Comparison of breed of dairy cow under grass-based spring milk production systems

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SUMMARY

The objective of this study was to investigate the potential differences among different dairy cow breeds across two feeding systems on milk production, udder health, milking characteristics, body weight, body condition score, hormone parameters, ovarian function, survival and overall reproductive efficiency. The breeds investigated included Holstein-Friesian (HF), Montbéliarde (MB), Normande (NM), Norwegian Red (NRF) and Holstein-Friesian × Montbéliarde (MBX) and Holstein- Friesian × Normande (NMX). Selection within the HF breed has, until recently, been predominantly for milk production with little or no direct selection for functional traits other than those correlated with superior type. The MB and the NM have been simultaneously selected for both milk and beef production in the past. The NRF were imported as calves and come from a more balanced total merit index incorporating production and cow functionality since the early 1970s. The dairy cow breeds were grouped into blocks of two within breed groups and randomized across two spring-calving grass-based feeding systems: low concentrate feeding system (LC) and high concentrate feeding system (HC). Those on LC feeding system were offered approximately 530 kg/cow over the total lactation, while those on HC feeding system were offered approximately 1030 kg/cow.

There was no genotype by environment interaction observed for any of the milk production, BCS, BW, udder health, milking characteristics, reproductive performance or feed intake/efficiency parameters investigated. Compared to the MB and NM, all other breeds had higher total lactation milk, fat, protein and lactose yield, with the HF having the highest. Animals on the HC feeding system had higher total lactation milk, fat, protein and lactose yield. Compared to the NRF, SCS was higher for the HF, NM, MBX and NMX breed groups, while SCS of the MB was not different. The NM and MB had lower AMF compared to all breeds. The crossbreds achieved the higher AMF. The NM had the lowest PMF, while that of the crossbreds were higher compared to all breeds. Milking duration was not affected by breed. Differences between breeds for AMF, PMF and MD were not apparent after adjustment for milk yield. Animals offered a HC diet had higher AMF, PMF and MD compared to those on the LC feeding system. Somatic cell score did not differ between the feeding systems. The interaction between breed and milk yield influenced SCS, AMF, PMF and MD thus implying that for each unit increase of milk yield by breed, the response in SCS, AMF, PMF and MD was different for some breeds. The response in SCS was similar for the NRF, MBX and NMX, while MD was similar for the MB and MBX. The effect of one unit increase in daily average milk yield caused a favourable decrease in SCS; however a one unit increase in PMF and MD did not influence SCS. No interactions were observed for breed with any milking characteristic on SCS. The HF had the lowest BCS, the MB and NM the highest, while the NRF, MBX and NMX were intermediate. The NRF had the lowest BW; the NM had the highest while the other breeds were intermediate. The NRF had increased likelihood of SR24, PREG1, PREG42 and FINALPR and greater survival compared to the HF. Both MBX and NMX had

shorter CSI and CCI and were more likely to be pregnant at the end of the breeding season, thus had higher survival rates compared to the HF; however heterosis estimates for these traits was not significant, likely due to the small data size. Feed system did not influence reproductive performance of the different breeds. Breed of dairy cow did not influence any of the ovarian parameters studied. Breed of dairy cow did not influence insulin or IGF-1 concentrations at any sampling period. Breed significantly effected gestation length, calf birth weight and calving ease score. The NRF had the shortest gestation, lightest calves and least calving difficulty.

Genotype had a significant effect on estimated dry matter intake, being highest with the HF, MBX, NMX and lowest with NM and NRF. Genotype also had a significant effect on yield of milk solids per kg of DMI. The highest yield of milk solids per kg of DMI was achieved with the NRF, HF and MBX. Comparisons between genotypes reveal that estimated residual feed intake estimates were lowest (most favourable) for the NRF, compared to other genotypes with the exception of HF.

INTRODUCTION

Milk production systems in Ireland are based mainly on seasonal calving, with the vast majority of milk being produced by grazed grass. To exploit fully the seasonal grass production profile, a high pregnancy rate, with a short time-period following a planned start of mating is needed to achieve a concentrated calving pattern in the following season. Similarly, this type of cow needs to be an efficient converter of grazed grass into milk solids. In recent years the relevance of continued selection for higher milk yield alone has been questioned. This study was established to compare the performance of four pure-breeds (Holstein-Friesian, Normande, Montebeliarde and Norwegian Red) and two cross breeds (Montebeliarde×Holstein-Friesian and Normande×Holstein-Friesian) under two grass-based spring milk production systems. The rationale behind the study was that 1) the introduction of milk quotas in some countries as a means of controlling national production e.g. European Union in 1984, thus dual purpose cows may provide improved income through superior male calf and cull cow value, 2) the deleterious effect of selection for yield on the health, fertility and welfare of cows, and 3) the increased emphasis in payment schemes in many countries on the composition of the milk. Some dual-purpose breeds differ genetically in milk yield, milk composition, body composition and health traits to that of the Holstein-Friesian. A cross-breeding programme may allow dairy farmers to combine desirable traits and, at the same time, take advantage of any hybrid vigour.

MATERIALS & METHODS

A five year study to compare Holstein-Friesian (HF), Montbéliarde (MB), Normande (NM), Norwegian Red (NRF) and Holstein-Friesian × Montbéliarde (MBX) and Holstein- Friesian × Normande (NMX) took place on the Ballydague Dairy Research Farm at Moorepark Dairy Research Centre, from January 2001 through December 2005. This study was a continuation of a breed comparison trial described by Dillon et al. (2003), but included crossbreds of MB and NM with HF, as well as pure NRF cows chosen based on their past selection for fertility and general health. In year one, 92% of the animals were primiparous while 8% were of second parity. In year two, 37%, 58% and 5% were of first, second and third parity, respectively. In year three, 28%, 23%, 45% and 4% were of first, second, third and fourth parity respectively. In year four, 26%, 22%, 15%, 34%, and 3% were of first, second, third, fourth and fifth parity respectively. In the final year, 27%, 19%, 18%, 12% and 24 % were of first, second, third, fourth and fifth parity respectively. Breed groups were not balanced for parity (1, 2, 3, 4 or 5) or calving date.

Purebred MB and NM cows were available upon completion of a five year comparison of Dutch HF, MB, NM and Irish HF, as described by Dillon et al. (2003). In 1999, NRF calves were imported and reared with the other breeds. Crossbreds and HF were generated by randomly mating HF, MB and NM sires to HF cows from herds within Moorepark Dairy Research Centre. Replacement animals were generated within the herd during the five year. A total of 23, 19, 11, 17, 17 and 19 sires were represented in the HF, MB, NM, NRF, MBX and the NMX breeds respectively. Sires used were common across pure and crossbreds and were also representative of sires commonly used in Ireland. The HF sires used were of North American HF ancestry.

Lactation records of 96 and 73 MBX and NMX F1 crossbreds, 42 and 23 MBX and NMX backcrosses, produced by mating F1 crossbreds with HF sires, and 2 and 1 MBX and NMX backcrosses, produced by mating F1 crossbreds with MB and NM sires respectively, were available.

FEEDING SYSTEM AND COW MANAGEMENT

Throughout the 5 year, the trial was carried out on the same permanent grassland site consisting of almost 100% perennial ryegrass. The soil type on the farm was free draining acid brown earth of sandy loam to loam texture. Cows were out on grass from mid February until late November each year and housed during the winter months, while they were dry for the most part (Dillon et al., 2003). During winter, they were offered grass silage ad libitum and dry cow minerals at a rate of 100 g per cow per day. Calcined magnesite (Calmag; Nutribio Ltd, Cork, Ireland) in powder form was used for pasture dusting on the paddocks at a rate of 60 g/cow/day to prevent Mg deficiency during the risk period. A 10 week dry period was given to first lactation animals, while an 8 week dry period was deemed adequate for multiparous animals. Grass silage ad libitum and 6 kg of concentrates were offered daily post-calving and prior to turnout to pasture. Throughout the trial, the cows grazed as a single herd and were milked at 07.00 and 16.00 hours daily. In mid to late April every year, calving date and milk yield were used as criteria to group cows into blocks of two within breed groups. The breed groups were then randomized across two spring-calving grass-based feeding systems; low concentrate feeding system (LC) and high concentrate feeding system (HC). Those on LC feeding system were offered approximately 530 kg/cow over the total lactation, while those on HC feeding system had a higher concentrate input (approximately 1030 kg/cow). Concentrates were offered on a flat rate basis within feeding system in individual stalls twice daily in a 20 unit side by side herringbone milking parlour. The ingredient composition of the concentrate (pelleted) offered (kg/t as fed) was as follows: barley 250 kg, corn gluten 260 kg, beet pulp 350 kg, soybean meal 110 kg and minerals plus vitamins 30kg. The chemical composition of the concentrate offered (g/kg DM) was 180 and 800 crude protein and cellulase gamanase digestibility, respectively.

Throughout the trial, the cows grazed as a single herd and were milked at 07.00 and 16.00 hours daily. Milk yield was recorded daily using electronic milk meters. Somatic cell count was determined from morning milk samples using a Bently Somacount 300 (Bentley Instruments Incorporated, USA). The mean number of SCC records per cow per year was 14. However in the first 4 years of the study, SCC sampling was infrequent compared to year 5, which had an average of 22 SCC records per cow (every 2 weeks).

DATA COLLECTION

Milk yield and milk composition

Individual cow milk yield was recorded daily using electronic milk meters (Dairymaster, Causeway, Co. Kerry, Ireland). Milk samples, collected once weekly from successive morning and evening milkings, were analyzed using a Milkoscan 203 (Foss Electric DK-3400 Hillerod, Denmark) to determine milk fat, protein and lactose concentrations. Solids corrected milk yield (**SCM**) was calculated as defined by Tyrrell and Reid (1965). A total of 31,167 weekly records from 749 lactations of 309 cows were included in the analysis for milk production.

Body condition score and body weight

Body condition score (BCS) was recorded every 3 to 4 weeks during the lactation on a 1 to 5 scale (1 = emaciated, 5 = extremely fat) with increments of 0.25. Body weight (BW) was recorded once weekly using calibrated electronic weighing scales (Dairymaster, Causeway, Co. Kerry, Ireland). A total of 8,207 BCS and 39,743 BW records of 309 cows were analysed. Cow BCS and BW were categorised into 10 stages; wk 1 to 4, wk 5 to 8, wk 9 to 12, wk 13 to 16, wk 17 to 20, wk 21 to 24, wk 25 to 28, wk 29 to 32, wk 33 to 36 and wk 37 to 44. Average weekly BW was calculated within these 10 stages.

