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The influence of cow genetic merit for milk production on response to level of concentrate supplementation in a grass-based system

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Abstract

The objective of this study was to investigate if there is a genotype × feeding system interaction for milk production in Holstein-Friesian dairy cows. For this purpose, 48 high genetic merit (HM) and 48 medium genetic merit (MM) dairy cows, were used in a two (genotypes) × three (levels of concentrate feeding) randomized-block design experiment in three consecutive years. In year 1, all animals were in their first lactation, while in year 2 and year 3, 18 and 12 first lactation cows replaced animals culled at the end of the previous lactation. A total of 66 cows remained in the study in the same feeding system for the 3-year duration of the study. Concentrate feeding levels were 376, 810 and 1540 kg per cow per lactation; these were identified as the LC, MC and HC feeding systems respectively. There was a separate farmlet for each feeding system; farmlets were managed so that pre-grazing and post-grazing herbage height were similar for all three feeding systems. When compared on treatment means there was a significant genotype × feeding system interaction for fat yield, while for mean solid-corrected milk yield the interaction was close to statistical significance (P = 0·07)*. However, regression coefficients of both milk and protein yield on pedigree index for milk and protein yield were significantly different between the LC and the HC. The interaction between feeding system and the regression of both on pre-experimental milk and protein yield were close to statistical significance* (P = 0·08 *and* P = 0·09 *respectively). Outputs of milk, fat, protein and lactose were greater for the HM than the MM cows. Feeding system had a significant effect on milk, fat, protein and lactose yields. There was a significant genotype × feeding system interaction for body condition score (BCS) at the end of lactation; the MM cows had a higher rate of body tissue repletion than the HM cows especially in the HC system. The results suggest that there is a genotype × concentrate feeding level interaction and that feeding systems developed in the past for animals of lower genetic merit may require adaptation if they are to be optimal for higher genetic merit animals.*

Keywords: *concentrates, dairy cows, genotype nutrition interaction, grazing, milk production.*

Introduction

The rate of genetic improvement for milk production in dairy herds in Ireland up to the mid 1980s was low (approximately 0·5% per year) compared with North America where it increased by 1·5% per year (Funk, 1993). Since then changes in legislation have allowed greater access across the world to genetic material, and, in the past 10 years, this has resulted in rapid genetic improvement in UK and Irish dairy herds (Lindberg *et al.*, 1998). This has been achieved mainly through the importation of North American Holstein genetic material. Milk production in Ireland is characterized by having relatively low milk yield per cow and low cost of production (Anonymous, 1993). This is due to a combination of relatively lower genetic merit for milk production (Weigel *et al.*, 2000) and the Irish seasonal calving pasture-based system of milk production (Dillon *et al.*, 1995).

As cows of higher milk yield potential and hence higher nutrient requirement become more numerous, feeding systems developed in the past for animals of lower genetic merit may require adaptation if they are to be optimal for these higher merit animals. This would be especially true if a genotype × nutrition interaction were found. A number of studies have investigated the occurrence of genotype × nutrition interaction in feeding systems based on ensiled forages and relatively large amounts of concentrates (Veerkamp *et al.*, 1994; Gordon *et al.*, 1995; Ferris *et al.*, 1999). These studies have discovered little evidence for a genotype × nutrition interaction, however Veerkamp *et al.*, (1994) indicated that it may become important in the future with continued selection for fat plus protein yield. Little information is available on genotype × level of concentrate feeding in seasonal calving pasture-based systems of milk production. Therefore the present study differed from previous studies where animal production responses were predominantly obtained in high concentrate indoor feeding systems. The milk production responses to concentrate supplementation at pasture have been extensively defined for animals of low to medium genetic merit (Leaver *et al.*, 1968; Stakelum *et al.*, 1988); the issue of whether or not high genetic merit cows respond in a similar manner needs to be addressed. A number of more recent studies have shown higher responses with higher yielding cows (Hoden *et al.*, 1991; Dillon *et al.*, 1997; Delaby *et al.*, 2001). For these reasons, a 3-year (1998 – 2000) experiment was carried out at Teagasc Moorepark, Ireland. The present experiment was designed to examine whether the production responses to supplementary concentrate, given in an adequate grass supply situation, are influenced by the genetic merit of the dairy cow.

Material and methods

Two genetic groups containing 48 cows each were used in the study in 1998 (year 1). The genotypes were selected from two groups of 60 animals each. In year 1, all were first lactation. First lactation animals of similar genetic merit replaced animals culled at the end of lactation in 1998 (18) and 1999 (12). The resulting data set contained 96 first lactation animals in year 1, 78 second lactation and 18 first lactation animals in 1999 (year 2) and 72 third lactation, 12 second lactation and 12 first lactation animals in 2000 (year 3). Sixty-six animals had records for all three lactations on the same feeding system. The average age at first calving for all cows in the study was 758 (s.d. 55) days.

The high genetic merit (HM) cows were selected based on their superior pedigree index (PI) for milk production, while the medium genetic merit (MM) cows were selected on their least superior pedigree index for milk production. Mean pedigree index (PI) within each group were + 276 (s.d. 100) kg milk, + 8·9 (s.d. 4·75) kg fat, + 9·7 (s.d. 3·19) kg protein, –0·03 (s.d. 0·086) g fat per kg and + 0·01 (s.d. 0·035) g protein per kg for the HM group; the corresponding values for the MM group were + 81 (s.d. 95) kg milk, + 3·8 (s.d. 4·95) kg fat, + 4·3 (s.d. 2·59) kg protein, + 0·013 (s.d. 0·099) g fat per kg and + 0·031 (s.d. 0·036) g protein per kg. The PI for each cow was calculated as 0·50 × sire predicted difference (PD) + 0·25 × maternal grandsire PD. The PD of the sires and maternal grandsires were those from the August 2001 international evaluations of the Animal Centre, Uppsala, Sweden using the technique known as MACE (multiple-trait across-country evaluation). In 2001, the sires of the cows in both the HM and MM groups had at least 75 daughters in at least 70 Irish herds contributing to these evaluations with a sire reliability of greater than 90%. The average proportion of Holstein-Friesian genes in the HM and MM cows were 75% and 65% respectively.

