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Effects of interaction between genotype and feeding system on milk production, feed intake, efficiency and body tissue mobilization in dairy cows

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Abstract

The objective of this study was to investigate genotype by feeding system interactions in Holstein-Friesian dairy cows. For this purpose, selection (S) and control line (C) cows, housed and managed at the Langhill Dairy Cattle Research Centre, were offered ad lib. complete mixed diets, with proportions (in total DM) of concentrates, silage and brewers grains of either 20:5:75 (LC) or 45:5:50 (HC), over a full lactation. No significant feeding system × genetic line interactions were observed for a number of traits, describing milk production, feed intake, efficiency and body tissue mobilisation, when compared as treatment means (128 heifer lactations and 249 cow lactations). However, regression coefficients of milk yield (P < 0.01) and condition score (P < 0.05) on pedigree index for fat plus protein yield were significantly different between LC and HC. This indicates that G × E might become of importance in the future, with continued selection for fat plus protein yield.

Keywords: Dairy cattle; G × E interaction; Feed intake; Efficiency; Live weight

1. Introduction

There is a wide range in production circumstances both between and within countries. However, one of the major breeding goals of most dairy farmers, whatever the production circumstances, is to increase profitability. The introduction of quotas on milk production in the EC in 1984 has led to interest in reduced cost systems in some countries. For this reason, the large influx of North American Holstein semen to most EC countries, and also because of the introduction of new breeding schemes involving testing bulls in nucleus herds, investigating genotype × environment (G × E) interactions is particularly important at the present time.

Danell (1982) reviewed several studies in which interactions between feeding regime and sire, production level and sire, and housing system and sire were found to be of no importance. More recently, Van der Werf and Ten Napel (1991) found a genetic correlation for milk traits of 0.78 between high and low yielding herds, and the sire by herd interaction accounted for only 3% of the phenotypic variance. Most previous studies have focussed primarily on milk production traits. In some studies G × E interaction for food intake or efficiency of milk production has been considered when animals were fed according to yield (Richardson et al. 1971; Lamb et al., 1977; Wang et al. 1992), however feeding according to yield makes biological
interpretation of the results difficult. Studies where animals were not fed according to production have been performed by Korver (1982) and Oldenbroek (1988), but together these studies present a rather confusing view of the positive existence and magnitude of genotype × feeding interactions in dairy cows.

We have been concerned to establish whether the advantages of high genetic merit for milk solids production in a high input system of feeding (Persaud et al., 1990; Simm et al., 1994) in an earlier study from the Langhill Dairy Cattle Research Centre, are maintained under a regime of lower input feeding. Indications that high genetic merit animals might not be able to maintain their advantage under a low input system (hence, a G × E interaction) come from other studies (e.g. Grieve et al., 1976; Custodio et al., 1983), which have indicated that the increase in gross energetic efficiency of high genetic merit cows is not due to better utilization of feed, but rather to a higher degree of body tissue catabolism and to a simple dilution of maintenance. If there was a limit to the rate of tissue mobilization or the amount of mobilizable tissue, high genetic merit cows might lose their advantage on a low input diet, i.e. there could be a genotype by feeding system interaction for production, or for efficiency or for body composition. Because tissue reserves in dairy cows are substantial (e.g. Gibb et al., 1992; Butler-Hogg et al., 1985) it is possible that the use of these reserves in one lactation might buffer high merit animals against nutritional adversity and so diminish interactions in the short term, with these only becoming evident in the longer term (i.e. in subsequent lactations). For these reasons we have established a long-term study of genotype × feed system interactions. In this experiment which started at Langhill in 1988, cows have been offered ad lib. two complete mixed diets, varying in the proportions of concentrate and grass silage.

The objective of this part of the study is to use preliminary records from the Langhill G × E experiment to estimate the effects of genotype by feeding system interaction, within a single lactation, on performance traits and body composition of heifers and cows.

2. Material and methods

2.1. Animals

Records were obtained from cows housed and managed at the Scottish Agricultural College/University of Edinburgh Langhill Dairy Cattle Research Centre. In each year calving began early in September and animals joining the trial all calved between September and January in any year. All cows involved in the study were Holstein-Friesians, kept indoors in conventional cubicle housing from calving to July and offered complete mixed diets ad lib. Through the use of Calan Broadbent electronic gates the extended indoor period allowed measurement of feed offered to, and refused by, individual cows for four days a week, from calving to a minimum of 26 weeks and up to 38 weeks after calving (depending on the calving date of each cow). The data reported here are for performance over the first 26 weeks of lactation, recorded over four consecutive years from 1988–1991 inclusive. Cows were milked twice daily (0500 and 1500 hours) and 0.4 kg concentrates was fed in the parlour at each milking during the housed period.