Udder health and milking characteristics

Somatic cell count was determined from morning milk samples using a Bently Somacount 300 (Bentley Instruments Incorporated, USA). The mean number of SCC records per cow per year was 14. However in the first 4 years of the study, SCC sampling was infrequent compared to year 5, which had an average of 22 SCC records per cow (every 2 weeks). Milking duration (seconds) and milk flow (kg/min) were automatically recorded 7 days a week at both at morning and evening milking for years 3, 4 and 5 of the study using the same electronic milk meters. The time from cluster attachment to cluster removal determined milking duration. When milk flow decreased below 0.2 kg/min and a minimum milking time of 4 min had elapsed, clusters automatically detached, thus eliminating any possible effects of over-milking on the milking characteristics variables measured. The milk meter computed the rate of milk flow continuously by calculating the change in weight every 20 seconds. The maximum flow was the peak of this value. Milking was performed at a 48 kPa vacuum, with a pulsation ratio of 65:35 at a rate of 60 cycles/min.

Fertility and calving performance

Seven traditional fertility parameters were investigated. These included 24 day submission rate (SR24; proportion of all cows detected in oestrus and submitted for AI in the first 24 days of the breeding season), calving to first service (CSI; interval in days from calving to first AI), pregnancy rate to first service (PREG1; number of cows confirmed pregnant (6 wk after the end of the breeding season) to first AI divided by the total number of cows), 6 wk incalf rate (PREG42; number of cows confirmed pregnant (6 wk after the end of the breeding season) to an insemination occurring within 6 wk after start of breeding season divided by the total number of cows), overall pregnancy rate (FINALPR; proportion of cows confirmed pregnant 6 wk after the end of the breeding season), calving to conception interval (CCI; days from calving to confirmed pregnancy diagnosis 6 wk after the end of the breeding season), and finally services per cow (total number of services divided by the total number of cows). Gestation length (interval in days from successful insemination to subsequent parturition, degree of calving difficulty and calf birth weight were also investigated.

During yr 3 and 4 of the study, composite milk samples were obtained thrice weekly on Mondays, Wednesdays and Fridays during morning milking. Commencement of sampling began 5 days post partum and extended to 26 days after first AI. A potassium dichromate preservative tablet (Lactab Mark III, Thompson & Capper Ltd., Chesire, England) was added to each milk sample and all samples were stored at 4°C until assayed for progesterone. Whole-milk progesterone was measured using enzymeimmunossay (Ridgeway Science Ltd, Gloucestershire, UK) as outlined by Sauer et al. (1986). Inter- and intra-assay coefficients of variation were 13.7 and 15.7%, respectively. The sensitivity, calculated using the absorption of the blank standard minus 2 standard deviations, was 0.5ng/ml. Data from 187 cows was included for the progesterone parameter analysis, taking cognisance of repeated measures for these cows. Milk progesterone profile parameters were defined as outlined by Royal et al. (2000) and Horan et al. (2005b). The thrice weekly milk sampling protocol introduced sampling bias to some parameters; hence these were adjusted for accordingly (Royal et al., 2000).

Insulin and insulin-like growth factor 1

A total of 556 samples were available for analysis; 131 pre-calving, 145 within one wk of calving, 118 post calving and 111 samples at the start of the breeding season. The mean number of days for pre-calving, calving, post-calving and at the start of the breeding season was -4, 5, 36 and 53, respectively. Plasma insulin-like growth factor 1 (IGF-1) concentrations were determined using a validated double-antibody radioimmunoassay following ethanol-acetone-acetic acid extraction. The standard and iodinated tracer used was recombinant human IGF-1 (R&D Systems Europe, UK). Iodine – 125 (PerkinElmer (Unitech BD Ltd., Dublin, Ireland)) was used for the iodination. The extraction and assay were carried as described by Echternkamp et al. (1990). Inter- and intra-assay coefficients of variation were 21.54 and 16.63%, respectively. The plasma insulin data were not normally distributed; hence the natural logarithm was determined prior to statistical analysis. Plasma insulin concentrations were determined using a solid-phase fluoroimmunoassay (AutoDELFIA, PerkinElmer Life and Analytical Science, Turku, Finland). The inter- and intra-assay coefficients of variation were 14.8 and 3.7%, respectively.

Survival

Data from 293 cows, which entered the study in their first lactation, were included in the survival analysis. Survival was measured as the number of days post first calving to the date of culling. Date of culling for infertility was defined as the date of drying off at the end of lactation during which the cow failed to conceive. Culling date for reasons other than fertility was defined as the date on which the animal was removed from the herd. Animals that were pregnant on the last day of 2005 were assumed censored as their survival time was unknown (146 cows).

Grass intake and feed efficiency

Intakes were estimated for each cow on two occasions in early lactation during both 2003 and 2004. A total of eight measurements that were carried out each year targeted all cows at two measurement periods; week 4 and week 8 of lactation. The final data set included a total of 507 observations across 167 individual cows, and corresponded to 31 and 59 days in milk. During each intake measurement, the cows being assessed were out doors full time on pasture. In Year 1 (2003) cows received a standard concentrate allowance of 7 kg (6.14 kg DM) per cow per day, while in Year 2 (2004) cows received a standard concentrate allowance of 3.6 kg (3 kg DM) per cow per day. Dry matter intakes (DMI) were estimated using the n-alkane technique (Mayes et al., 1986) as modified by Dillon and Stakelum, (1989). Energy related parameters were calculated for each cow using the French Net Energy (NE) system of Jarrige (1989), where energy values are expressed in UFL (Unité Fourragère Lait). One UFL is defined as the NE content of one kg of standard barley for milk production. For the purpose of energy calculations in both studies the energy value of the herbage on offer was assumed to be 1.05 UFL and the concentrate to be 1.1 UFL. Energy balance (EB) was defined as the difference between energy intake and energy required for production and maintenance. Residual feed intake (RFI) was estimated by regressing energy intake on its assumed components:

$$Y = \text{ß}0 + \text{ß}1(SCM) + \text{ß}2(LW0.75) + \text{ß}3(ADG) + RFI$$

Other measures of efficiency calculated included: MS per100kg LW, MS per kg DM intake, SCM per kg total dry matter intake (TDMI), TDMI per 100kg LW, and TDMI per kg metabolic LW (LW0.75).

STATISTICAL ANALYSES

Mixed Model Analysis

Milk production, BW, BCS, DMI, continuous fertility variables (incl. number of services, CSI and CCI) and endocrine variables, were analyzed using mixed model methodology in **PROC MIXED** (SAS Institute, 2006). Class variables common for all dependant variables included in the model were breed, feeding system, parity and yr, while calving day of yr was included as a continuous covariate. A pre-experimental covariate was created for milk production, BCS and BW to adjust for differences that may have existed in pre-experimental performance (bias). The covariate was created using the mean of the 2 wk performances immediately prior to the feeding treatments being applied. The covariate was centered (with a mean of 0) within breed group and lactation number prior to inclusion in the models. Additionally, stage was included as a repeated effect within cow-lactation and cow included as a random effect for stage analysis of BW and BCS. The interaction between breed and lactation stage was also included. All progesterone parameters and insulin and IGF-1 concentrations taken at the four time points were analysed with cow included as a repeated effect. Class variables included in both models were breed, parity, days in milk and calving day of yr. Feeding system was not applied during sampling timeframe and hence was not included in the model. The linear model used to analyse the intake data included the fixed effects of genotype, parity, measurement period (four across the two years), the interaction between genotype and measurement period, and the random effect of cow. Calving day of the year was fitted as a continuous variable. In this data set the best error structure for the residuals of repeated measures on the same cow was a heterogeneous compound symmetry.

For all models, selection of the most appropriate covariance structure was based on Akaike's information criterion. Interactions between independent variables were also investigated. Evidence of hybrid vigour was tested using the CONTRAST/ESTIMATE statements (SAS Institute, 2006) where appropriate.

Generalized Estimating Equations

Analysis of SR24, PREG1, PREG42 and FINALPR was undertaken using **PROC GENMOD** (SAS Institute, 2006) assuming a logit link function. Cow was included as a repeated effect with an exchangeable correlation structure assumed between records within cow. The odds ratios were calculated as the exponent of the associated model solution for that variable. Empirical model solutions and standard errors are reported. Class variables included in the model were breed, feed system, parity and yr with calving day of yr included as a continuous covariate. The HF and LC feed system were designated the reference groups (odds ratio (OR) = 1) when determining the effect of breed and feed system, respectively. Interactions between independent variables were also investigated.

Survival Analysis

Kaplan-Meier survival functions were estimated for each breed using the **LIFETEST** procedure in SAS.

RESULTS

Milk yield and milk composition

The interaction between breed and feeding system was not significant for total milk production; therefore Table 1 presents only the main effects. Breed of dairy cow influenced ($P < 0.05$) all milk yield variables, with the exception of protein percent. Compared to the MB (5604 kg) and NM (5464 kg), all other breeds had higher total lactation milk yield ($P < 0.05$), with the HF having the highest (5925 kg). The SCM yield of the HF (5467 kg) was higher ($P < 0.001$) than the MB (5125 kg) and NM (5044 kg), but was similar to MBX (5332 kg), NMX (5382 kg) and NRF (5278 kg). The HF produced more fat (226 kg), protein (202 kg) and lactose (279 kg) over the lactation ($P < 0.01$) compared to both the MB (207, 193, 266 kg, respectively) and NM (204, 188, 260 kg, respectively). The NRF had similar fat (216 kg), protein (198 kg) and lactose (270 kg) yield compared to the MBX (219, 198, 274 kg, respectively) and NMX (222, 198, 275 kg, respectively). Compared to the HF (38.3 g/kg), fat content was similar for the NM (38.0 g/kg), MBX (37.8 g/kg) and NMX (39.1 g/kg), higher than that of the MB (37.1 g/kg) and NRF (37.2 g/kg). Lactose content of the MB (47.6 g/kg) and NM (47.8 g/kg) was higher ($P < 0.05$) compared to all other breeds, with the exception of the NRF (47.5 g/kg). Protein content did not differ between the breeds. Heterosis estimates for milk yield, SCM, fat, protein and lactose yield for the MBX were 0.4, 0.7, 0.9, 0.3 and 0.8% respectively, while for the NMX were 2.3, 3.2, 4.4, 2.0 and 2.5% respectively.

Animals offered a high concentrate diet achieved higher milk (5840 kg), SCM (5380 kg), fat (220 kg), protein (200 kg), lactose yield (276 kg) and lactose content (47.4 %) compared to those on the LC feeding system (5614, 5163, 211, 193, 265 kg and 47.2 %, respectively). Fat and protein content did not differ between feeding systems.

