Irish Journal of Agricultural and Food Research **43:** 161–176, 2004

Genetic relationships among linear type traits, milk yield, body weight, fertility and somatic cell count in primiparous dairy cows

D.P. Berry[1]†, F. Buckley[1], P. Dillon[1], R.D. Evans[1] and R.F. Veerkamp[2]
[1]*Teagasc, Moorepark Production Research Centre, Fermoy, Co. Cork*
[2]*Animal Resources Development, Animal Sciences Group, Wageningen UR, PO Box 65, 8200 AB Lelystad, The Netherlands*

Phenotypic and genetic (co)variances among type traits, milk yield, body weight, fertility and somatic cell count were estimated. The data analysed included 3,058 primiparous spring-calving Holstein-Friesian cows from 80 farms throughout the south of Ireland. Heritability estimates for the type traits varied from 0.11 to 0.43. Genetic correlations among some type traits were very strong and may indicate the possibility of reducing the number of traits assessed on each animal; the genetic correlation between angularity and body condition score was –0.84. Genetic correlations between all type traits (except body condition score, udder depth and teat length) and milk yield were positive and ranged from 0.08 to 0.69. The possibility of selecting for body weight may be achievable within a national progeny-testing programme using type traits within a selection index. Moderate to strong genetic correlations existed between some type traits and the various fertility measures and somatic cell count indicating the opportunity of indirect selection for improved fertility and health of animals using type traits within a selection index; however, the standard errors of some of the genetic correlations were large and should thus be treated with caution. Genetically taller, wider, deeper, more angular cows with tighter, stronger, shallower udders were predisposed to have inferior pregnancy rates to first service and require more services.

Keywords: Body weight; fertility; genetic; somatic cell count; type

†Corresponding author: dberry@moorepark.teagasc.ie

Introduction

There is by now a general consensus that genetic selection towards increased milk production alone has reduced the genetic merit for health (Pryce *et al.,* 1998) and fertility (Roxström *et al.,* 2001; Berry *et al.,* 2003) in dairy cattle. Continual deterioration in genetic merit for health/fertility internationally has led to increased diversification of selection indexes which now include more non-production, functional traits. However, the long time interval required and the poor recording of some health and fertility traits has led to increased interest in ancillary traits which can be more easily measured, preferably early in life, and possess a co-heritability with the traits of interest that is larger than the heritability of the individual traits of interest. Possible ancillary traits include linear type traits.

Linear type traits describe biological extremes for a range of visual characteristics of an animal. International conversions for sire predicted transmitting ability (PTA) is available for most type traits. Generally the type traits associated with body size tend to show the largest heritabilities (0.07 to 0.59; Brotherstone, 1994; Koenen and Groen, 1998; Pryce, Coffey and Brotherstone, 2000) followed by the udder traits (0.11 to 0.44; Short and Lawlor, 1992; Brotherstone, 1994; Veerkamp and Brotherstone, 1997). Heritability estimates for the feet and legs traits tend to be smallest (0.07 to 0.27; Ahlborn and Dempfle, 1992; Brotherstone, 1994).

Research from other countries indicates the usefulness of linear type traits as predictors of body weight (Veerkamp and Brotherstone, 1997; Koenen and Groen, 1998), health (Rogers *et al.,* 1991; Pryce *et al.,* 1998; Rupp and Boichard, 1999) and fertility (Pryce *et al.,* 1998; Royal *et al.,* 2002) in dairy cattle. Royal *et al.* (2002) inferred negative genetic correlations between commencement of luteal activity and chest width (–0.23), rump width (–0.25), fore-udder attachment (–0.13), and udder depth (–0.16); a positive genetic correlation was evident between commencement of luteal activity and angularity (0.15). Pryce *et al.* (1998) reported only chest width to be genetically correlated with fertility; a narrower chest was associated with longer calving intervals and a lower conception rate to first service.

Both Rogers *et al.* (1991) and Rupp and Boichard (1999) reported negative genetic correlations between somatic cell count (SCC) and udder depth (–0.41 to –0.40) and fore-udder attachment (–0.41 to –0.32) while positive genetic correlations were evident between SCC and teat length (0.08 to 0.20). Although clinical mastitis is more likely to be included in a breeding objective than SCC, the moderate to strong genetic correlations between clinical mastitis and SCC (average of 0.70; for review see Mrode and Swanson, 1996) suggests that selection for reduced SCC may improve resistance to mastitis (Coffey, Vinson and Pearson, 1986).

Other type traits include docility (temperament) and speed (ease) of milking; these traits tend to be assessed by the individual herdsman. Fewer heritability estimates for these traits are available and range from 0.06 to 0.25 (for reviews see Schutz and Pajor, 2001; Rupp and Boichard, 1999; Pryce *et al.,* 2000). Previous estimates of genetic correlations between temperament and milk yield and between ease of milking and milk yield were favourable (for review see Schutz and Pajor, 2001); however, little is known about the genetic relationship between measures of docility and fertility or between speed of milking and fertility.