All animals were on a similar feeding system from calving (mid January) until mid April in year 1 of the study. This consisted of grass silage *ad libitum* while indoors, grass by day from early February onwards and day and night from mid March onwards. The level of concentrate feeding was 6 kg per cow per day in two equal meals. In mid April, cows were grouped into blocks of three within each genetic group on the basis of calving date and milk yield and randomly assigned to one of three levels of concentrate feeding. Mean pre-experimental (MP) values within each group for milk and protein yield were 28·5 (s.d. 2·17) kg and 0·9 (s.d. 0·07) kg for the HM and were 23·8 (s.d. 3·10) kg, and 0·8 (s.d. 0·07) kg

Table 1 *Concentrate feeding strategy (kg per cow per day)*

Feeding system†	Calving to turn-out‡	Early March to late April‡	1st May to late June§	1st July to early Oct.	Early Oct. to end of lactation
LC	5	3 – 4	0	0	0
MC	7·5	4 – 5	3	0	2
HC	10	6 – 7	6	4	4

† LC = low concentrate feeding level; MC = medium concentrate feeding level; HC = high concentrate feeding level.
‡ Strategy is for year 2 and year 3 only (year 1, all on 6 kg per cow per day for this period).
§ 0·4 kg per cow per day of a high calcined magnesite supplement was given to LC group.

for the MM group. MP is the average milk production for weeks 5, 6, 7 and 8 of lactation for each cow in year 1.

Over the total lactation in years 1, 2 and 3 respectively, 436, 348 and 345 kg concentrate per cow per year were offered in the low concentrate feeding system (LC); 806, 781 and 844 kg were offered in the medium concentrate feeding system (MC); and 1422, 1558 and 1641 kg were offered in the high concentrate feeding system (HC). The MC feeding system is the industry norm for seasonal spring-calving herds in Ireland (Buckley *et al.*, 2000b). With such a feeding system, no concentrate supplementation occurs in July, August, and September, because grass supply is normally adequate and cows are 3 a later stage in lactation. Supplementation is reintroduced in October, because of decreasing grass supply and reduction in forage intake, the lower DM content, increasing proportion of wastage, fouling, and reduced grazing time. The concentrate feeding strategy is outlined in Table 1.

The ingredient composition of the concentrate food on a kg/t as fed basis was as follows : barley 250, maize gluten 250, beet pulp 250, soya-bean meal 100, rapeseed meal 100, tallow 10, and minerals plus vitamins 40.

Grass-based feeding system

A permanent grassland site was used consisting of a sward with almost 100% perennial ryegrass (*Lolium perenne*). Each feeding system had its own farmlet consisting of 18 paddocks of (on average) 0·59 ha. The grazing season extended from late February until late November each year. Cows were housed full time in December, January and in the first half of February. The breeding season each year was confined to 13 weeks. It started in late April and ended in late July. Therefore, most of the cows calved from February to April.

During the winter indoor period before calving, the cows were offered grass silage *ad libitum*. Post calving and prior to turn-out to pasture (late February) all cows were offered grass silage *ad libitum* and the level of concentrate as specified by the feeding system. Post turn-out, animals were grazed on a rotational management system (Dillon *et al.*, 1995). Pre-grazing herbage yields (> 4 cm) were maintained at between 1800 and 2100 kg of DM per ha. A flexible approach to pasture allocation was adopted; this aimed to provide a post grazing herbage height of 6 to 8 cm for all three feeding systems. Pasture allowances (> 4 cm) on average were 23·6 (s.d. 1·81), 22·3 (s.d. 2·30), and 20·0 (s.d. 2·32) kg DM per cow per day for the LC, MC, and HC feeding systems, respectively, when cows were allocated 0, 3, and 6 kg concentrate per cow per day during early lactation respectively. The corresponding pasture allowances were 24·9 (s.d. 1·21), 24·6 (s.d. 2·42), and 23·6 (s.d. 1·49) kg DM per cow per day for the LC, MC, and HC feeding systems respectively, when cows were allocated 0, 0 and 4 kg concentrate per cow per day in late lactation. This was facilitated by weekly monitoring of farmlet grass cover (O'Donovan, 2000).

All concentrate was offered in individual stalls in the milking parlour in two equal meals each day, except prior to turn-out to pasture when concentrate was offered in three equal meals with the HC feeding system. Cows were milked twice daily at 07:00 and 16:00 h over the 3 years of the study. First lactation cows were given a 10-week dry period while 8 weeks was considered adequate in subsequent lactations.

Animal measurements

Throughout the 3 years, individual milk yields were recorded on five consecutive days per week (Monday to Friday). Milk fat, protein and lactose concentrations were determined in successive morning and evening samples of milk once each week using a Fos-let instrument (AS/N Foss Electric; Hillerod, Denmark). Live weights were recorded weekly and body condition scores (BCS; Lowman *et al.*, 1976) were determined once every 3 to 4 weeks where 0 is severe emaciation and 5 is obese.

Food measurements

Pre-grazing herbage yield (above 4 cm horizon) was determined on each grazing paddock based on four strips (0·95 m wide; 4·5 to 5·5 m long) of grass cut with an Agria mower. The grass from each strip was weighed, and sampled and a sub-sample was dried overnight at 90ºC for DM determination. The remaining herbage from the four samples from each paddock were bulked and a sub-sample taken. This sample (*ca.* 100 g) was freeze-dried and used for chemical analysis.

A total of 30 pre- and post-grazing sward surface heights were recorded in each paddock immediately prior to grazing and immediately post grazing (Hutchings, 1991).