Table 1. Effect of breed of dairy cow[1] and feeding system[2] on milk production over the complete lactation

	Breed								Feed system			
Variable	HF	MB	NM	NRF	MBX	NMX	[3]S.E.M.	*P*-value	HC	LC	S.E.M.	*P*-value
Milk yield (kg/cow)	5925^{a}	5604^{b}	5464^{b}	5788^{a}	5789^{a}	5795^{a}	70.7	< 0.001	5840	5614	47.1	< 0.001
[4]SCM yield (kg/cow)	5467^{a}	5125^{b}	5044^{b}	5278^{c}	5332^{ac}	5382^{ac}	62.4	< 0.001	5380	5163	42.0	< 0.001
Fat yield (kg/cow)	226^{a}	207^{b}	204^{b}	216^{c}	219^{c}	222^{ac}	2.8	< 0.001	220	211	1.9	< 0.001
Protein yield (kg/cow)	202^{a}	193^{bc}	188^{c}	198^{a}	198^{a}	198^{ab}	2.3	< 0.001	200	193	1.5	< 0.001
Lactose yield (kg/cow)	279^{a}	266^{bc}	260^{b}	270^{c}	274^{ac}	275^{ac}	3.4	< 0.01	276	265	2.3	< 0.001
Milk composition (g/kg)												
Fat	38.3^{ad}	37.1^{bc}	38.0^{acd}	37.2^{bc}	37.8^{ac}	39.1^{d}	0.36	< 0.001	37.8	38.0	0.21	NS
Protein	34.0	34.2	34.5	33.9	34.0	34.3	0.18	NS	34.2	34.1	0.11	NS
Lactose	47.0^{a}	47.6^{b}	47.8^{b}	46.7^{d}	47.3^{c}	47.5^{bc}	0.11	< 0.001	47.4	47.2	0.07	< 0.01

[a-d] Means within a row with different superscripts differ ($P < 0.05$).

[1] HF = Holstein-Friesian; MB = Montbèliarde; MBX = Montbéliarde x Holstein-Friesian; NM = Normande; NMX = Normande x Holstein Friesian; NRF = Norwegian Red. [2] HC = high concentrate feeding system; LC = low concentrate feeding system.

[3] S.E.M. = pooled standard error of the mean. [4] SCM = Solids-corrected milk.

Body condition score and body weight

Breed and feeding system influenced both lactation average BCS and BW ($P < 0.001$). Compared to all breeds, the lactation average BCS of the HF was lower (2.77 BCS; $P < 0.001$). The lactation average BCS of the MB and NM were similar at 3.15 and 3.16, respectively, while the MBX, NMX and NRF were similar at 3.00, 3.00 and 3.06, respectively. Lactation average BW was lower for NRF (537 kg; $P < 0.001$) compared to all breeds. The NM had the highest lactation average BW (587 kg; $P < 0.05$) compared to all breeds (HF = 570kg; MB = 568 kg; MBX = 572 kg), while BW of the NMX was similar (575 kg).

The interaction between stage of lactation and breed was significant for BCS ($P < 0.001$) and BW ($P < 0.001$) and is detailed in Figure 1. All breeds lost BCS immediately postpartum. Body condition score loss from wk 2 to 8 was greatest in the NRF (-0.19 BCS) and the HF (-0.15 BCS), was lowest in the MB and NMX (-0.09 BCS), while BCS loss for the MBX and NM was intermediate (-0.11 BCS). At each stage of lactation, the HF had lower BCS ($P < 0.001$) compared to all breeds. Between wk 29 to 44, all breeds began to regain body condition and reach values that were observed previously in wk 5 to 8 of lactation. Lowest BW throughout lactation was observed for the NRF ($P < 0.001$); while numerically higher BW was observed for the NM at each stage of lactation compared to all other breeds.

Animals in both feeding systems had similar BCS from wk 2 to 12 (feeding system not applied from wk 2 to 8); thereafter animals on the HC feeding system achieved higher BCS (approximately 0.1 BCS) for the remainder of the lactation ($P < 0.001$). Similarly for BW, feeding system influenced the lactation profile from wk 13 to 44 ($P < 0.001$), with those animals on the HC diet achieving higher BW from mid to late lactation (approximately 10 kg heavier).

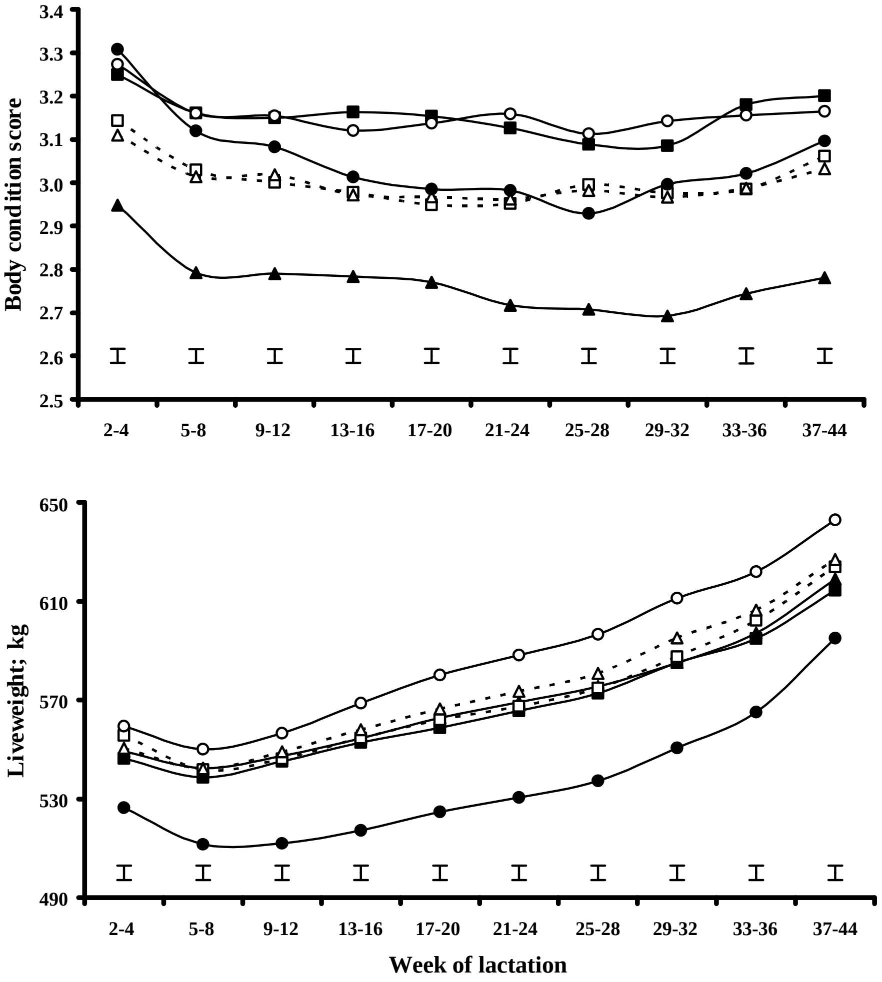

Figure 1. Effect of HF (▲), MB (■), NM (○), NRF (●), MBX (□) and NMX (Δ) on body condition score and live weight across different stages of lactation. Vertical bars indicate one pooled standard error.

Udder health and milking characteristics

Lactation average SCS over all breeds was 10.55 SCS (back transformed SCS; 38,177 somatic cells/mL) over the 5 years (Table 2). Lactation average (± standard deviation) AMF and PMF were 1.48 (±0.29) kg/min and 3.64 (±0.89) kg/min respectively, while the median of the MD was 834 secs/day, and the first and third quartiles were 990 and 696 secs /day, respectively. Compared to the NRF (30,031 somatic cells/mL), SCS was higher ($P < 0.05$) for the HF (57,526 somatic cells/mL), NM (53,104 somatic cells/mL), MBX (55,826 somatic cells/mL) and NMX (51,021 somatic cells/mL) breed groups, while SCS of the MB (35,242 somatic cells/mL) was not different.

The NM and MB had lower AMF ($P < 0.01$) compared to all breeds. The crossbreds achieved the higher AMF. The effect of breed of dairy cow on PMF tended towards significance ($P = 0.079$). The NM had the lowest PMF, while that of the crossbreds were higher compared to all breeds. Milking duration was not affected by breed. Differences between breeds for AMF, PMF and MD were not apparent after adjustment for milk yield.

Animals offered a HC diet achieved higher daily average AMF, PMF and MD ($P < 0.001$) compared to those on the LC feeding system. Somatic cell score did not differ between the feeding systems. The effect of feeding system on AMF and MD remained significant ($P < 0.01$) following adjustment for milk yield.

The interaction between stage of lactation and breed was significant for daily average milk yield ($P < 0.05$), AMF ($P < 0.01$), PMF ($P < 0.001$) and MD ($P < 0.001$) and is detailed in Figures 2 and 3. Breed significantly affected SCS in each stage of lactation ($P < 0.001$) but the effect of breed did not differ significantly by stage (Figure 2). Similar to the lactation average findings when all breeds were compared to the NRF, the HF ($P = 0.065$) and MBX ($P = 0.012$) had higher SCS and that of the MB, NMX and NM were not different.

All breeds reached peak AMF in week 5 to 8 of lactation, followed by a gradual decline until nadir AMF at the end of lactation. The crossbreds displayed a higher AMF ($P < 0.05$) in weeks 5 to 8 compared to the MB and NM. In contrast the NM displayed a lower ($P < 0.01$) AMF at peak compared to all breeds, except the MB. The lactation profile for PMF was relatively static compared to the lactation profile of milk yield and AMF for all breeds. Highest PMF was observed for the MB, NM, MBX and NMX in weeks 1 to 4, while the HF and NRF had higher PMF in weeks 9 to 12 and weeks 13 to 16, respectively. Following weeks 21 to 24, PMF declined to a minimum at the end of lactation for all breeds. Maximum MD was reached in weeks 5 to 8 of lactation after which it declined until the end of lactation across all breeds. The HF had the greatest MD in weeks 5 to 8 compared to all breeds ($P < 0.05$) apart from the NRF, with which it was similar.

