBCS^{-} describes a cow losing BCS. Fat and protein corrected milk (FPCM) yield (kg) was calculated based on it's fat and protein content of 4.0% fat and 3.3% protein

$$\text{FPCM kg} = (0.337*\text{Milk kg})+(11.6*\text{Fat kg})+(5.999*\text{ Prot kg}) \quad (2)$$

where Milk kg, Fat kg, and Protein kg are the average daily milk yield, fat and protein yield measured in the same week as when DMI estimates were available.

Statistical analyses. Paternal average estimated breeding value (EBV) for live-weight, as well as 305-day milk, fat, and protein yield were obtained for all cows from the Irish national genetic evaluation; an EBV for FPCM was also calculated. Within each stage of lactation, cows were stratified into ten strata within their experimental treatment by year contemporary group based on paternal average EBV for live-weight and separately on their EBV for FPCM. Estimated breeding values were standardized prior to analyses. A continuous covariate representing ten equally spaced points spanning −2 to +2 standard deviations was derived for live-weight and FPCM. This approach ensured that the predicted marginal means from the subsequent statistical model was based on equal spacing between strata and enabled the assessment of linear trends in performance across EBV strata. Linear mixed models were used to estimate predicted marginal means for each NEI EBV stratum and separately for each NEI_{adj} EBV stratum in PROC MIXED (SAS 9.4). Days in milk class, parity (1, 2, 3, 4, ≥5), the interaction between parity and days in milk class, EBV strata for either live-weight or FPCM, and the EBV covariate were all included as fixed effects. Experimental treatment by year contemporary group nested within farm and a repeated cow effect were included as random effects. Additionally, a separate series of analyses included the EBV for FPCM as a covariate to determine whether changes in predicted marginal means of NEI across live-weight EBV strata were independent of genetic merit for milk production.

Results

Mean NEI was 17.0 unité fourragère du lait (UFL;SD = 3.7), 17.8 UFL (SD = 3.4), and 16.7 UFL (SD = 3.0) in early, mid, and late lactation, respectively. Across all stages of lactation, NEI increased in an approximately linear manner with increasing genetic merit for live-weight, irrespective of whether or not genetic merit for FPCM was included as a covariate (Figure 1). In early lactation, cows that were genetically the heaviest (i.e., highest live-weight EBV stratum) consumed, on average, 0.9 UFL more NEI per day than the genetically lightest stratum of cows; corresponding differences of 1.0 and 1.1 UFL were observed when cows in genetically divergent strata for live-weight were compared in mid and late lactation, respectively. When cows were ranked on their genetic merit for FPCM, there were no differences in NEI in early lactation; in mid and late lactation, however, cows of higher genetic merit for FPCM consumed more net energy than cows that were genetically inferior for FPCM (Figure 1).

Predicted marginal means of NEI_{adj} by live-weight EBV stratum and FPCM EBV stratum are in Figure 2. In contrast to NEI, NEI_{adj} decreased in a broadly linear pattern with increasing genetic merit for live-weight. On average, the genetically heaviest cows (after accounting for energy sinks) consumed, on average, 0.8, 0.9, and 0.6 UFL less net energy than the genetically lightest cows in early, mid, and late lactation, respectively. When stratified on their EBV for FPCM, there were no differences in NEI_{adj} in either early or late lactation, while cows genetically expected to produce more FPCM consumed more in mid lactation than their contemporaries of lower genetic merit for FPCM (Figure 2).

Discussion

The strong linear increase in NEI with increasing genetic merit for live-weight across the range of genetic merit explored confirms that, on average, genetically heavier cows require more energy intake, consistent with established phenotypic relationships between live-weight and maintenance requirements (O'Mara, 1996) and previous studies linking phenotypic live-weight and feed intake in grazing cows (Walsh et al., 2008; Williams et al., 2021). This confirmation of linearity is critical for justifying live-weight as a proxy trait for feed intake in dairy breeding objectives. Furthermore, the persistence of the relationship between NEI and genetic merit for live-weight after adjusting for FPCM indicates that the increase in NEI reflects an underlying relationship between genetic live-weight and energy requirements rather than differences in milk production.