Chemical analysis

The composite herbage samples for each week were analysed for modified acid-detergent fibre (MADF) (Clancy and Wilson, 1966), organic matter digestibility (OMD) (Morgan *et al.*, 1989) and Kjeldahl nitrogen. Similarly in periods of silage supplementation, a composite grass silage sample for each week was analysed for residual moisture, dry matter digestibility (DMD) (Tilley and Terry, 1963), Kjeldahl nitrogen, MADF, neutral-detergent fibre (NDF) (Van Soest *et al.*, 1966). Concentrates were sampled weekly, bulked over each month, and analysed for DM, total nitrogen, crude fibre, NDF, neutral cellulase gammanase digestibility (NCGD) (Agricultural and Food Research Council, 1993), oil and ash.

Statistical analysis

Two approaches were used in the analysis of the data, namely : (1) it was firstly analysed as a factorial experiment to test the differences between the treatment groups and, (2) it was analysed by covariance analysis to test for interactions between the feeding systems and the regression of phenotypic performance on pedigree index for the appropriate traits. Regression of experimental performance on pre-experimental performance (MP) was also carried out. PI was used as a measure of genetic potential, while MP was a measure of milk production incorporating both genetic factors and pre-experimental environmental factors. The regression analysis has the advantage of making use of the full range of the individual animal MP data and the most up to date pedigree index information available at the time of the analysis.

In the first method, the animal production data for the 3 years (3 × 96 cows) were analysed as a 2 × 3 factorial experiment arranged in a split plot design using statistical procedures of SAS (Statistics Analysis Systems Institute, 1991). The model used was as follows:

$$Y_{ijkl} = G_i + L_j + (G \times L)_{ij} + B_k \ (G_i \times L_j) + F_l + (G \times F)_{il} + (L \times F)_{ji} + (G \times L \times F)_{ijk} + e_{ijkl}$$

where : G_i = genetic group (i = 1, 2), L_j = lactation number (j = 1, 2, 3), $B_k(G_i \times L_j)$ = effect of block k within genetic group i by lactation number j interaction (k = 1, 2, 3…. 16), F_l = concentrate feeding level (l = 1, 2, 3), e_{ijkl} = residual error term.

The genotype, lactation number, and genotype × lactation number were tested for significance using the block (genotype × lactation number) mean square as the error term; while food, genotype × food, lactation number × food and genotype × lactation number × food were tested using the residual as the error term.

In the second method the various milk production traits were analysed by covariance analysis using a linear model, with either pedigree index or pre-experimental performance of the individual animals obtained during the pre-experimental period in spring 1998 (MP) as a covariate. This was possible as the dataset contained animals that started and remained in the same feeding system for the 3 years. The two groups of cows MM and HM were managed together within each feeding system. The MP covariable was obtained when the cows were all on the same concentrate feeding level in 1998. PI was used as a covariate rather than the animal's own breeding value, because there is no environmental covariance between PI and the phenotypic measurement, i.e. equivalent to a genetic analysis. In this case, the block effect was not necessary to

Table 2 *Chemical composition of grass, grass silage and concentrate offered in years 1, 2 and 3* (*s. d.*)

	Year 1			Year 2			Year 3		
	Grass	Concentrate	Grass silage	Grass	Concentrate	Grass silage	Grass	Concentrate	Grass silage
Dry matter (g/kg)	-	910 (0·4)	899 (8·1)	-	920 (4·5)	889 (29·7)	-	918 (6·8)	878 (17·5)
Composition of dry matter (g/kg)									
DMD†	-	-	724 (37·0)	-	-	746 (20·0)	-	-	771 (42·0)
OMD†	801 (14·5)	-	-	817 (18·7)	-	-	838 (27·4)	-	-
Crude protein	188 (10·2)	208 (6·9)	163 (13·8)	197 (13·5)	209 (17·7)	166 (16·4)	178 (12·2)	202 (27·3)	163 (16·9)
Crude fibre	-	94·7 (10·70)	-	-	88·8 (22·90)	-	-	86·4 (21·42)	-
MADF†	243 (15·0)	-	372 (31·7)	260 (11·0)	-	347 (35·7)	257 (17·8)	-	-
NDF	-	286 (7·7)	564 (41·3)	-	289 (46·4)	526 (55·5)	-	285 (14·5)	534 (115·3)
Oil	-	21·5 (0·50)	-	-	39·9 (11·50)	-	-	-	-
NCGD†	-	836 (10·0)	-	-	837 (22·0)	-	-	-	-
Ash	-	93·8 (3·50)	79·0 (29·50)	-	90·2 (29·20)	77·8 (11·81)	-	99·1 (5·43)	91·6 (27·73)

† DMD = dry-matter digestibility, OMD = organic-matter digestibility, MADF = modified acid-detergent fibre, NDF = neutral-detergent fibre and NCGD = neutral cellulose gammanase digestibility.

Table 3 *The effect of feeding system on pre- and post-grazing sward surface height (cm) and pre-grazing herbage yield (kg dry matter per ha) in years 1, 2 and 3*

	Pre-grazing height			Post-grazing height			Pre-grazing herbage yield		
Year	1	2	3	1	2	3	1	2	3
LC†	-	23·1	21·2	6·9	7·1	7·1	2227	2165	2015
MC	-	23·5	21·7	6·9	7·2	6·9	2327	2086	2043
HC	-	23·4	21·7	6·9	7·1	7·1	2248	1996	2100
s.e.	-	0·32	0·40	0·09	0·10	0·18	48·2	56·8	70·1

† LC = low concentrate feeding level; MC = medium concentrate feeding level; HC = high concentrate feeding level.

explain the cow variation between the groups. The model used was as follows:

$Y_{ij} = C_i + bX_{ij} + C_i \times bX_{ij} + e_{ij}$

where : Y_{ij} = observation for milk/protein at concentrate feeding level i on animal j, C_i = concentrate feeding level (i = 1, 2, 3), X_{ij} = value of the covariable (PI or MP) for each concentrate feeding level i for cow j, $C_i \times bX_{ij}$ = slope interaction term between concentrate feeding level i and covariable (PI or MP), e_{ij} = residual error term.