Table 2. Effect of breed of dairy cow[1] and feeding system[2] on milk yield (kg/day), somatic cell score (SCS units), average milk flow (AMF; kg/min), peak milk flow (PMF; kg/min) and average milking duration (MD; log secs/day)

	Breed								Feeding system			
Variable	HF	MB	NM	NRF	MBX	NMX	S.E.M.[3]	P-value	HC	LC	S.E.M.	P-value
Milk (kg/day)	22.6^{a}	20.1^{b}	19.1^{b}	21.5^{c}	22.0^{ac}	21.4^{c}	0.30	<0.001	22.3	19.9	0.16	<0.001
SCS	10.96^{a}	10.47^{b}	10.88^{a}	10.31^{b}	10.93^{a}	10.84^{a}	0.127	<0.001	10.68	10.79	0.078	0.149
AMF(kg/min)	1.52^{acd}	1.41^{b}	1.33^{b}	1.48^{ad}	1.56^{c}	1.54^{cd}	0.030	<0.001	1.55	1.40	0.016	<0.001
PMF(kg/min)	3.67	3.58	3.22	3.68	3.81	3.76	0.119	0.079	3.69	3.55	0.060	<0.001
MD(log sec/day)[4]	6.78 (880)	6.74 (846)	6.75 (854)	6.75 (854)	6.74 (846)	6.72 (829)	0.019	0.359	6.76 (863)	6.74 (846)	0.010	0.002

a-d Means within a row with different superscripts differ ($P < 0.05$).

[1] HF = Holstein Friesian; MB = Montbéliarde; MBX = Montbéliarde × Holstein-Friesian; NM = Normande; NMX = Normande × Holstein-Friesian; NRF = Norwegian Red.

[2] HC = high concentrate feeding system; LC = low concentrate feeding system.

[3] S.E.M. = pooled standard error of the mean.

[4] Mean MD in seconds, antilog of MD least squares means are presented in parenthesis.

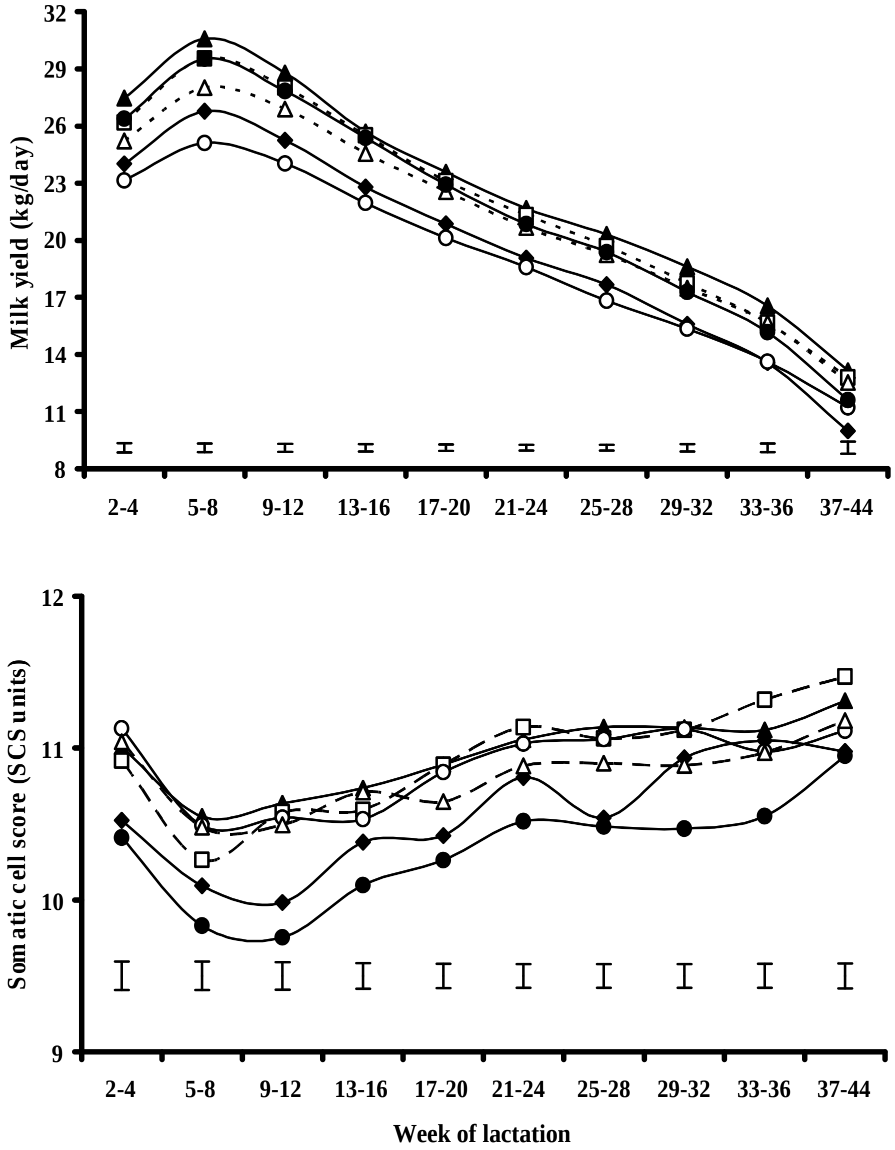

Figure 2. Effect of HF (▲), MB (♦), NM (○), NRF (●), MBX (□) and NMX (Δ) on average milk yield (kg/min) and somatic cell score (SCS units) across different stages of lactation. Vertical bars indicate one pooled standard error.

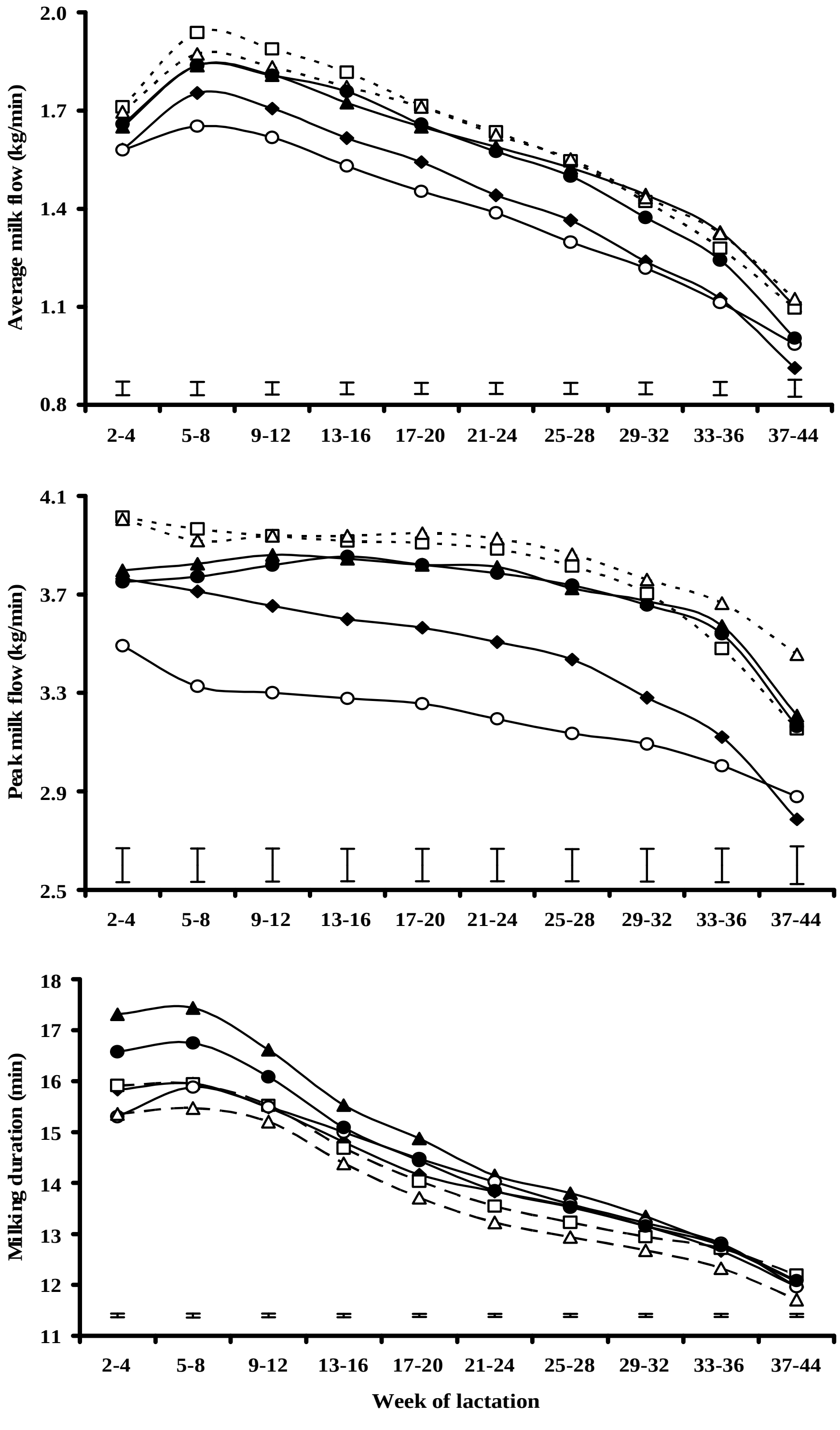

Figure 3. Effect of HF (▲), MB (♦), NM (○), NRF (●), MBX (□) and NMX (Δ) on average milk flow (kg/min), peak milk flow (kg/min) and milking duration (back-transformed MD presented in min) across different stages of lactation. Vertical bars indicate one pooled standard error.

An interaction between stage of lactation and feed was observed for daily average milk yield ($P < 0.05$), AMF ($P < 0.01$), PMF ($P < 0.001$) and MD ($P < 0.001$) and is detailed in Figures 4 and 5. Somatic cell score was similar for the first two stages of lactation (feeding systems not applied during this period). Feeding system influenced SCS ($P < 0.05$) from weeks 21 to 36 inclusive. Similarly, animals in the LC feeding system exhibited a lower AMF ($P < 0.001$) and PMF ($P < 0.001$) from weeks 9 to 36, and from weeks 13 to 44, respectively. From week 13 (stage 4), MD of the animals on LC feeding system was lower through to the end of lactation ($P < 0.001$) .