After adjusting for energy sinks, genetically heavier cows consumed less per day than predicted from their production and maintenance requirements; nevertheless, this does not necessarily indicate that genetically heavier cows are more efficient, as they may still consume more feed in absolute terms to achieve the same level of production. Notably, when the relationship between NEI and genetic merit for live-weight was examined with differences in FPCM accounted for, genetically heavier cows continued to consume more NEI.

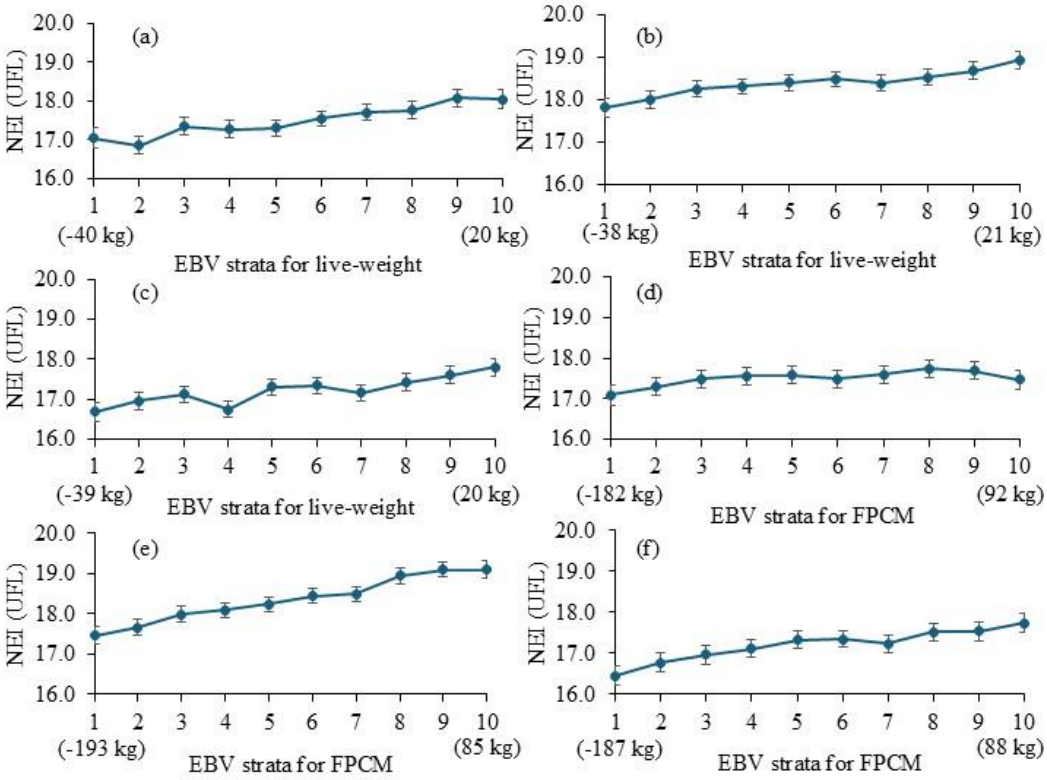

Figure 1. Predicted marginal means for NEI adjusted for EBV for FPCM in (a) early, (b) mid, and (c) late lactation when cows were stratified on EBV for live-weight; predicted marginal means for NEI in (d) early, (e) mid, and (f) late lactation when cows were stratified on EBV for FPCM. The mean EBV of the extreme strata for live-weight and FPCM of are included in brackets.

The absence of any difference in mean NEI in early lactation among cows stratified on genetic merit for FPCM EBV suggests that cows with genetic merit to produce higher volumes of FPCM in early lactation are constrained by grazing intake capacity. Consequently, cows of higher genetic merit for FPCM are likely relying on body reserves to support milk production

in early lactation, consistent with what has been reported previously (Walsh et al., 2008). Nonetheless, no mean difference in BCS change by FPCM strata in early lactation existed in the present study, even though a greater loss of BCS would have been expected in the stratum with the highest genetic merit for FPCM. In mid and late lactation, when constraints on intake capacity relative to production are likely relaxed in grazing production systems, the expected positive association between FPCM EBV and NEI was more evident.