The 96 first lactation cows were used in year 1, 77 second lactation cows in year 2, and 66 third lactation cows in year 3 (one cow in year 2 and six cows in year 3 were not used in the analysis because of changing feeding system from the previous year). The 66 cows, which remained on the study in the same feeding system, were used for the analysis over the 3 years.

The statistical analysis of the live weights and BCS records was performed similarly to the estimation of the differences between the treatment groups for milk production. A smoothing spline was fitted in Genstat 5 (Lawes Agricultural Trust, 1997), to facilitate the estimation of missing BCS records prior to analysis.

Results

Table 2 shows the results of the chemical analyses of the herbage, grass silage and concentrate offered in each of the three years. Data in Table 3 shows that the herbage allocated in each of the three feeding systems had similar pre-grazing yields and pre-grazing heights and that the cows in each of the feeding systems grazed to a similar intensity.

Milk production

Factorial analysis. There was a significant effect of genotype, feeding system, genotype × feeding system interaction and feeding system × lactation number interaction for some or all of the milk production parameters measured. Table 4 shows the effect on milk production and composition over the three years, of genotype, feeding system and genotype × feeding system interaction. The HM cows produced significantly ($P < 0·001$) higher yields of milk (+ 1100 kg/year), solids corrected milk

Table 4 *The effect of genotype and feeding system over the 3 years (3 × 96 cows) on milk production*

Genotype†	MM			HM				Significance§		
Feeding system‡	LC	MC	HC	LC	MC	HC	s.e.	F	G	G × F
Milk (kg per cow per year)	6421	6681	7196	7389	7739	8461	86·4	***	***	
SCM# (kg per cow per year)	5938	6380	6674	6683	7013	7666	80·1	***	***	¶
Fat (kg per cow per year)	247	269	272	274	288	313	4·0	***	***	*
Protein (kg per cow per year)	217	232	250	247	261	288	3·0	***	***	
Lactose (kg per cow per year)	299	312	339	343	357	391	4·1	***	***	
Fat (g/kg)	38·6	40·6	38·0	37·2	37·3	37·2	0·50	***	***	*
Protein (g/kg)	34·0	34·8	34·9	33·5	33·8	34·1	0·24	***	**	
Lactose (g/kg)	46·6	46·8	47·2	46·4	46·1	46·2	0·17	***		¶

† MM = medium genetic merit, HM = high genetic merit.
‡ LC = low concentrate feeding level, MC = medium concentrate feeding level, HC = high concentrate feeding level.
§ F = effect of concentrate feeding level; G = effect of genotype. G × F = effect of interaction between genotype and concentrate feeding level.
¶ Approaching significance ($P < 0·10$).
# SCM = solids-corrected milk.