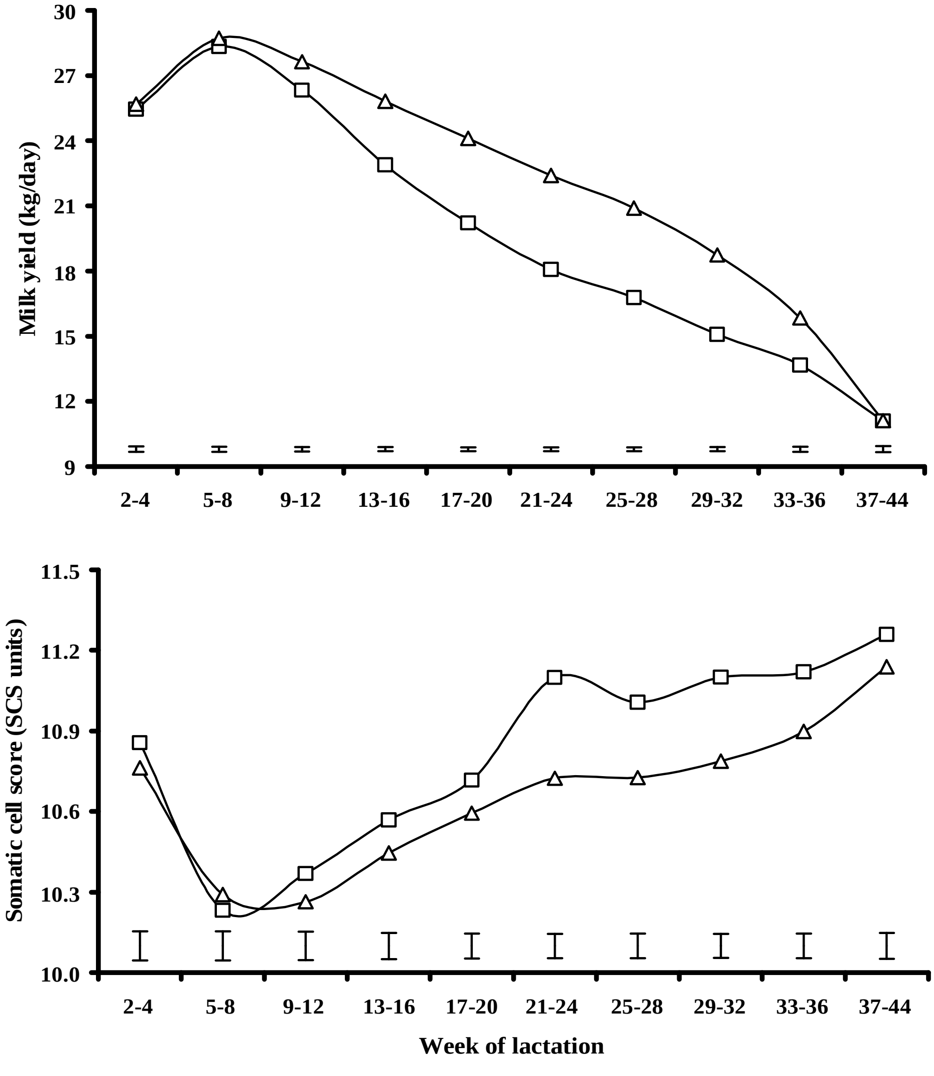

Figure 4. Effect of high concentrate feeding system (Δ) and low concentrate feeding system (□) on average milk yield (kg/day) and somatic cell score (SCS units) across different stages of lactation. Vertical bars indicate one pooled standard error.

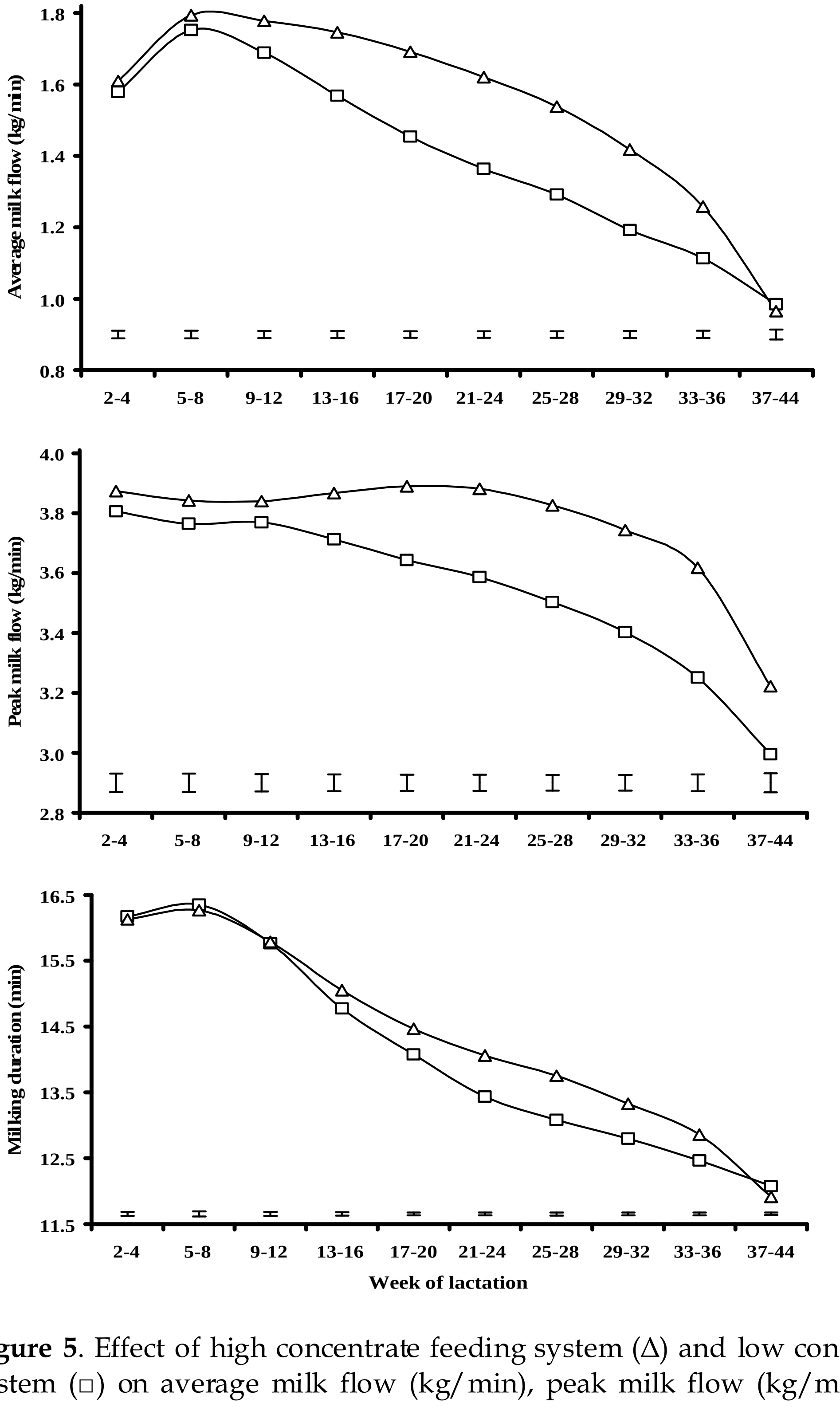

Figure 5. Effect of high concentrate feeding system (Δ) and low concentrate feeding system (□) on average milk flow (kg/min), peak milk flow (kg/min) and milking duration (back-transformed MD presented in min) across different stages of lactation. Vertical bars indicate one pooled standard error.

Fertility and calving performance

The interaction between breed and feeding system was not significant for traditional fertility parameters. On average over the 5 yr of the study, the MB had a later calving date ($P < 0.05$) compared to all other breeds (Table 3). Table 4 shows the association between breed of dairy cow and feeding system with the likelihood of SR24, PREG1, PREG42 and FINALPR. The NRF (OR=2.49) and MBX (OR=3.11) had increased likelihood of SR24 ($P < 0.05$) than the HF (Table 3). This corresponds to rates of 89, 91 and 76% for the NRF, MBX and HF, respectively. Compared to the HF, the CSI was shorter ($P < 0.05$) for the NM, NRF and MBX, while CSI of the MB and NMX was not different. The MB had a later CCI compared to all other breeds with the exception of the HF ($P < 0.05$). The number of services per conception during the defined breeding season did not differ between the breeds. The NRF (OR = 1.57) and NMX (OR = 1.62) tended to have a higher pregnancy PREG1, compared to the HF. Corresponding PREG1 rates for the HF, MB, NM, NRF, MBX and NMX were 46, 39, 52, 57, 46 and 58 %, respectively. The PREG42 was higher in the NM (OR = 1.80; $P < 0.05$) and also tended to be higher in the NRF (OR = 1.56; $P = 0.074$) compared to the HF. Compared to the HF, the MB (1.99), NRF (2.48), MBX (2.40) and NMX (2.37) had a higher likelihood of FINALPR at the end of the breeding season ($P < 0.05$). Corresponding FINALPR rates for the HF, MB, NM, NRF, MBX and NMX were 80, 89, 87, 91, 90 and 90 %, respectively.

Animals offered a LC feed system required fewer services per conception ($P < 0.05$) compared to those on the HC feed system. The likelihood of PREG1 was greater for those animals offered a LC feed system (OR = 1.41; $P < 0.05$) and also tended to be higher for FINALPR (OR = 1.51; $P = 0.086$) compared to the HC feed system.

Table 3. Effect of breed of dairy cow[1] and feeding system[2] on calving day of yr (CALDOY), calving to first service interval (CSI; days), calving to conception interval (CCI; days) and the number of services per conception (SERNO)

	Breed								Feed system			
Variable	HF	MB	NM	NRF	MBX	NMX	[3]S.E.M.	*P*-value	HC	LC	S.E.M.	*P*-value
CALDOY	50^{a}	62^{b}	54^{a}	49^{a}	52^{a}	53^{a}	2.3	<0.001	54	52	1.3	NS
CSI	73.3^{a}	71.8^{ac}	68.9^{bc}	70.1^{bc}	68.2^{bd}	71.3^{acd}	1.28	<0.05	70.3	70.9	0.82	NS
CCI	89.9^{ab}	95.3^{b}	83.6^{a}	85.4^{a}	86.7^{a}	87.9^{a}	2.46	<0.05	89.3	86.9	1.62	NS
SERVNO	1.98	2.05	1.89	1.82	1.97	1.83	0.105	NS	2.01	1.83	0.068	<0.05

$^{a-d}$ Means within a row with different superscripts differ ($P < 0.05$).

[1] HF = Holstein-Friesian; MB = Montbèliarde; MBX = Montbéliarde× Holstein-Friesian; NM = Normande; NMX = Normande × Holstein Friesian; NRF = Norwegian Red.

[2] HC = high concentrate feeding system; LC = low concentrate feeding system.

[3] S.E.M. is the average standard error of the mean.