2.2. Genetic groups

There were two genetic groups: a selection line (S) and a control line (C). Since 1973 S animals have been bred to bulls with the highest genetic merit for kg fat plus protein (F + P) available in the UK. Since 1976 the C animals have been bred to bulls of about national average genetic merit for F + P. For each line every year 4–5 bulls are selected solely on their predicted transmitting abilities (PTA). The bulls are then each used randomly over the cows and heifers in the relevant line. The only exceptions are that a bull is not mated to a close relative and bulls known to cause a high incidence of calving difficulties are not used on heifers. The S bulls were originally selected on their UK proofs, but during the last 15 years predicted transmitting abilities of foreign bulls have been converted to British proofs. In 1986 animals were re-allocated to S and C to balance these lines for average Holstein percentage. Allocation was based on genetic merit for F + P and Holstein percentage. Since the beginning of this experiment heifers were selected on pedigree index (predicted genetic merit, based on pedigree information).
and allocated to either the high concentrate (HC) or low concentrate (LC) feeding system. Allocation to the diets was random, except that offspring from the same bull were allocated equally to the two diets (similarly in the first year multiparous cows were allocated equally to the two diets). Cows have been maintained on the same diet in subsequent lactations and the objective is to record at least three lactations from each cow on a single diet. The mean PTAs (on the 1990 base) for fat + protein yield were 4.3 kg (s.d. = 7.7) for the C and 18.8 kg (s.d. = 9.9) for the S animals involved in the study reported here.

2.3. Diets

A complete diet based on grass silage, brewers grains and concentrates, was offered ad lib. to all animals. The feeding systems were designed to achieve, over a full lactation, proportions (in total DM) of concentrates, brewers grains and silage of 20 :5 :75 (LC) and 45 :5 :50 (HC). The animals on HC had an annual average concentrate intake of about 2.5 tonnes per cow. The LC animals ate about 1.0 tonnes of concentrate per annum. Animals were grouped according to stage of lactation and diet type. For both feeding systems the proportion of the dry matter from silage in the diet was altered when the group had completed 100 and 200 days of lactation, on average, so that problems of underfeeding in early lactation were minimised but a substantial differential between feeding systems was maintained. Silage dry matter as a proportion of total DM in the diet was designed to average 0.40, 0.50, and 0.60 for HC and 0.65, 0.75 and 0.85 for LC in early, mid and late lactation respectively. Different compound balancer meals were included in HC and LC, with metabolisable energy and crude protein contents in the concentrate dry matter of about 12.9 MJ kg⁻¹ and 209 g kg⁻¹, respectively for HC and 12.4 MJ kg⁻¹ and 310 g kg⁻¹ for LC. This was done so that protein, mineral and micronutrient contents of both feed systems were not limiting performance (AFRC, 1991 and 1992) leaving forage:concentrate ratio as the key feed variable. The chemical composition of the diets used in the four years of study reported here is given in Table 1.

2.4. Milk yield and composition

Milk yields and milk composition analyses were recorded once every week, for a morning and afternoon milking separately.

Fat, protein and lactose percentages were calculated as the average from the morning and afternoon sample, weighted by milk production. Average weekly milk, fat, protein and lactose yields for each cow were calculated as the sum of the morning and afternoon yields, multiplied by 7. The energy (MJ) in the milk was estimated from the morning and afternoon samples, using the formula of Tyrrell and Reid (1965):

\[ LE = (0.384 \times F\% + 0.223 \times P\% + 0.199 \times L\% - 0.108) \times MY \]

Table 1

<table>
<thead>
<tr>
<th>Lactation period (days):</th>
<th>HC Early 0–100</th>
<th>HC Mid 100–200</th>
<th>HC Late 200+</th>
<th>LC Early 0–100</th>
<th>LC Mid 100–200</th>
<th>LC Late 200+</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM (g/kg)</td>
<td>350</td>
<td>327</td>
<td>311</td>
<td>277</td>
<td>265</td>
<td>256</td>
</tr>
<tr>
<td>ME (MJ/kg DM)</td>
<td>11.96</td>
<td>11.82</td>
<td>11.56</td>
<td>11.60</td>
<td>11.45</td>
<td>11.15</td>
</tr>
<tr>
<td>CP (g/kg DM)</td>
<td>180</td>
<td>180</td>
<td>169</td>
<td>193</td>
<td>183</td>
<td>166</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>78</td>
<td>88</td>
<td>90</td>
<td>102</td>
<td>80</td>
<td>97</td>
</tr>
<tr>
<td>ADF</td>
<td>218</td>
<td>240</td>
<td>265</td>
<td>254</td>
<td>276</td>
<td>308</td>
</tr>
<tr>
<td>NDF</td>
<td>370</td>
<td>412</td>
<td>445</td>
<td>405</td>
<td>450</td>
<td>493</td>
</tr>
<tr>
<td>AHEE</td>
<td>61</td>
<td>61</td>
<td>64</td>
<td>52</td>
<td>55</td>
<td>58</td>
</tr>
<tr>
<td>pH</td>
<td>4.3</td>
<td>4.4</td>
<td>4.4</td>
<td>4.3</td>
<td>4.2</td>
<td>4.2</td>
</tr>
</tbody>
</table>