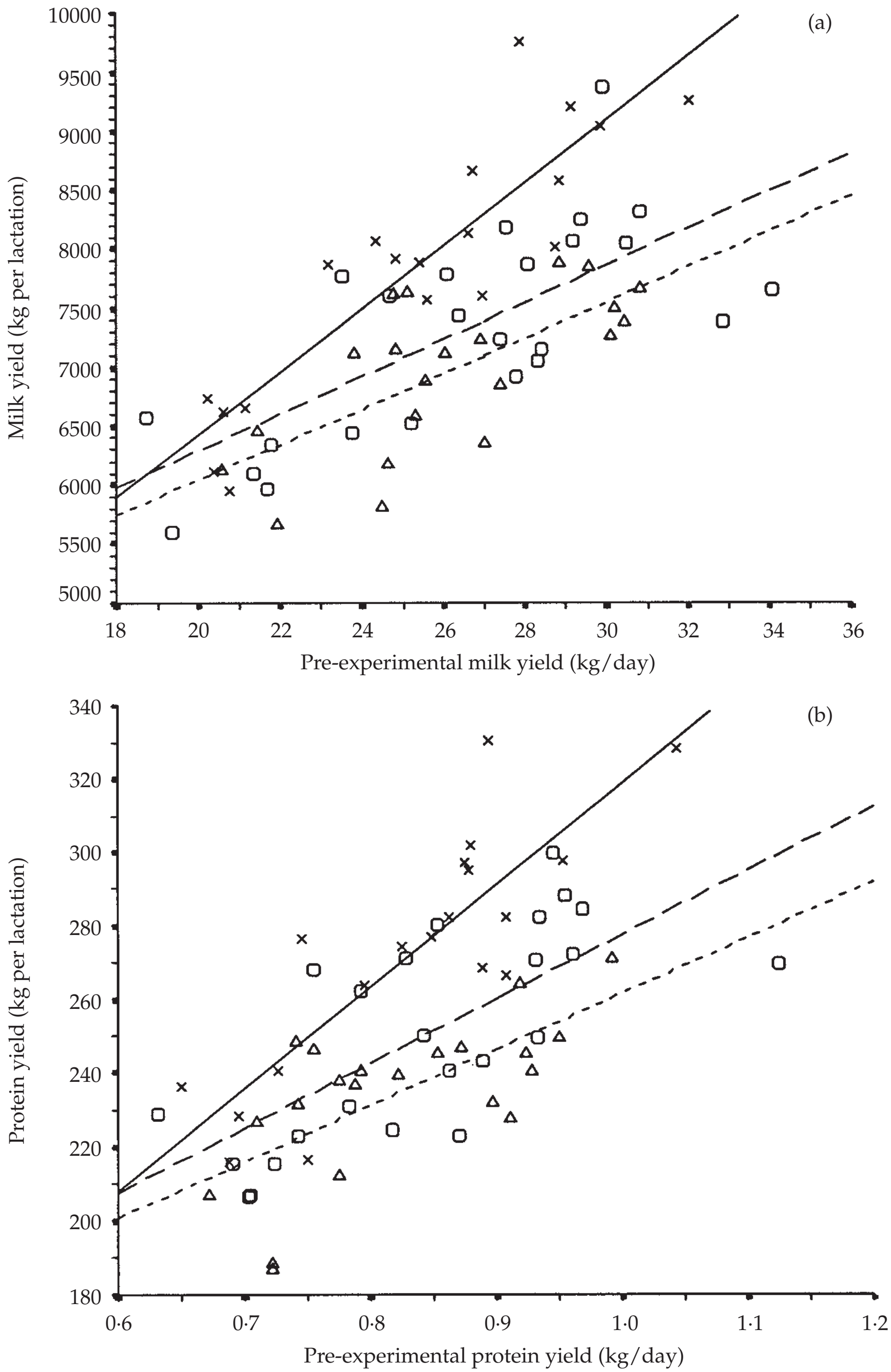

Figure 1 The relationship between (a) pre-experimental milk yield, (b) pre-experimental protein yield and subsequent lactation performance over the three years (no. = 66) (△ and - - - - - - = low concentrate feeding system, □ and – – – = medium concentrate feeding system, ✕ and ——— = high concentrate feeding system).

Table 5 *The effect of lactation number and feeding system on milk production*

Lact. no.†	1			2			3				Significance§		
Feeding system‡	LC	MC	HC	LC	MC	HC	LC	MC	HC	s.e.	L	F	L × F
Yield (kg per cow)													
Milk	5893	6183	6521	7250	7406	8083	7572	8041	8881	105	***	***	*
SCM#	5436	5777	6056	6593	6866	7424	6902	7446	8031	98	***	***	
Fat	225	241	249	273	287	305	283	308	323	4·8	***	***	
Protein	199	211	224	243	254	278	255	275	306	3·7	***	***	*
Lactose	276	289	307	334	340	374	353	375	414	5·0	***	***	*
Composition (g/kg)													
Fat	38·4	39·3	38·4	37·8	39·0	37·8	37·6	38·6	36·5	0·60		***	*
Protein	33·8	34·2	34·5	33·6	34·3	34·5	33·8	34·3	34·5	0·29		**	
Lactose	46·9	46·8	47·1	46·1	45·9	46·3	46·5	46·7	46·9	0·20	***		

† Lactation number.
‡ LC = Low concentrate feeding level; MC = medium concentrate feeding level; HC = high concentrate feeding level.
§ L = effect of lactation number; F = effect of concentrate feeding level; L × F = effect of interaction between lactation number and concentrate feeding level.
# SCM = solids-corrected milk.

(+ 790 kg/year) (SCM) (Tyrell and Reid, 1965), fat (+ 29 kg/year), protein (+ 32 kg/year) and lactose (+ 47 kg/year) over the three years. Milk fat and milk protein concentrations were higher for the MM cows. Similarly, feeding system had a significant effect on all milk production parameters. There was a significant genotype × feeding system interaction for fat yield, while the interaction for SCM was close to statistical significance ($P = 0·07$).

Table 5 shows the effect of lactation number, feeding system and lactation number × feeding system interaction on milk production parameters. Lactation number had a significant ($P < 0·001$) effect on all milk yield parameters. There was a significant ($P < 0·05$) lactation number × feeding system interaction for milk yield, protein and lactose yield and fat concentration.

Table 6 *Significance of the interaction between concentrate feeding level and slope of the covariables for experimental milk and protein yields*

Year	Year 1	Year 2	Year 3	Cumulative
Cow numbers	96	77	66	66
Covariable	Significance			
PI† milk yield (kg)			¶	*
PI† protein yield (kg)			¶	*
MP‡ milk yield (kg)	*	¶		¶
MP‡ protein yield (kg)	*	*		¶

† Pedigree index for milk and protein yield.
‡ Pre-experimental milk and protein yield.
¶ Approaching significance ($P = < 0·10$).

Regression analysis. Figure 1 shows the relationship between experimental milk and protein yields and pre-experimental (MP) milk and protein yields at each concentrate feeding level. Similarly, Figure 2 shows the relationship between experimental milk and protein yields and PI for milk and protein yields at each concentrate feeding level. The interaction between the feeding systems and the regression of both milk and protein yield on PI for both milk and protein yield respectively was significant. The interaction between the feeding systems and the regression of both milk and protein yield on pre-experimental milk and protein yield was close to statistical significance ($P = 0·08$ and $P = 0·09$, respectively). The differences in experimental milk and protein yields between the concentrate feeding systems increased as both MP and PI for milk and protein yield increased. Table 6 shows the significance of the interactions for each of the individual years and the average over the three years.

The significance of the interactions increased from year 1 to year 3 using PI milk and protein as covariables, while the reverse was true when using MP milk and protein yield as covariables.

Live weight and body condition score
Genotype had no significant effect on live weight, while feeding system had a significant effect at all stages of lactation (Table 7). There was a significant genotype × feeding system interaction for live weight ($P < 0·05$) at the end of lactation in year 3. Both genotype and feeding system had a significant effect on BCS at all stages of lactation. The MM cows and HC feeding systems had the highest BCS values.