Table 4. Estimated odds ratios and their 95% confidence intervals (CI) for the effect of [1]breed and [2]feeding system on 24 d submission rate (SR24), pregnancy rate to first service (PREG1), 6 wk incalf rate (PREG42) and overall pregnancy rate (FINALPR)

Variable		OR†	95% CI‡	*P*-value
Likelihood of SR24				
[1]Breed	HF	1		
	MB	1.78	0.92-3.42	0.085
	NM	1.92	0.79-4.69	0.152
	NRF	2.49	1.20-517	0.014
	MBX	3.11	1.47-6.57	0.003
	NMX	1.92	0.82-4.50	0.131
[2]Feed system	HC	1		
	LC	0.92	0.57-1.47	0.727
Likelihood of PREG1				
[1]Breed	HF	1		
	MB	0.75	0.44-1.27	0.287
	NM	1.28	0.77-2.13	0.349
	NRF	1.57	0.97-2.52	0.064
	MBX	1.03	0.62-1.73	0.902
	NMX	1.62	0.98-2.71	0.062
[2]Feed system	HC	1		
	LC	1.41	1.04-1.92	0.027
Likelihood of PREG42				
Breed	HF	1		
	MB	0.91	0.54-1.55	0.737
	NM	1.80	1.08-3.00	0.025
	NRF	1.56	0.96-2.55	0.074
	MBX	1.43	0.85-2.41	0.183
	NMX	1.34	0.78-2.29	0.288
Feeding system	HC	1		
	LC	1.31	0.94-1.82	0.115
Likelihood of FINALPR				
Breed	HF	1		
	MB	1.99	1.04-3.82	0.039
	NM	1.72	0.77-3.85	0.185
	NRF	2.48	1.23-4.97	0.011
	MBX	2.40	1.20-4.80	0.013
	NMX	2.37	1.10-5.08	0.027
Feeding system	HC	1		
	LC	1.51	0.94-2.41	0.086

[1] HF = Holstein-Friesian; MB = Montbèliarde; MBX = Montbéliarde× Holstein-Friesian; NM = Normande; NMX = Normande × Holstein Friesian; NRF = Norwegian Red.

[2] HC = high concentrate feeding system; LC = low concentrate feeding system.

†OR = odds ratio. ‡CI = confidence interval.

Breed of dairy cow had a significant effect (P<0.001) on gestation length. The MB (289 days) had a significantly longer (P<0.01) gestation length than the HF (281 days), MBX (284 days), NMX (284 days) and NR (280 days), and tended (P=0.0892) to have a longer gestation length than the NM (285 days). The NRF had the lightest calves and the least calving difficulty recorded. Of the pure breeds, calving difficulty was highest with the MB. Crossbred cows mated to MB or NM tended to have increased calving difficulty.

Table 5. Calving ease and birth weights

Dam breed	Sire breed	No. records	Calf weight	Assistance
HF	HF	92	41.4	1.40
MB	MB	136	43.4	1.50
HF×MB	HF	85	44.5	1.41
	MB	19	41.3	1.68
NM	NM	60	43.2	1.32
HF×NM	HF	60	43.7	1.20
	NM	12	48.2	1.50
NRF	NRF	117	39.6	1.09

Milk progesterone

Breed of dairy cow did not influence any of the post partum luteal activity profiles studied. However the effect of breed on the first luteal phase and average luteal phase length tended towards significance (P = 0.0689 and P = 0.0687, respectively). The HF had the longest, while the NRF had the shortest first luteal phase and average luteal phase length. The mean CLA across all breeds for the two yr was 31.3 days (standard deviation 13.78), ranging from 29.4 days for the MBX to 33.8 days for the NRF.

Insulin and IGF-1

Neither insulin nor IGF-1 concentrations were influenced by breed at any sampling period. However, insulin and IGF-1 concentrations were different (P < 0.001) over time.

Survival

Survival function curves are presented in Figure 6. Age at first calving for HF, MB, NM, NRF, MBX and NMX was 761 (S.D. 78.7), 777 (S.D. 121.4), 758 (S.D. 110.6) 730 (S.D. 29.1), 744 (S.D. 87.9) and 749 (S.D. 111.9) days, respectively. Minimum and maximum number of days post-first calving were 260 and 1807 respectively for the HF, 130 and 1790 respectively for the MB, 221 and 1770 respectively for the MBX, 248 and 1794 respectively for the NM, 253 and 1774 respectively for the NMX and 259 and 1804 respectively for the NRF. Median survival days post-first calving for the HF, MB, MBX, NM, NMX and the NRF were 695 (1.9 lactations), 1023 (2.8 lactations), 1385 (3.8 lactations), 1068 (2.9 lactations), 1290 (3.5 lactations) and 1416 (3.9 lactations), respectively.

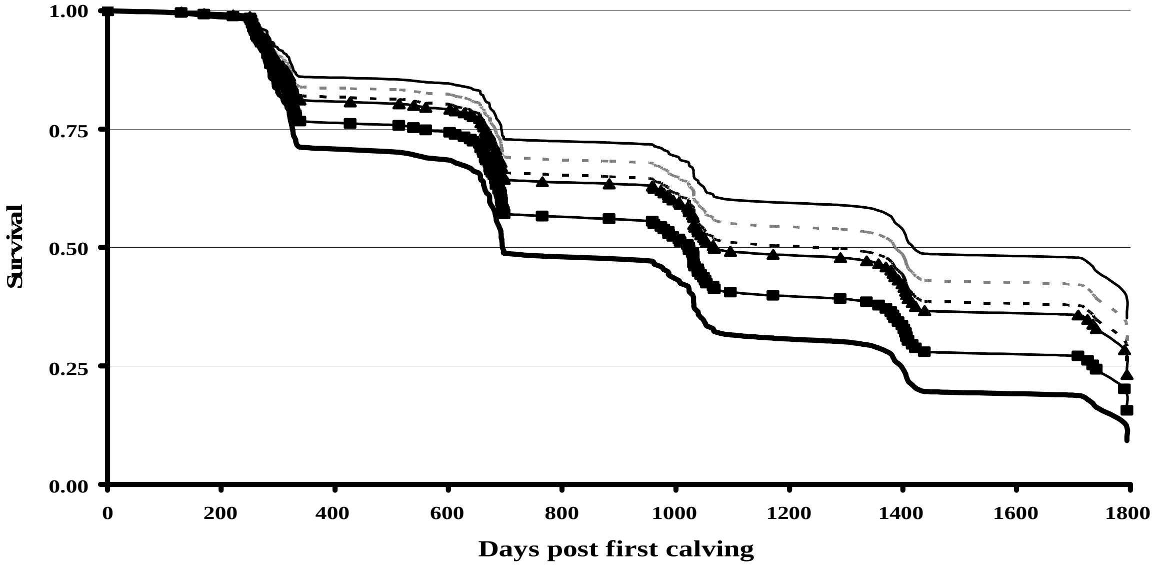

Figure 6. Survival curves for the HF (—), MB (■), NM (▲), NRF (—), MBX (---) and NMX (---) across days post-calving.

DMI and feed efficiency

The effects of genotype and measurement period on milk production, DMI and feed efficiency are presented in Table 6. During the period of measurement genotype had a significant effect on all milk production parameters, while measurement period had a significant effect on all milk production parameters with the exception of MS yield. Daily milk yield was highest with HF (31.6 kg), MBX (30.7 kg), NRF (30.6 kg), lowest with NM (25.2 kg) and intermediate with MB (27.5 kg) and NMX (28.2 kg). Milk fat content was highest with NMX and lowest with MB, NM and NRF. Milk protein content was highest with the NM and NMX and lowest with the NRF. The highest daily MS yield was obtained with the HF (2.25 kg), being significantly higher than all other genotypes with the exception of MBX (2.14 kg), which was intermediate between HF and NRF (2.09 kg) and NMX (2.07 kg), all higher than MB (1.90 kg) which were higher than NM (1.78 kg) breed. Live weight of the NRF was significantly lower than that of the other five genotypes. Genotype had a significant effect on TDMI, being highest with HF (15.8 kg), MBX (15.6 kg), NMX (15.3 kg), and lowest with NM (14.5 kg) and NRF (14.3 kg). Estimated DMI per 100 kg LW of HF (2.99), MBX (3.00), NMX (2.94) and NRF (2.92) were significantly higher than NM (2.70), with that of MB (2.77) intermediate. The DMI per kg metabolic LW measures followed similar trends. Genotype also had a significant effect on yield of MS per kg of DMI. The highest kg of MS produced per kg of DMI was achieved with the NRF, HF and MBX with values of 0.149, 0.146 and 0.142, respectively. These were significantly higher than values observed for the MB (0.135) and NM (0.127) genotypes. There was a tendency towards a significant effect of genotype for RFI. Comparisons between genotypes reveal that estimated RFI was lowest (most favourable) for the NRF (-0.95 UFL), compared to other genotypes with the exception of HF (-0.38 UFL). The RFI values of -0.05, -0.16, -0.10 and -0.10 UFL were estimated for MB, MBX, NM and NMX, respectively. A significant effect of measurement period was observed for all efficiency parameters investigated. While production per unit LW and EB were increased with the higher concentrate allocation (year 1 compared to year 2), efficiency of milk production was generally reduced.

Table 6. The effect of breed group and measurement period on a range of performance and feed efficiency parameters