*All values per kg DM values indicated. DM = g dry matter/kg diet; ME = metabolic energy (MJ) (see text for details); CP = crude protein (g); NH₃-N = ammonia N (g) per kg total N; ADF = acid detergent fibre; NDF = neutral detergent fibre; AHEE = acid hydrolysed ether extract.
Table 2
Structure of the data set (data are the number of records for each category)

<table>
<thead>
<tr>
<th>Group</th>
<th>Month of calving</th>
<th>Year of calving</th>
<th>Lactation number</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-LC</td>
<td>Sept</td>
<td>118</td>
<td>1988</td>
</tr>
<tr>
<td>S-LC</td>
<td>Oct</td>
<td>94</td>
<td>1989</td>
</tr>
<tr>
<td>C-HC</td>
<td>Nov</td>
<td>102</td>
<td>1990</td>
</tr>
<tr>
<td>S-HC</td>
<td>Dec</td>
<td>63</td>
<td>1991</td>
</tr>
</tbody>
</table>

Number of cows: 204.
Number of records: 377.
1 record = data for one cow in one lactation.
2 C and S are the control and selection line on the high and low concentrate diets (HC and LC respectively).

Table 3
Estimates for the mean effects of genetic line and feeding system, corrected for fixed effects and the covariance of repeated lactations of the same cow (records are up to 26 weeks of lactation)

<table>
<thead>
<tr>
<th>Cows only, (N=249)</th>
<th>S-HC mean</th>
<th>C-HC mean</th>
<th>S-LC mean</th>
<th>C-LC mean</th>
<th>s.e.d.2</th>
<th>Diet</th>
<th>Line</th>
<th>Line X Diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk (kg)</td>
<td>6123</td>
<td>5425</td>
<td>5031</td>
<td>4533</td>
<td>166</td>
<td>**</td>
<td>**</td>
<td>-</td>
</tr>
<tr>
<td>F%</td>
<td>4.10</td>
<td>4.11</td>
<td>4.50</td>
<td>4.37</td>
<td>0.13</td>
<td>*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P%</td>
<td>3.05</td>
<td>3.12</td>
<td>3.02</td>
<td>3.01</td>
<td>0.05</td>
<td>*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>F+P (kg)</td>
<td>436</td>
<td>391</td>
<td>375</td>
<td>334</td>
<td>12</td>
<td>**</td>
<td>**</td>
<td>-</td>
</tr>
<tr>
<td>DMI (kg)</td>
<td>3648</td>
<td>3474</td>
<td>3232</td>
<td>3099</td>
<td>87</td>
<td>**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ENEF (%)</td>
<td>43.6</td>
<td>40.9</td>
<td>43.9</td>
<td>40.6</td>
<td>1.2</td>
<td>-</td>
<td>*</td>
<td>-</td>
</tr>
<tr>
<td>PROTEF (%)</td>
<td>28.1</td>
<td>26.7</td>
<td>24.7</td>
<td>23.2</td>
<td>0.7</td>
<td>**</td>
<td>*</td>
<td>-</td>
</tr>
<tr>
<td>ALW (kg)</td>
<td>633</td>
<td>614</td>
<td>622</td>
<td>612</td>
<td>11</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ACS</td>
<td>2.43</td>
<td>2.56</td>
<td>2.35</td>
<td>2.52</td>
<td>0.08</td>
<td>-</td>
<td>*</td>
<td>-</td>
</tr>
<tr>
<td>GF (kg)</td>
<td>109</td>
<td>104</td>
<td>100</td>
<td>96</td>
<td>3</td>
<td>**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lipid (kg)</td>
<td>132</td>
<td>136</td>
<td>126</td>
<td>135</td>
<td>7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LFEBBW (kg)</td>
<td>393</td>
<td>374</td>
<td>396</td>
<td>381</td>
<td>6</td>
<td>-</td>
<td>*</td>
<td>-</td>
</tr>
</tbody>
</table>