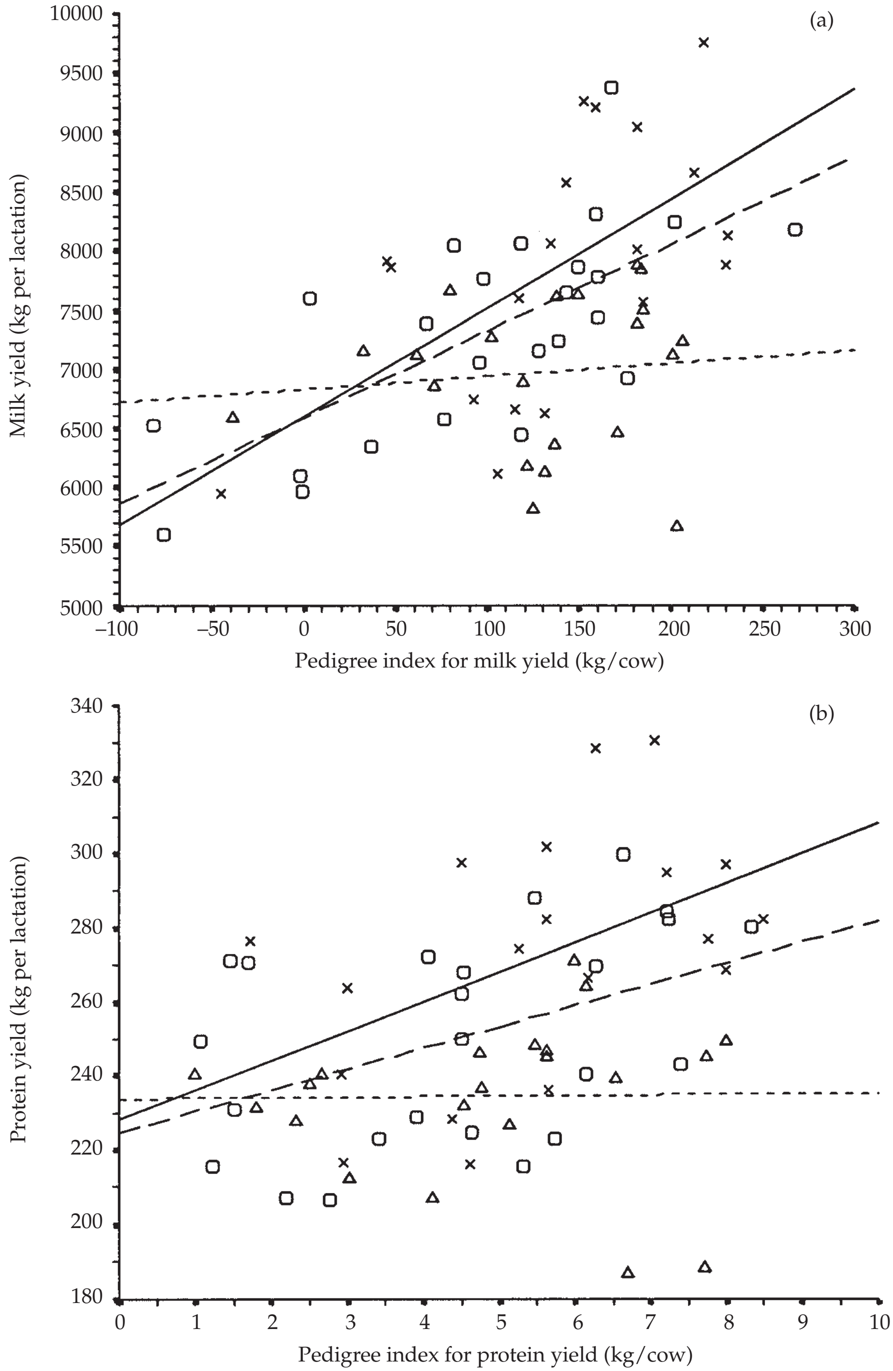

Figure 2 The relationship between pedigree index for (a) milk yield, (b) protein yield and subsequent lactation performance over the three years (no. = 66) (△ and - - - - - - = low concentrate feeding system, □ and – – – = medium concentrate feeding system, ✕ and ——— = high concentrate feeding system).

Table 7 *The effect of genotype and feeding system on live weight* (*LW*) *and body condition score* (*BCS*)

Genotype†		MM			HM				Significance§		
Feeding system‡	Year	LC	MC	HC	LC	MC	HC	s.e.	G	F	G × F
LW(kg per cow)											
Pre-experimental	1	496	492	505	509	502	512	10·2			
End of lactation	1	556	583	503	564	572	592	11·5		**	
Lactation week											
Week 1	2	539	554	586	560	563	581	9·6		***	
Week 8	2	563	521	539	515	523	543	9·0		**	
End of lactation	2	604	616	667	617	623	626	13·1		*	¶
Week 1	3	592	629	656	611	619	647	11·5		***	
Week 8	3	537	558	582	546	552	574	9·4		***	
End of lactation	3	580	622	659	605	599	630	12·1		***	*
BCS											
Pre-experimental	1	3·34	3·19	3·30	3·08	2·96	3·15	0·090	**		
End of lactation	1	3·13	3·31	3·49	2·67	2·78	3·07	0·123	***	**	
Week 1	2	3·23	3·41	3·48	3·21	3·22	3·40	0·069	*	*	
Week 8	2	2·84	2·98	3·17	2·70	2·80	2·97	0·077	*	**	
End of lactation	2	2·74	2·94	3·25	2·68	2·60	2·97	0·065	*	***	*
Week 1	3	3·35	3·38	3·46	3·29	3·19	3·31	0·045	*	*	
Week 8	3	2·97	3·08	3·25	2·83	2·79	2·96	0·089	**	**	
End of lactation	3	3·04	3·20	3·46	2·96	2·99	2·95	0·088	*	*	*

† MM = medium genetic merit; HM = high genetic merit.
‡ LC = low concentrate feeding level; MC = medium concentrate feeding level; HC = high concentrate feeding level.
§ G = effect of genotype; F = effect of concentrate feeding level; G × F = effect of interaction between genotype and concentrate feeding level.
¶ Approaching significance ($P < 0·10$).

At the end of lactation in both year 2 and year 3 there was a significant ($P < 0·05$) genotype by feeding system interaction for BCS. There was a larger difference in BCS between the two genotypes in the HC feeding system than in the LC system (0·47 *v.* 0·14).