	Breed group						SE	Sig.	Period				SE	Sig.
	HF	MB	MBX	NM	NMX	NRF			MP1	MP2	MP3	MP4		
Daily milk production														
Milk (kg)	31.6^{a}	27.5^{b}	30.7^{a}	25.2^{c}	28.2^{b}	30.6^{a}	0.65	***	29.7^{a}	30.1^{b}	27.4^{c}	28.6^{d}	0.36	***
Fat (%)	3.81^{a}	3.67^{ac}	3.78^{ac}	3.67^{ac}	3.97^{b}	3.65^{c}	0.073	*	3.62^{a}	3.42^{b}	4.07^{c}	3.93^{d}	0.049	***
Protein (%)	3.31^{ac}	3.28^{a}	3.22^{bd}	3.39^{c}	3.34^{ac}	3.20^{d}	0.032	***	3.27^{a}	3.27^{a}	3.34^{b}	3.27^{a}	0.018	***
Lactose (%)	4.80^{a}	4.93^{bd}	4.84^{ac}	4.94^{bd}	4.89^{cd}	4.78^{a}	0.025	***	4.89^{a}	4.91^{b}	4.80^{c}	4.85^{d}	0.013	***
Milk solids (kg)	2.25^{a}	1.90^{b}	2.14^{ad}	1.78^{c}	2.07^{d}	2.09^{d}	0.049	***	2.05	2.01	2.04	2.06	0.028	NS
Live weight														
Weight (kg)	526^{a}	518^{a}	523^{a}	538^{a}	524^{a}	496^{b}	7.11	***	521^{a}	530^{b}	512^{c}	522^{a}	3.4	***
Δ Weight (kg/day)	0.19	0.03	-0.01	0.09	0.11	-0.05	0.080	NS	-0.05^{a}	-0.13^{b}	0.20^{a}	-0.15^{b}	0.073	***
DM Intake														
Grass DM Intake (kg)	11.2^{a}	10.3^{bc}	11.0^{ab}	9.9^{bc}	10.7^{ab}	9.7^{c}	0.29	***	10.2^{ab}	10.6^{a}	9.7^{b}	11.5^{c}	0.21	***
Total DM Intake (kg)	15.8^{a}	14.9^{bc}	15.6^{ab}	14.5^{bc}	15.3^{ab}	14.3^{c}	0.29	***	16.4^{a}	16.7^{a}	12.7^{b}	14.5^{c}	0.21	***
Efficiency														
Milk solids/100kg LW (kg)	0.43^{a}	0.37^{b}	0.41^{ad}	0.33^{c}	0.39^{d}	0.42^{a}	0.010	***	0.40^{a}	0.39^{b}	0.39^{ab}	0.39^{ab}	0.005	***
Milk solids/TDMI (kg)	0.146^{ad}	0.132^{bc}	0.142^{ad}	0.125^{c}	0.138^{ab}	0.149^{d}	0.0036	***	0.128^{a}	0.121^{b}	0.163^{c}	0.143^{d}	0.0024	***
SCM/TDMI (kg)	1.90^{ad}	1.74^{b}	1.85^{ad}	1.63^{c}	1.80^{ab}	1.95^{d}	0.046	***	1.68^{a}	1.59^{b}	2.11^{c}	1.87^{d}	0.031	***
TDMI/100kg LW (kg)	2.99^{a}	2.87^{ab}	3.00^{a}	2.75^{b}	2.94^{a}	2.92^{a}	0.052	*	3.21^{a}	3.24^{a}	2.45^{b}	2.75^{c}	0.038	***
TDMI/$LW^{0.75}$ (kg)	0.143^{a}	0.137^{bc}	0.143^{a}	0.131^{c}	0.140^{ab}	0.137^{bc}	0.0024	**	0.152^{a}	0.154^{a}	0.117^{b}	0.131^{c}	0.0018	***
Energy Balance (UFL)	-2.21^{ad}	-1.21^{bc}	-1.94^{abd}	-0.84^{c}	-1.55^{abc}	-2.69^{d}	0.329	***	-0.41^{a}	0.05^{b}	-4.12^{c}	-2.50^{d}	0.229	***
Residual Feed Intake (UFL)	-0.38^{ab}	-0.05^{a}	-0.16^{a}	-0.10^{a}	-0.10^{a}	-0.95^{b}	0.270	0.09	1.23^{a}	1.41^{a}	-2.67^{b}	-1.13^{c}	0.206	***

DISCUSSION

Until recently, many breeding programs placed most emphasis on milk production without cognisance of functional traits (e.g. fertility, SCC). Intense genetic selection for milk yield has predisposed animals to increased negative energy balance (EB), greater disease susceptibility (Pryce and Veerkamp, 2001) and decreased fertility (Veerkamp et al., 2003). The current study provided a unique opportunity to investigate the performance of different dairy cow breeds selected with very different breeding objectives across two pasture-based feeding systems. The United States breeding program has exerted considerable influence on dairy cow populations internationally, due to the replacement of native genotypes with North American Holsteins (Evans et al., 2006). Consequently, the rate of genetic gain in milk production per cow per yr since 1985 has been 193, 131, 35 and 46 kg, for the United States, The Netherlands, New Zealand and Ireland, respectively (Dillon et al., 2006). In the current study, the superior milk production of the HF relative to the other breeds reflects the greater emphasis on milk yield in the breeding program from which it originates and agrees with Dillon et al. (2003). Although the Norwegian breeding program encompassed a wide range of traits since the 1970s, milk production has been the most important trait in their breeding objective until 1997 (Andersen-Ranberg et al., 2003). Mean milk yield per cow per yr has increased from 5,428 in 1975 to 6,605 kg in 2005 in Norway (Østerås et al., 2007). Cumulative milk yield of the NRF in this study did not differ to that of the HF. The superior milk production of the HF compared to MBX and NMX in this study corroborates the findings of Heins et al. (2006a), who reported lower milk, fat, protein and lactose yield for MBX and NMX. In the current study, milk production of the crossbreds was higher than the MB and NM. Heterosis estimates for milk production traits are within previously reported ranges (Touchberry, 1992).

The current study did not identify any genotype by environment interaction for milk production. Similarly, Kennedy et al. (2003) reported comparable milk yields for high and medium merit animals offered low and high concentrate supplementation, respectively (approximately 376 and 810 kg/cow per yr, respectively). The difference in concentrate supplementation between the feeding systems imposed by Horan et al (2005a) was greater than for the current study (approximately 1100kg versus 500kg, respectively). Therefore, differences between the feeding systems imposed in the current study may not have been sufficient to elicit a genotype by environment interaction.

Previous studies have highlighted the negative correlations between BCS and BCS change with milk yield (Buckley et al., 2000; Berry et al., 2003b). Furthermore, genetically superior milk producers tend to have greater BCS change in early lactation and lower BCS throughout lactation compared to low genetic merit animals (Buckley et al., 2000). In the current study, the BCS of HF was lower compared to the other breeds throughout lactation. The lower BCS loss over lactation and the lower milk yield reported with the MB and NM relative to that of the HF in the present study are similar to the findings of Dillon et al. (2003). Mean BCS for the NRF was similar to that reported by Yan et al. (2006) and BCS for the NRF in both studies was higher than HF contemporaries. Differences between breeds in their ability to partition energy towards milk production and body reserves have been reported (Dillon et al., 2003; Yan et al., 2006). In the current study, the HF and NRF mobilized similar body condition in early lactation. However, in mid to late lactation the NRF showed a greater propensity to gain BCS than the HF, thus replenishing more body condition for the subsequent lactation. This supports the hypothesis that energy partitioning is under genetic control (Veerkamp et al., 2003). Gallo et al. (1996) reported a decline in mean BCS per lactation for the HF. Begley et al. (2007) reported lower BCS in first lactation HF compared to first lactation NRF.

Body condition score has been shown to be favourably correlated to reproductive performance, both phenotypically (Buckley et al., 2003) and genetically (Berry et al., 2003a). In a seasonal system where grazed grass constitutes a large proportion of the diet such as in Ireland, Buckley et al. (2003) reported reduced 21 day submission rate, PREG1 and PREG42 for HF in low BCS. Lower SR24 and FINALPR were reported here for the HF compared to other breeds. The performance of the NRF is consistent with the breeding objectives for the breed. Female fertility has been included in the Norwegian total merit index since 1972, the relative weighting of which had increased from 5% in 1974 to 14% in 1997 (Andersen -Ranberg et al., 2003). In early lactation, BCS loss was similar for the HF and NRF; however due to differences in pre-calving BCS, the HF reached a lower BCS nadir, the magnitude and duration of which are related to health and fertility (Butler and Smith, 1989). Therefore, BCS could be the mediator of the fertility differences observed between the breeds. A genetic analysis of the French dairy cattle population has shown a decline in the reproductive performance of the Holstein breed in the past decade whereas reproductive performance of the MB and NM have remained stable over the same period (Boichard et al., 2002). Corroborating previous research, varying levels of concentrate offered in tandem with adequate amounts of high quality pasture had resulted in no improvement in reproductive performance (Snijders et al., 2001; Horan et al., 2005b). Higher BCS and BW throughout lactation were observed in animals on the HC diet; however differences between the feeding systems were small.

Observed phenotypes are a function of genotypic (breed) and environmental effects. Previous literature suggests significant genetic variation in SCC and milking characteristics (Mrode and Swanson, 1996; McCarthy et al., 2007a), hence differences in expressed phenotype between breeds may be expected if the breeding programs responsible for the development of the different breeds are diverse. Because milk yield is positively genetically correlated with SCC (Mrode and Swanson, 1996), the higher SCS of the HF, compared to some of the other breeds reported in this study, is perhaps not surprising, considering the progress achieved by the HF in milk production. Similar trends for the HF were reported in previous research that included different breeds (Washburn et al., 2002).

In contrast to the US breeding program, Norway's criteria for the 'ideal cow' were formulated with a broad breeding goal that encompassed dairy, beef, health and reproduction traits (Heringstad et al., 2001). Consistent with the breeding goals of the Norwegian index, the NRF maintained a lower SCS throughout lactation. The MB and NM breeds, with origins in France had intermediate SCS compared to the HF and NRF. A genetic evaluation for SCC was introduced in France in 2001 by INRA (Ducrocq et al., 2001). Although the MB and NM do not stem from a breeding program with long term selection for udder health traits, the differences in SCS among all six breeds suggest that the breeds differ genetically to disease susceptibility.

Grindal and Hillerton (1991) reported that cows with higher PMF are more susceptible to mastitis. A similar trend was observed by McCarthy et al. (2007a) of higher SCS in addition to higher PMF with a New Zealand strain of HF. In this study, despite the crossbreds having the higher PMF and relatively higher SCS compared to all other breeds, a positive relationship between SCS and PMF was not observed. This may relate to the relatively low milk production levels and therefore closer range among breeds than in studies where cows were provided more feed. The positive genetic correlation between milk production and milk flow rates have previously been documented (Petersen et al., 1986); hence the higher AMF of the crossbreds may be a consequence of the higher daily average milk yield attained over their purebred counterparts (MB and NM). Analogous studies (Gandini et al., 2007) of the effect of breed on MD reported a difference between breeds; however these were not significant, which is consistent with the findings in this study. The AMF reported in this study is lower than has been previously documented (Gandini et al., 2007; McCarthy et al., 2007a); however this may be attributable to differences in milk yield by the animals in the respective studies. Oldenbroek (1984) reported that HF heifers milked faster than Dutch-Friesian and Dutch Red and Whites, but because of their higher milk yield, they had similar milking time. In contrast, this study did not observe differences in MD between breeds before or after accounting for milk yield. The nadir of the SCC curve coincides with peak milk production; hence a dilution effect has been suggested as a possible contributor (Wicks and Leaver, 2006). This theory is further supported by this study, where a decrease in SCS per 1 kg increase in daily average milk yield was observed.

Currently, crossbreeding is not common on Irish dairy farms; however interest is growing because of the potential to improve profitability and efficiency through favored selection traits and heterosis. The F1 and backcross cows were grouped together to represent the early stages of a crossbreeding strategy. Exclusion of backcross cows from the analysis did not significantly affect the results for udder health and milking characteristics. Heterosis for SCS was not significant, similar to previous findings of VanRaden and Sanders (2003). The authors are unaware of previous research on the effect of heterosis on milking characteristics. In this study, heterosis for PMF and MD was not significant. However, heterosis for AMF was evident in both crossbred groups at 6.5% and 8% for the MBX and NMX, respectively. Heterosis for milk yield was estimated to be 3% and 2.6% for the MBX and NMX, respectively.