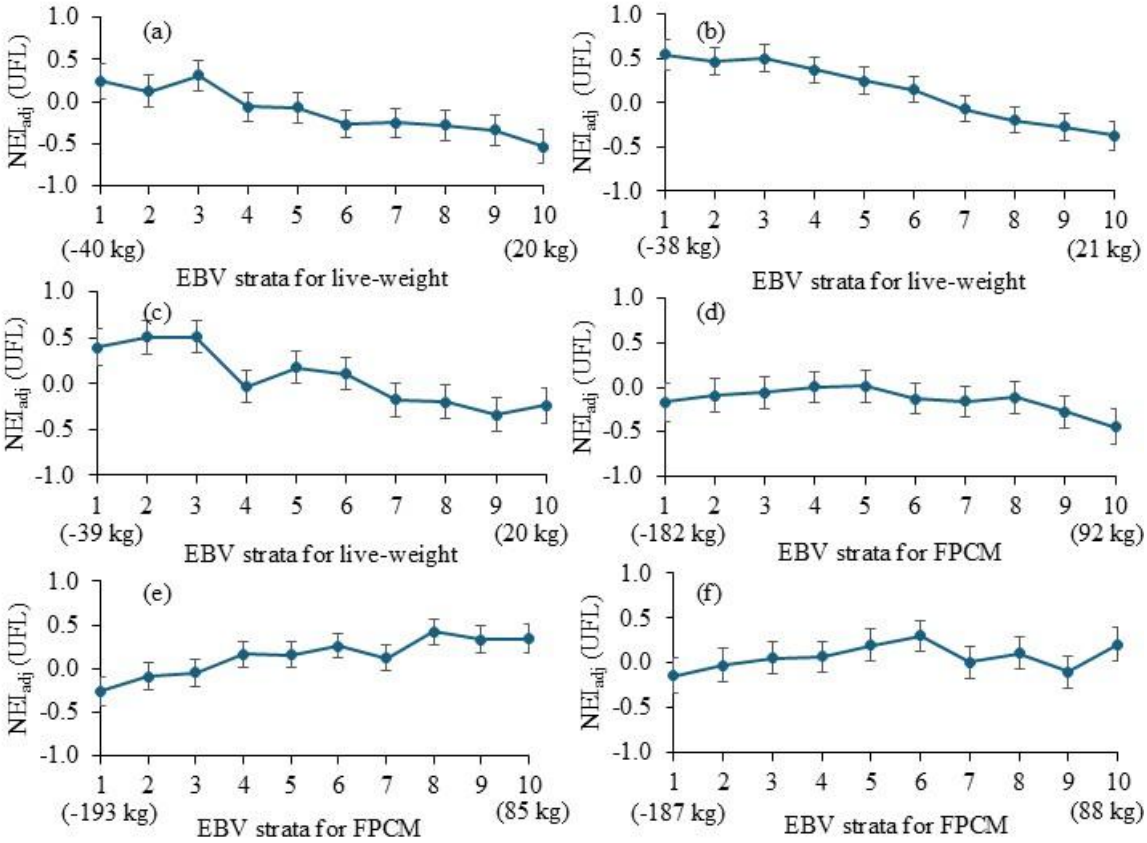

Figure 2. Predicted marginal means for net energy intake adjusted for energy sinks (NEI_{adj}) in (a) early, (b) mid, and (c) late lactation when cows were stratified on their genetic merit (EBV) for live-weight; predicted marginal means for NEI_{adj} in (d) early, (e) mid, and (f) late lactation when cows were stratified on their EBV for energy corrected milk (FPCM). The mean EBV of the extreme strata for live-weight and FPCM of are included in brackets.

Conclusions

Results from this study demonstrate that NEI increased linearly with increasing live-weight EBV across all stages of lactation, supporting the current use of live-weight as a proxy for feed requirements in total merit indexes for grazing Holstein-Friesian dairy cows.

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