Live weight and body condition score change
Neither genotype nor feeding system significantly affected live-weight change in weeks 1 to 8 of lactation (Table 8). In year 2 the MM cows had a significantly ($P < 0·05$) higher live-weight gain from week 8 to the end of lactation (0·45 kg/day *v.*

Table 8 *The effect of genotype and feeding system on live-weight* (*LW*) *change and body condition-score* (*BCS*) *change*

Genotype†		MM†			HM‡				Significance§		
Feeding system‡	Year	LC	MC	HC	LC	MC	HC	s.e.	G	F	G × F
LW(kg per cow)											
Lactation week											
Week 1 to 8	2	−0·64	−0·59	−0·84	−0·81	−0·71	−0·68	0·105			
Week 8 to end	2	0·41	0·41	0·53	0·40	0·38	0·35	0·040	*		¶
Week 1 to 8	3	−1·12	−1·46	−1·51	−1·33	−1·37	−1·50	0·147			
Week 8 to end	3	0·23	0·30	0·41	0·30	0·24	0·28	0·037		*	*
BCS											
Lactation week											
Week 1 to 8	2	−0·39	−0·43	−0·31	−0·52	−0·42	−0·43	0·053			
Week 8 to end	2	−0·09	0·04	+0·09	−0·02	−0·20	+0·02	0·063		*	¶
Week 1 to 8	3	−0·38	−0·30	−0·21	−0·46	−0·41	−0·35	0·061	*	*	
Week 8 to end	3	+0·08	+0·10	+0·16	+0·13	+0·19	−0·02	0·035			

† MM = medium genetic merit; HM = high genetic merit.
‡ LC = low concentrate feeding level, MC = medium concentrate feeding level, HC = high concentrate feeding level.
§ G = effect of genotype; F = effect of concentrate feeding level; G × F = effect of interaction between genotype and concentrate feeding level.
¶ Approaching significance ($P < 0·10$).

0·38 kg/day); in year 3, although numerically greater in MM, live-weight gain was not significantly different between genotypes. Feeding system had a significant effect ($P < 0·05$) on live-weight gain from week 8 to the end of lactation in year 3 (0·27 *v.* 0·27 *v.* 0·35 for the LC, MC and HC, respectively), while in year 2 live-weight gain although numerically greater for the HC feeding system was not significantly affected. There was a significant genotype × feeding system interaction for live-weight gain for the period week 8 to the end of lactation in year 3, while the interaction for year 2 was close to statistical significance ($P < 0·10$).

Genotype had no significant effect on BCS change except in year 3 when the MM group had a lower BCS loss than the HM group in early lactation (–0·30 *v.* –0·41) (weeks 1 to 8). The HC feeding system had a significantly higher ($P < 0·05$) BCS gain from week 8 to the end of lactation in year 2 (–0·06 for LC *v.* –0·15 for MC and + 0·06 for HC) and lower BCS loss in weeks 1 to 8 in year 3 (–0·28 for HC *v.* –0·36 for MC and –0·42 for LC). There was a similar tendency for a significant genotype × feeding system interaction for BCS change from week 8 to the end of lactation as with live-weight change.

Discussion

The aims of this study were to determine if there are genotype × feeding system interactions in pasture-based systems of milk production and secondly, if there are such interactions, to determine whether these are large enough to necessitate a change in the feeding systems which have been developed in the past for animals of lower genetic merit. The analysis as a factorial experiment of treatment means showed a significant genotype × feeding system interaction for fat yield and an almost significant interaction for SCM ($P = 0·07$). There was also a significant genotype × feeding system interaction for BCS at the end of lactation in both 1999 and 2000, and there was a tendency for the MM cows especially on HC to have higher BCS gain and live-weight gain from week 8 to the end of lactation. When the individual cow values were regressed on pedigree index the interactions between the feeding system and the regressions for milk and protein yield were significant. Also using pre-experimental performance as a covariable, the interactions were close to statistical significance for milk and protein yield ($P = 0·08$ and $P = 0·09$, respectively). The results are discussed against this background.

Milk yield and composition

The average milk production of 7389 kg per cow for the HM cows in the LC feeding system indicates that relatively high milk production is achievable with high genetic merit cows in a grass-based system under environmental conditions typical for Ireland. This average is much higher than that achieved in other grass-based systems with high genetic merit cows. Kolver *et al.* (2001) obtained 4678 kg milk per cow with high genetic merit North American Holstein-Friesian cows in a low stocked New Zealand grazing system. Fulkerson (2000) obtained 4953 kg per cow with high genetic merit North American Holstein-Friesian cows in an Australian grazing system. However, the LC feeding system prevented HM cows from fully expressing their genetic potential in the present study. In the LC system, milk production potential is reduced not only by the lower level of concentrate feeding but also by the reduced live weight and BCS (Garnsworthy, 1988). The milk production achieved in the HC feeding system with the HM cows is close to that achieved in US total mixed rations feeding systems (Lucy, 2001).

The higher milk production of the HM cows is similar to that published previously (Grainger *et al.*, 1985; Veerkamp *et al.*, 1994; Ferris *et al.*, 1999). The significantly higher fat and protein concentration of the milk with the MM cows compared with the HM cows in the present study is likely to reflect the genetic predisposition of the animals to produce milk of differing composition as indicated in the pedigree index. The higher milk lactose concentration with the MM cows is similar to that obtained previously (Buckley *et al.*, 2000a). The mean milk yield response in the HM cows to additional concentrate was 0·89 kg milk per kg concentrate DM going from the LC to MC and 1·01 kg milk per kg concentrate DM going from LC to HC. The corresponding values for the MM cows were 0·66 and 0·74 kg milk per kg concentrate DM, respectively. These responses are much larger (especially for the HM cows) than most of those published previously (Leaver *et al.*, 1968; Stakelum *et al.*, 1988), but are similar to those in recent publications (Delaby *et al.*, 2001; Reis and Combs, 2000). The significant lactation number × feeding system interaction probably results from the fact that cows in first lactation and, to a lesser extent, cows in second lactation would not have reached mature body weight and, therefore, must have used nutritional supplies for growth as well as lactation. The lower milk fat concentration and higher milk protein concentration with the HC feeding system agree with previously published data (Castle *et al.*, 1980).