Heifers only, (N=128)

| Milk (kg)           | 4769      | 3962      | 3924      | 3234      | 147    | **   | **   | -           |
| F%                  | 4.09      | 4.06      | 4.42      | 4.33      | 0.13   | *    | -    | -           |
| P%                  | 3.11      | 3.22      | 3.01      | 3.14      | 0.05   | -    | *    | -           |
| F+P (kg)            | 343       | 286       | 290       | 240       | 10     | **   | **   | -           |
| DMI (kg)            | 3096      | 3044      | 2614      | 2512      | 72     | **   | -    | -           |
| ENEF (%)            | 40.6      | 34.3      | 42.6      | 36.3      | 1.3    | -    | *    | -           |
| PROTEF (%)          | 26.2      | 22.9      | 23.8      | 21.3      | 0.8    | **   | -    | -           |
| ALW (kg)            | 537       | 552       | 535       | 530       | 10     | *    | -    | -           |
| ACS                 | 2.52      | 2.65      | 2.48      | 2.60      | 0.06   | -    | *    | -           |
| GF (kg)             | 93        | 91        | 81        | 78        | 2      | **   | -    | -           |
| Lipid (kg)          | 116       | 127       | 116       | 123       | 5      | -    | -    | -           |
| LFEBBW (kg)         | 329       | 334       | 338       | 330       | 6      | -    | -    | -           |

1 C and S are the control and selection line on the high and low concentrate diets (HC and LC respectively).
2 Standard error of the differences (s.e.d.) is the average of the 6 approximate s.e.d.'s. Approximated significance levels for Line, Diet and Line X Diet effects are specified as: * < 0.05; ** < 0.01.
Fig. 1. Mean gross energetic efficiency during lactation, for selection (S) and control (C) line heifers and cows, on high- and low concentrate diets (HC and LC, respectively).

LB = milk net energy (MJ); F%, P%; L% = fat, protein and lactose percentage and MY = milk yield (kg)

2.5. Feed intake and diet composition

Heifers were trained before calving to use individual electronic feeding gates. The complete diet was dispensed into individual feed bins, once daily. The weights of fresh diet offered and refused were recorded on 4 days consecutively each week. Daily samples from the different diets (early, mid and late lactation; HC and LC) and daily samples from refusals were analysed for dry matter. Each daily intake was calculated as:

\[ DMI = (FF \times DMFF) - (FR \times DMFR) \]

DMI = dry matter intake (kg); FF, FR = Feed offered and feed refused; DMFF, DMFR = Dry matter proportion of feed offered and refused.

Daily samples of each diet were bulked to monthly samples and analysed to determine chemical composition. The estimated metabolisable energy content (ME MJ kg dry matter) was based on the summation of the estimated ME contents of the different dietary components (Thomas et al., 1988). The ME of silage was based on in vitro digestibility, and the ME contents of the balancer meal and brewer grains were estimated with neutral cellulase gamma mannase digestibility (NCGD) incubation techniques.

2.6. Live weight and condition score

Cows were weighed and condition scored within 24 hours post calving and thereafter once a week after...
Fig. 3. Mean condition score during lactation, for selection (S) and control (C) line heifers and cows, on high- and low concentrate diets (HC and LC, respectively).

2.7. Data handling

About 132,500 weekly records were available, on 391 lactations (210 cows). All lactations with fewer than 20 weekly records and all lactations with fewer than 7 weekly records in the first 15 weeks and no record after 23 weeks of lactation were discarded. Range checks were carried out before entering the data, and additionally a simple procedure was used to check for outliers as follows: for each separate lactation a cubic polynomial was fitted through the weekly records for milk yield, fat %, protein %, lactose %, dry matter intake, ME intake, CP intake, live weight and condition score. Outliers were discarded on the basis of the estimated variance, within each separate lactation, about the fitted curve. When the observed value was more than 3.5 standard deviations different from the fitted value the observed value was rejected. In total 161 weekly milk yields were rejected, and from the other recorded traits the number of records discarded varied between 8 and 48. Given the fact that at least twenty weekly records were available in each lactation to estimate the curve and the low number of discarded records, it is not likely that any strong bias was introduced by this method. Missing and discarded records were replaced by fitted values from a second polynomial, fitted without the outliers (fewer than 5% of the weekly records were finally estimated in this way). Records from the first 2 weeks of lactation were ignored throughout, because most missing values for yield and intake were in this period. Also previous studies at Langhill have shown that these are of limited value.

2.8. Dependent variates

The weekly records were combined to form 12 traits of interest during the first 26 weeks of lactation: Milk yield (Milk), fat plus protein yield (F+P) and dry matter intake (DMI), were calculated as the average of the weekly records multiplied by 26. Fat (F%) and protein (P%) percentage, were calculated as the average of the weekly percentage weighted by the weekly milk yields. Gross energetic efficiency (ENEF) was calculated as 100 × LE (MJ)/ME intake (MJ). Gross protein efficiency (PROTEF) was calculated as 100 × protein yield (kg)/CP intake (kg). Average live weights (ALW) and condition scores (ACS), were calculated as the average weekly measurements.