Few studies have investigated the effect of feeding system on udder health (Ouweltjes et al., 2007). Similarly, there is a paucity of information on interactions between breed or genotype and feeding systems in dairy cattle on udder health and milking characteristics. Consistent with previous studies carried out on a grass based system of production, varying levels of concentrate offered (Turner et al., 2003; McCarthy et al., 2007a) did not influence lactation average SCS. However, feeding system had an effect on SCS in late lactation (from wk 21 to 36 inclusive). In the current study, animals on the HC diet had lower SCS, which was probably a dilution effect as higher milk yield was achieved by those on HC diet. In corroborating research in which all production originated from within a grazing environment (McCarthy et al., 2007a), animals offered a high concentrate diet had higher AMF and MD. As tabulated (Table 2), animals offered a high concentrate diet produced more milk. Therefore, the higher milk production coupled with the higher AMF attained by those animals in the HC feeding system supports the positive correlation between milk yield and AMF (Petersen et al., 1986). McCarthy et al. (2007a) and Weiss et al. (2004) observed a positive correlation between milk yield and AMF of 0.64 and 0.29, respectively. In addition, positive correlations have been reported between milk yield and MD (Petersen et al., 1986; Weiss et al., 2004). Similarly, results from this study indicate positive correlations for milk yield with AMF, PMF and MD and that these correlations differ depending on breed. On adjustment for milk yield, feeding system differences in AMF and MD persisted. The authors are unsure why this is the case. It may be that milk yield is not the sole driving force behind the effect of feeding system on AMF and MD. The effect of feeding system on all traits was mediated through, not only milk yield, but also the effect of stage of lactation. Stage of lactation has been previously identified as a determining factor of SCS and milk flow characteristics (Olde Riekerink et al., 2007).

Results from the current study contrast with those of Dillon et al. (2003b) who reported greater conception rate to first service and submission rate in the first three wk of the breeding season for the MB compared to the HF. Our results showed that SR24 and PREG1 did not differ between the HF and MB, which was reflected in the similarity of PREG42 between the breeds. However, likelihood of FINALPR was greater in the MB compared to the HF indicating that a greater proportion of MB conceived late in the breeding season. This factor coupled with the longer gestation length of the MB (Dillon et al., 2003b) contributed to the later calving day of yr for the MB breed, the effect of which was cumulative as parity increased. Collectively, the results indicate that, relative to the other breeds, the lower survival of the MB was contributed by an inability to maintain a 365 day calving interval, while that of the HF was due to their inability to conceive during the breeding season.

Heins et al. (2006b) evaluated the reproductive efficiency of HF, NMX, MBX and Scandinavian Red × HF during first lactation. The results showed that the crossbreds had fewer days to first breeding, had higher first service conception rates, had fewer days open and survived longer compared to the purebred HF during first lactation. The present study found that both crossbred groups had shorter CSI and CCI and were more likely to be pregnant at the end of the breeding season, thus had higher survival rates compared to the HF; however heterosis estimates for these traits was not significant, likely due to the small data size. Lopez-Villalobos et al. (2000) reported advantages of crossbreeding under New Zealand's seasonal calving pasture based system of production, through a reduction in replacement rates and higher milk, fat and protein yields attributable to the ability of the crossbreds to survive longer in the herd. In Ireland, the potential to improve profitability and reproductive efficiency by crossbreeding is generating interest.

Negative EB in the early postpartum period has been cited as the critical regulator of reproductive status as defined by the animal's ability to resume cyclicity (Butler and Smith, 1989). This effect, caused by low energy availability suppresses pulsatile LH secretion, reduces ovarian responsiveness to LH stimulation and ultimately results in delayed ovulation (Butler, 2003). Delayed ovulation reduces the number of oestrus cycles preceding insemination which has been shown to decrease conception rate (Butler and Smith, 1989). Therefore, early re-establishment of luteal activity post partum has been suggested as an indicator trait to select for improved fertility (Darwash et al., 1997; Royal et al., 2000). In non-seasonal dairy systems, Royal et al. (2000) reported lower conception rates for animals with short (≤ 12.9 days) or long CLA (≥ 49 days). Darwash et al. (1997) reported higher conception rates in animals that ovulated earlier postpartum. However, our results provide no evidence that selection for CLA would lead to improved reproductive performance in a seasonal dairy system. Similarly, McNaughton et al. (2007) concluded that in a seasonal grass based dairy system, CLA was not related to fertility; however prolonged CLA post partum (> 70 days) reduced submission rate by decreasing the proportion of animals available for service at the start of the breeding season. Therefore, it will be necessary to take cognisance of different dairy production systems when considering fertility traits for genetic improvement. Royal et al. (2000) reported a significant increase in LP length of almost 2 days from 1975 to 1998, which coincided with the upgrade in the national herd from British-Friesian to HF. Our results show that the HF and NRF had the greatest difference in the first and average luteal phase length. Royal et al (2000) suggested that the length of the luteal phase may provide an indication of uterine environment. Therefore, differences between the breeds in fertility may relate to some underlying difference in endometrial or uterine environment.

Negative EB reduces plasma insulin and IGF-1 concentrations in early lactation. This can lead to poorer ovarian follicular development thus compromising reproductive efficiency (Butler, 2003). Plasma IGF-1 concentrations decrease after calving, and rise gradually as energy status of the cow improves (McGuire et al., 1992). Results from the current study showed that insulin and IGF-1 profiles follow this natural trend. However, breed did not influence insulin and IGF-1 profiles in the peri-parturient period. In a study comparing Jersey, Friesian and crossbred cows on an all-pasture system, Back et al. (2006) reported no difference between the breeds in IGF-1 concentrations in the first 6 wk of lactation. Low IGF-1 concentrations have been associated with a delay in CLA (Roberts et al., 1997). Our results and those of Back et al. (2006) reported no difference between the breeds in CLA. Similarly, no difference in CLA and IGF-1 concentrations were observed in different strains of HF in early lactation (Horan et al., 2005b; McCarthy et al., 2007b). Breed of dairy cow in the current study did not influence insulin and IGF-1 concentrations at the start of the breeding season. However, comparison of circulating insulin and IGF-1 in different strains of Holstein-Friesian (McCarthy et al., 2007b) at the start of and during the breeding season revealed that the high production and high durability strain had lower insulin and IGF-1 concentrations compared to the New Zealand strain.

The importance of feed efficiency as one of the key factors influencing farm profitability has been recognised for many years (Wallace, 1956). Improvements in FCE can be made (all other things being equal) if a cow achieves: (1) higher feed intake per unit of live weight; (2) lower loss of energy in faeces, urine or methane per unit of intake; (3) lower loss of energy as heat for a given intake; or (4) greater partitioning of metabolisable energy to milk and less to body tissue. Selection in dairy cattle principally for increased milk production has been shown to increase LW and feed intake, but also to lower body condition score, resulting in greater mobilisation of adipose tissue in early lactation, lower plasma concentrations of glucose and IGF1 in early lactation and poorer reproductive performance (Veerkamp et al., 2003; Dillon et al., 2006). Therefore, partitioning more metabolisable energy to milk and less to body tissue resulting in greater weight loss will only improve FCE in the short term. Unless the above points 1, 2 or 3 operate there maybe no long term gain in FCE. For these reasons, gross efficiency is not a very useful for identifying sources of genetic variation in feed efficiency. To overcome problems arising from the use of gross efficiency RFI can be used. Unlike measures of gross feed efficiency, RFI attempts to apportion energy intake to the functions for which it is used compared to a population mean. In the case of the lactating dairy cows it apportions the total feed intake to those functions that it is used for i.e. milk production, maintenance and LW gain/loss (Veerkamp and Emmans, 1995).

In this study differences in kg MS produced per unit of DMI were observed between the breeds evaluated. Greatest efficiency was observed with the two ‘dairy breeds’ (HF and NRF) compared to the more dual purpose MB and NM. Intermediate values were obtained with the two crossbred genotypes. This is not surprising given the strong genetic and phenotypic correlation between milk yield and gross efficiency (Veerkamp and Emmans, 1995). The most likely explanation for this is the dilution of maintenance and increased tissue mobilization at higher milk yields. The trend in SCM per kg DMI was similar. Intake capacity, defined as intake per unit LW, was highest for the HF and lowest for the two dual purpose breeds. The ‘dairy’ breeds also had a more favourable RFI. Differences across measurement period were observed for many of the variables. While milk yield increased from Week 4 to Week 8, milk composition tended to reduce, resulting in similar MS yield across measurement period. Intake capacity tended to increase with time, as did LW. However, measures of efficiency generally reduced. With the possible exception of the NRF, the most favourable RFI estimates were obtained in the HF genotype selected most intensively for milk production. This seems plausible. However, the estimates of RFI used in the present study were based on measurements made during a short time period. Such differences in RFI when considered over total lactation or total life time may not hold true. It is accepted, for example, that live weight/live weight change in early lactation is a poor predictor of body tissue composition/tissue mobilisation (Sutter and Beaver, 2000). Furthermore, variation in partial efficiencies and animal characteristics that may influence RFI, likely exist between contrasting genotypes such as those examined in this study (Veerkamp and Emmans, 1995; Yan et al., 1997). Therefore, to be more conclusive, Further investigations that incorporate estimates of intake spanning a lactation cycle are therefore warranted. Buckley et al. (2005) concluded that daily feed intake in a grazing system is limited to lower levels than are achievable on concentrate plus conserved forage rations, and consequently, cows most suited to grazing environments are likely to have a lower genetic potential for milk production than cows selected in high concentrate systems. This approach would facilitate a compatibility between the cow and system, and thus minimise the relative energy deficit in order to optimise production and profit. The key drivers of success are undoubtedly a propensity to achieve high intake per unit LW together with a high yield of MS per unit intake. When the data presented here is considered together with that previously outlined by Buckley et al. (2005) and McCarty et al. (2007b), it is clear that improvements in metabolic efficiency must be made in conjunction with other traits influencing economic efficiency, i.e. a holistic approach must be considered.

CONCLUSIONS

The results from this study highlight differences among dairy cattle breeds for milk production potential, milking characteristics, reproductive efficiency, udder health and management traits such as calving ease. The results highlight the potential benefits that may be gained from utilising positive characteristics from some of these 'alternative' breeds through crossbreeding. The differences expressed likely stem from differences in the breeding goals from which these breeds were established, namely the intensity of selection for milk yield, the inclusion of beef merit and the inclusion of traits aimed at maintaining or improving fertility and udder health. The results of this study highlight in particular the benefits of incorporating health and fertility traits into a breeding program. While the NRF cows in the current study produced slightly less milk compared to the HF, they displayed many favourable traits, namely superior reproductive efficiency and udder health, moderate cow size, favourable feed efficiency, short gestation length and minimal calving difficulty. Therefore, crossbreeding with the NRF is likely to lead to improved profitability on Irish dairy herds. The current study found no significant G×E interactions.

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