The significant genotype × feeding system interaction in the regression analysis using the individual cow values suggests that individual cows of very high genetic merit may have the expression of their milk potential compromised by inadequate concentrate feeding in a grass-based system. The milk yield responses to increasing concentrate feeding were 0·45, 0·84, 1·46 kg milk per kg concentrate DM for cows with PI of < 100, 100 to 200 and 200 to 300 kg respectively. Mayne and Gordon (1995) reviewed a number of studies, which included an examination for evidence of a genotype × nutrition interaction. They concluded that in most of the studies not involving a feeding to yield system, an additional increment of concentrate produced similar increases in metabolic energy intake and hence, similar additional milk output with both high and low yielding cows (Thomas, 1980; Gordon, 1984). A more recent study (Ferris *et al.*, 1999) also showed that both high and medium genetic merit cows responded similarly in milk production to increasing proportion of concentrate in the diet. Veerkamp and Emmans (1995) showed that there was not a significant interaction between level (proportion) of concentrate feeding and genetic merit; however, regression coefficients between pedigree index and milk yield were significantly different for low and high forage diets. Cromie *et al.* (1998) showed a genetic correlation of greater than 0·85 between bulls tested in Ireland with their Interbull proofs for US bulls in the US, indicating there was little re-ranking of sires between US and Ireland. However, the data showed a large scaling effect of 0·52 and 0·32 for high and low input herds respectively. This indicated that proofs over-predicted genetic merit in low input systems and under-predicted genetic merit in high input systems. This is similar to that observed in the present study.

The difference in the levels of significance of the interaction between genotype and feeding system when using PI and MP as covariables in the regression analysis compared with that in the factorial analysis of the treatment means may be due to the range of PI and MP for milk and protein yield within and between the genetic groups. Using the PI as a covariable had the advantage of making use of the full range of genetic merit available in the data set. When the two genetic groups were established in 1998 the reliability of the pedigree information available was much lower than the pedigree index values which were used eventually in the regression analysis of the results of this study. The values used in the regression analysis were based on the August 2001 Interbull values. The pedigree index of some of the sires at the start of the trial in 1998 was calculated using MACE with no daughters in Irish herds contributing to the estimates of the pedigree index values at that stage. The lack of agreement between the significance of the interaction between genotype and feeding system using PI and MP for each of the individual years highlights the difference in statistical power achievable using different covariables. Using MP milk and protein yields in the first year as the covariable showed a significant treatment × covariable interaction; this decreased in significance in subsequent years. This may indicate that the covariable was a weaker measure of MP in subsequent lactations. The PI is a genetic covariable, because there is no environmental covariance between PI and the phenotypic measurement of milk production. The significance of the interaction using PI increased from year 1 to year 3. This is similar to results obtained by Veerkamp *et al.* (1994), in that the regression coefficient of milk yield on pedigree index for fat plus protein yield was significantly different between low and high concentrate diets for cows, but was not significant for heifers.

Live weight and body condition score

The non-significant effect of genotype on live weight was expected given the fairly similar proportions of Holstein-Friesian genes in both genotypes. The higher live weight and BCS with the HC feeding system is expected due to the higher energy feeding (Broster and Broster, 1984).

The large difference in BCS between the two genotypes at all stages of lactation is probably a consequence of selecting for higher milk yield, a greater proportion of Holstein-Friesian genes and increased angularity (Veerkamp *et al.*, 2001; Veerkamp and Brotherstone, 1997). The significant genotype × feeding system interaction for BCS at the end of lactation demonstrates that high genetic merit cows have lower rates of body tissue repletion from early lactation to the end of lactation, especially in the HC feeding system. There was an average difference, over years 2 and 3, in BCS between feeding systems of 0·07 units in the LC system, while there was a difference of 0·40 in the HC system. The similar live-weight changes in early lactation (weeks 1 to 8) for both genotypes and feeding systems is probably as a result of the difference in pre-calving live weight and level of feeding in early lactation. Garnsworthy (1988) observed that a cow with a higher live weight and BCS at calving had greater live weight and BCS loss in the weeks post calving, while cows on a higher level of nutrition immediately post calving had lower live weight and BCS loss in early lactation. The significant or almost significant genotype × feeding system interaction for live-weight and BCS change, from week 8 to the end of lactation, indicates that the HM cows continue to direct energy towards milk production rather than repletion of body reserves even in the HC feeding system.

The ability of the cows (especially those in the LC feeding system) to replenish body reserves during the non-lactation period was important. This was facilitated by providing *ad libitum* high quality grass silage during the dry period. The contribution of these energy reserves to total nutrient supply may be significant. Gibb *et al.* (1992) stated that these body reserves were capable of supporting the synthesis of an additional 7 kg milk per day over the first 8 weeks of lactation. Therefore, it is possible that the use of these reserves might buffer high merit cows against nutritional adversity and so reduce the probability of obtaining a genotype × feeding system interaction.

Conclusions

The objective of this study was to evaluate the effect of genotype × feeding system interaction on the performance of Holstein-Friesian cows in a grass-based system of milk production. Covariance analysis, using PI as the covariable, indicated a significant genotype × level of concentrate feeding system interaction for milk and protein yields. The results suggest that the value of increased genetic merit in a low concentrate grass-based system of milk production will be less than in a high concentrate system and that the response to increased concentrate feeding depends on the genotype of the animal. The profitability of feeding high levels of concentrate in Ireland depends on the ratio of milk price : concentrate cost, as well as low quota leasing charges since the introduction of quotas on milk production in the EU in 1984. Other factors, namely the health and reproductive performance of high genetic merit dairy cows also need to be considered.

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