Measured ALW is the aggregate of gut fill (GF), lipid (L) and lipid free empty body weight (LFEBW). ACS is an index of L/(ALW-GF). To evaluate changes in body composition an attempt was made here to estimate the different components contributing to ALW and ACS. The value of GF was estimated as (Emmans, personal communication): GF = DMI (kg/day) × (11 - 7 × D) where D, the digestibility of feed,
Table 4
Estimates for the regression coefficients of a range of traits on pedigree index for kg fat + protein (on the high concentrate diet) and regression coefficients for the interaction between PI × DIET (the difference between the regression coefficient on HC and LC)

<table>
<thead>
<tr>
<th>Trait</th>
<th>PI</th>
<th>PI × Diet LC</th>
<th>Heifers only, 26 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b</td>
<td>se</td>
<td>b</td>
</tr>
<tr>
<td>Milk (kg)</td>
<td>47**</td>
<td>8</td>
<td>-29**</td>
</tr>
<tr>
<td>F%</td>
<td>-0.007</td>
<td>0.006</td>
<td>0.016</td>
</tr>
<tr>
<td>P%</td>
<td>-0.005*</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>F + P (kg)</td>
<td>2.53**</td>
<td>0.64</td>
<td>-1.18</td>
</tr>
<tr>
<td>DMI (kg)</td>
<td>11**</td>
<td>4</td>
<td>-8</td>
</tr>
<tr>
<td>ENEF (%)</td>
<td>0.16**</td>
<td>0.06</td>
<td>-0.03</td>
</tr>
<tr>
<td>PROTEF (%)</td>
<td>0.10*</td>
<td>0.04</td>
<td>-0.06</td>
</tr>
<tr>
<td>ALW (kg)</td>
<td>0.3</td>
<td>0.6</td>
<td>-0.1</td>
</tr>
<tr>
<td>ACS</td>
<td>-0.014**</td>
<td>0.004</td>
<td>0.010*</td>
</tr>
<tr>
<td>Gr (kg)</td>
<td>0.4**</td>
<td>0.1</td>
<td>-0.3</td>
</tr>
<tr>
<td>Lipid (kg)</td>
<td>-0.9*</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>LFEBW (kg)</td>
<td>0.8**</td>
<td>0.3</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

1Standard errors are approximates given by REML function (*P<0.05; **P<0.01; H₀=0).

was estimated as diet ME density (MJ/kg)/15. Based on data from Wright and Russell (1984) lipid (kg) per kg EBW was estimated as: L/EBW = -0.0431 + 0.120 × ACS.

2.9. Analysis

Residual maximum likelihood (REML) (Patterson and Thompson, 1971) was used to estimate fixed effects. The Genstat REML (Genstat 5 Committee, 1989) option was used, with a random cow effect to account for covariance between subsequent lactations of the same cow. This REML routine approximates standard errors (s.e.) and standard errors of the differences (s.e.d.) for the effects in the model included. Two univariate models were used for the heifer and cow data separately:

Model 1:

\[ Y_{ijkm} = U + Y_i + M_j + LN_k + DIET_i + LINE_m + DIET_i × LINE_m + b_1 AC_{ijklm} + b_2 H%_{ijklm} + b_3 PI_{ijklm} + C_{ijklm} + E_{ijklm} \]

Model 2:

\[ Y_{ijkl} = U + Y_i + M_j + LN_k + DIET_i + b_1 AC_{ijkl} + b_2 H%_{ijkl} + b_3 PI_{ijkl} + b_4 (DIET_i × PI_{ijkl}) + C_{ijkl} + E_{ijkl} \]

where

- \( Y_{ijkl} = \) Milk, F%, P%, FP, DMI, ENEF, PROTEF, ALW, ACS, GF, Lipid or LFEBW aggregated over 26 weeks
- \( U = \) overall mean
- \( M_j = \) month of calving (Sept, Oct, Nov, Dec)
- \( LN_k = \) lactation number (2-3, > 3 in cow data set only)
- \( b_1 AC_{ijkl} = \) linear regression on age at calving in days
- \( b_2 H%_{ijkl} = \) linear regression on Holstein percentage
- \( DIET_i = \) diet effect (concentrate nor forage)
- \( LINE_m = \) genetic line effect (Selection or control)
- \( LINE_m × DIET_i = \) interaction between line and diet
- \( b_3 PI_{ijklm} = \) regression on pedigree index
- \( b_4 (DIET_i × PI_{ijklm}) = \) regression on interaction between pedigree index and diet
- \( C_{ijklm} = \) random cow effect (only in cow data set)
- \( E_{ijklm} = \) residual effects
The pedigree index for F+P yield (PI) was calculated as 0.50 \times \text{sires' predicted transmitting ability (PTA)} for F+P plus 0.25 \times \text{maternal grandsires' (MGS) PTA for F+P}. PTAs of sires and MGS came from the August 1992 national animal model BLUP analysis (Wiggans et al., 1988; Animal Data Centre, 1993), but no Langhill records were included in this particular national run. This made the regression coefficients of phenotypic values on PI equivalent to genetic regressions, because there is no environmental covariance between PI and the phenotypic measurement. Model 1 (without the random cow effect) was used to estimate least square means for the weekly performance in the 4 groups.

### 3. Results

The number of cows and records within each of the fixed effect classes for both data sets is given in Table 2. Table 3 shows means corrected for fixed effects and for covariance between lactations of the same cow. Selected animals yielded more milk and fat+protein (kg) than control line animals ($P < 0.01$). There was no line effect on milk composition of older cows, but in heifers milk protein concentration was slightly, but significantly ($P < 0.05$) higher in control than selected animals.

The numerically greater dry matter intake (DMI) in selected animals was not significantly different from

![Fig. 4. Relationship between pedigree index (PI) for F+P and F+P yield during the first 26 weeks of the lactation, on both low and high concentrates diets (no heifers included). Arrows indicate the means for S and C.](image1)

![Fig. 5. Relationship between pedigree index (PI) for F+P and milk yield during the first 26 weeks of the lactation, on both low and high concentrate diets (no heifers included). Arrows indicate the means for S and C.](image2)
the controls; the difference in mean DMI between lines was small compared with the differences in milk production. As a result energetic and protein efficiency were both significantly \((P \lt 0.05)\) greater in selected animals than in controls. The pattern of change in gross efficiency was similar for heifers and cows in the same genetic groups (Fig. 1).

Mean condition score (ACS) was significantly lower \((P \lt 0.05)\) in selected animals. As there were no diet \(\times\) line interactions this difference applied in each of the dietary treatments.

Differences between the diets were observed for DMI and calculated gut fill (GF), which were greater with HC than LC. In heifers only this was associated with a greater average live weight (ALW; \(P \lt 0.05\)). The HC diet supported higher rates of milk, and fat + protein yield \((P \lt 0.01)\), a lower milk fat concentration \((P \lt 0.05)\) and, in cows only, a higher milk protein concentration \((P \lt 0.05)\) than diet LC. Protein efficiency was greater \((P \lt 0.01)\) with HC than LC. There was no significant diet effect on energetic efficiency in the cow data, but significance was approached in the heifer data for energetic efficiency. Control heifers on HC produced a similar yield of F + P to selected animals on LC, but with a lower fat concentration.

Differences in live weight and condition score during lactation are shown in Fig. 2 and 3 for heifers and cows, respectively. Heifers from the C line on HC become heavier during lactation than the other three groups (Fig. 2), probably through a combination of higher GF and, by calculation, more lipid stored. Most of the difference in condition score (Table 3), between control line animals and selection line animals, is created at the end of the lactation (Fig. 3). In early lactation, condition scores on the 2 diets were very similar within genetic line. However selection line cows on LC were clearly leanest by week 26 (Fig. 3).

Regressions on PI showed correlated responses for most traits (Table 4). Milk, F + P, ENEF, PROTEF all showed positive regressions on PI. The regression of milk production on PI was significantly different between LC and HC. Figs. 4 and 5 show these relationships graphically. For each PI point cows produced 18 kg and 47 kg more milk on LC and HC, respectively and 1.35 kg and 2.53 kg more F + P.

The interaction between PI and Diet LC was significant for milk yield (but not F + P) which suggests a genotype \(\times\) feed system interaction. High PI cows appear to be leaner than low PI cows, but this was primarily observed on the high concentrate diet (Table 4).

4. Discussion

The aim of the long-term study at Langhill is to explore whether or not genotype \(\times\) feeding system interactions exist and, if so, whether these are large enough to give rise to different selection decisions in different feeding systems which might be employed in the UK or elsewhere. From the treatment means for single lactation records which are reported here, there were no genotype \(\times\) feeding system interactions detected (Table 3). However regression of performance measures on PI and the PI \(\times\) Diet LC interaction indicated that interactions of potential importance may exist. The results are discussed against this background.

4.1. Milk yield

The decreasing effect of extra concentrate on fat % has been found by several other authors (for a review see Sutton, 1989). The magnitude of the effect of feed system on fat % was relatively large given that the HC feed contained, on average, only 45% concentrate, and the LC feed 20% concentrate in diets based on grass silage. A wide range of concentrate allowances (with grass silage available ad lib.) spanning this range of concentrate: forage ratio produced responses in milk fat % in Gordon's (1984) work. Also, concentrate manipulation (in kind or amount) when concentrates form less than 0.6 of feed DM has generally promoted only small changes in milk fat content (Sutton, 1989). It has been held that dietary effects on milk fat concentration are less extreme with diets containing a large proportion of grass silage (than, for example, with diets based on hay or maize silage) because the characteristics of the silage have such a major influence on patterns of rumen fermentation (Chalmers et al., 1978). Our data, collected over four years, show that diet effects on milk fat % can be substantial with complete mixed diets based on grass silage, and that the effects are in the direction expected from wider studies on forage:concentrate ratio and milk composition. In this study estimates for the diet effect on P% were just significant (Table 3) in the cows. Weekly records
showed a clear decline in P% at peak lactation on LC for both S and C (results not shown), but there was no difference between LC and HC for P% during mid and late lactation.

Regression coefficients for complete lactation F + P yield on PI are expected to be 2 for both cows and heifers because PI were estimated transmitting abilities. Higher regression coefficients were observed on HC and lower regression coefficients were observed on LC for the 26 week period included in this study. This might suggest that individuals of very high merit for milk solids production may have the expression of their potential compromised by inadequate nutrition, but the magnitude of this “trend” was not sufficient to indicate a statistically significant interaction. In contrast to the regression coefficients for F + P, regressions of milk on PI were significantly different between the diets. A log transformation and models with different combinations of diet, line and PI did not change this significant interaction between diet and genetic merit for milk yield (results not shown), and there is a suggestion of G × E interaction in this data set for milk. Lamb et al. (1977) found no genotype by diet interaction between daughters of USA Holstein Friesian bulls, but also concluded that regressions on index seem to have a stronger slope on high input diets. These differences between regression lines on high and low input diets suggest that continued selection for F + P in S is likely to make detection of any diet × line interaction easier. There is obviously something of a conflict here between the interpretation of the comparison between group means – which show no genotype × environment interactions – and the indications from the regression analysis (Fig. 5) that an interaction exists, at least for milk. By way of explanation the group mean values for F + P (kg) are shown on Fig. 5 from which it is readily seen that these are fairly close together in comparison with the full spread of the data and it is probably for this reason that the group mean contrasts failed to identify a significant interaction while the regression analysis did. A biological interpretation of this putative interaction should await a more definitive demonstration of its existence. The purpose of this report is to provide a first intimation that such an interaction may exist.

At the phenotypic level there has been interest for a long time in the response of cows at different yield levels to differential feeding strategies. In this study we are using forage: concentrate ratio in complete mixed diets to achieve different levels of nutrient and energy provision: in other studies variable concentrate allocations with forage rationed or available ad lib. have been used (Broster and Thomas, 1981). Neither Gordon (1984) nor Ostergaard (1979) were able to show any increase in the milk yield response to additional concentrates on milk yield per animal increased. The data presented here are consistent with this view in that the difference in F + P yield between HC and LC was around 60 kg for cows and 50 kg for heifers within each line when group means are used for the comparison. The interaction indicated in the regression analysis would suggest that a difference in response will become apparent as the PI difference (and hence difference in performance) becomes greater. Broster and Thomas’s (1981) analysis of the situation in which yield responses to differential feeding are a function of yield level when feed is rationed, but independent of yield level when feed (usually forage) is available ad lib. might therefore be challenged. In light of Gordon’s (1984) comment that “It is...important to clarify if the lack of a relationship (between response to concentrate allowance and cow yield level) would occur at a wider range of milk yields (than those used in his trial)” our work is perhaps giving the first indications of a differential response according to genotype.

4.2. Intake and efficiencies

Both heifers and cows were able to eat more of the drier and less bulky HC diet than they did of LC. That there was a small (though non-significant) difference in DMI between lines (with selected animals eating more) poses the interesting question of why the control animals on LC failed to eat more than they did; selected animals on that diet ate a little more than the controls on LC – but not as much as controls on HC. Whatever the factor that limited intake of the LC diet to less than that for HC, the intake difference between lines, though not statistically significant, might suggest that dietary factors alone could not account for the consumption of that feed.

Although the diets used had been designed to exclude dietary protein concentration (or metabolisable protein yield, AFRC, 1992) as a constraint on performance, gross protein efficiencies are reported here – not least because of the rapidly increasing interest in management factors which can reduce dietary N wast-
age in intensive production systems (Tamminga, 1992). Higher gross protein efficiencies were observed on HC, which was a consequence of higher milk P% and a lower protein/energy ratio in the diet. In neither case, however, was the protein efficiency of a magnitude which would suggest that dietary protein was limiting performance. In energetic terms S were more efficient than C on both diets. Although there was a large difference between LC and HC in condition score at the end of the lactation (Fig. 3), this does not seem to have affected energetic efficiencies in the same period (Fig. 1). Similarly, the cows on HC produced much more milk than those on LC and therefore diluted their maintenance costs over more output. Nevertheless, energetic efficiency was not different between the diets (over 26 weeks), and the major component affecting gross efficiency in this study seems to have been genetic line. Even after correcting gross energetic efficiencies for maintenance, lactation and live weight change there was still a 3.5% advantage for the selection line (Veerkamp et al., 1993). This suggests that there may be differences in energetic efficiency of performance between the two lines which are not simply a reflection of different combinations of maintenance and "performance" elements.

4.3. Live weights and body tissue

No significant diet effects were apparent for ACS or lipid, and from early to mid lactation, heifers and cows in the same genetic line had surprisingly similar condition scores (Fig. 3), with S being slightly leaner than C. This suggests that cows "seek" to reach a certain condition score in mid lactation, which is affected by genotype. It also supports the view presented by Emmans and Neilson (1984) that animals reduce their feed intake (or increase production) when more lipid is available for mobilization, rather than the view that animals mobilise lipid because they produce more milk than they can support from intake alone. Regression of the interaction between PI and diet on ACS and LIPID indicate that for every kg reduction in PI for F + P, 0.9 kg LIPID is deposited during the first 26 weeks of lactation. Lamb et al. (1977) also concluded that daughters of high genetic merit bulls used less of their feed intake for increase of body tissue, although in their experiment cows were fed according to yield. Korver et al. (1985) found a clear influence of diet on "stage of lactation at minimum live weight" and "maximum live weight decrease".

4.4. Conclusions

The objective of this study was to evaluate effects of genotype by feeding regime interaction within a single lactation, on performance and body tissue mobilization. The results clearly showed that selection line animals were leaner after 26 weeks of lactation, but the interaction between diet and PI for ACS suggest that this is not due to extra body tissue mobilisation of selected animals, but rather to a relatively higher feed consumption of the control line animals at the end of the lactation. The line x diet interaction was not significant which would suggest that G x E is not expected to have a large impact for dairy herds in the UK, within the range of diets and PI examined here. However regressions of performance on PI did show an interaction which, though small, may have more substantial implications for the very highest PI animals if feeding is not adequate.

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References


Résumé


L’objectif de cette étude a été de rechercher les interactions génotypégénoclimatique alimentaire chez les vaches Holstein. Dans ce but, des vaches de la lignée sélectionnée (S) et de la lignée de contrôle (C) au centre de recherche de Longhill ont reçu des aliments complets mixtes, offerts ad lib. sur toute la lactation. Les proportions de la matière sèche totale expliquées pour les concentrés, l’ensilage et les drêches de brasserie ont été respectivement 20/5/75 pour le régime bas (LC) et 45/5/50 pour le régime haut (HC). Aucune interaction lignée × régime n’a été trouvée pour un certain nombre de caractères décrivant la production laitière, la consommation alimentaire, l’efficacité alimentaire et la mobilisation corporelle. (128 lactations de génisse et 249 lactations d’adultes). Cependant, les coefficients de régression de la production laitière et de la noté d'état sur l'index laitier (production de matière grasse et de matière protéique) ont été significativement différents (P < 0.01 et 0.05 respectivement entre régimes. Ceci indique que l’interaction génotype × milieu pourrait devenir importante dans le futur, avec la sélection continue sur la production de matière grasse et protéique.

Kurzfassung


Das Ziel der Arbeit bestand in der Untersuchung von Interaktionen zwischen Genotyp und Fütterungssystem bei schwarzbunten Milchkühen. Zu diesem Zweck wurde eine Selektions- und eine Kontrolllinie im Longhill Dairy- Cattle Research Centre während einer Laktation mit zwei kompletten Milcherationen ad libitum gefüttert, die aus Konzentrat, Silage, und Braugerste zu folgenden Anteilen (in %) bestanden: 20:5:75 (LC) bzw. 45:5:50 (HC). Es wurden keine signifikanten Interaktionen vom genannten Typ für die Merkmale Milchmenge, Futteraufnahme, Effizienz und Mobilisation von Energie aus Körpergewebe an Hand der untersuchten 128 Erstlingslaktationen und 249 Laktationen von Kühen gefunden. Jedoch war der Regressionskoeffizient der Milchleistung (P < 0.01) und der Körperform (P < 0.05) anhand eines Pedigreexindexes (Fett- und Eiweißmenge) bei LC und HC signifikant unterschiedlich. Es deutet darauf hin, daß Interaktionen bei kontinuierlicher Selektion nach Milchfett- und Milcheiweißmenge in Zukunft Bedeutung gewinnen könnten.