The objective of the present study was to estimate the genetic (co)variances for linear type traits, milk yield, body weight

(BW), fertility and SCC in a sample of the Irish Holstein-Friesian population. Although the number of records included in the study are relatively few, there is no other published study of the covariances between type traits and fertility involving such detailed fertility measurements.

Materials and Methods

This study, carried out over two years (1999 and 2000) comprised 80 spring-calving dairy herds (76 commercial and 4 research herds) in the south of Ireland with a potential 3,081 primiparous cows with sire information available for inclusion in the analysis. In the present study classifiers scored 2,224 of these cows as part of the study protocol. All herds were incorporated into the Dairy Management Information System (DairyMIS) run by Moorepark Production Research Centre (Crosse, 1986). The DairyMIS is a recorder-based, computerized system for collecting detailed information on stock numbers, farm inputs, production and reproduction on a monthly basis. The pedigree information available on all animals in the study was described in detail by Berry *et al.* (2003).

Data editing

The data were edited to maximise the number of records for each trait included in the analysis so as to more accurately estimate trait variation (e.g., animals with fertility records but no type records were retained so that accurate variance components of fertility could be estimated). Five different Holstein-Friesian herdbook classifiers from Holstein UK and Ireland (HUKI) scored 17 traits on each cow while information on two supplementary traits (temperament and ease of milking) were supplied to the classifier by the herdsman. In this study 'type traits' refers to all these 19 traits. The list of type traits and their abbreviations are presented in Table 1. Each trait was classified on a scale of 1 to 9, inclusive, according to biological extremes (Table 1). Each herd, within year, was classified by only one classifier. Differences between classifiers in their range of scoring were accounted for by adjusting each of the 17 type traits by the ratio of the standard deviation of each classifier to the mean of the standard deviation calculated for each classifier as outlined by Brotherstone (1994); neither temperament nor ease of milking were re-scaled. Animals were assessed between 51 days in milk and 223 days in milk, inclusive. Forty-eight percent of the 2224 cows were registered Holstein-Friesian cows.

Trained Teagasc personnel visited the farms up to nine times annually. Visits were at 2.5- to 4-week intervals and BW of each cow was recorded during each visit. Body weight was measured electronically using portable weighing scales. Body weight at day 5, 60, 120, and 180 days post-partum was estimated for each cow using smoothing splines as outlined by Berry *et al.* (2003). Average BW was calculated as the mean of these estimated test-day records, where the animal had all records present; this minimized bias by ensuring all cows had the same number of BW records evenly dispersed throughout the lactation.

Milk test-day records for each cow were obtained from the Irish Dairy Records Co-operative. Cumulative milk yield to day 240 of lactation was calculated from smoothing splines fitted through each cow's test day records, as outlined by Berry *et al.* (2003). Fitted splines explained 97% of the variation in daily milk yield.

Four fertility variables similar to those used internationally (Grosshans *et al.,* 1997; Veerkamp, Koenen and de Jong, 2001) were calculated: interval to first service (IFS), pregnancy rate to first

Table 1. List of all type traits, with abbreviations and explanation of measurement scale and the corresponding least squares means†, additive genetic standard deviations (σ_g), heritability (h^2) estimates‡ and coefficients of additive genetic variation

Trait	Abbreviation	Score		Mean	σ_g	h^2	cv_g
		1	9				
Stature	STA	130 cm	154 cm	4.1	0.86	0.43	0.21
Chest width	CW	Narrow	Wide	4.9	0.73	0.26	0.15
Body depth	BD	Shallow	Deep	5.3	0.82	0.37	0.15
Angularity	ANG	Coarse	Sharp	5.2	0.85	0.36	0.16
Rump angle	RA	High pins	Low pins	4.3	0.66	0.24	0.15
Rump width	RW	Narrow	Wide	4.9	0.74	0.29	0.15
Body condition score	BCS	Thin	Fat	4.8	0.90	0.33	0.19
Fore-udder attachment	FUA	Loose	Tight	5.0	0.57	0.13	0.12
Rear-udder height	RUA	Very low	Very high	4.9	0.55	0.17	0.11
Udder support	US	Broken	Strong	5.7	0.40	0.11	0.07
Udder depth	UD	Below hocks	Above hocks	5.8	0.72	0.33	0.13
Teat position, rear view	TPR	Wide	Close	4.7	0.63	0.23	0.14
Teat position, side view	TPS	Close	Apart	4.8	0.73	0.38	0.15
Teat length	TL	Short	Long	4.5	0.65	0.21	0.14
Rear legs, side view	RLS	Straight	Sickled	5.6	0.53	0.19	0.09
Foot angle	FA	Low	Steep	5.1	0.51	0.17	0.10
Locomotion	LOCO	Lame	Even gait	5.0	0.41	0.14	0.08
Temperament	TEMP	Nervous	Quiet	5.5	0.42	0.11	0.08
Ease of milking	EASE	Slow	Fast	5.5	0.29	0.12	0.05

†Standard errors of the means ranged from 0.04 to 0.11.
‡Standard errors of the heritability estimates ranged from 0.02 to 0.04.

service (PRFS), number of services per cow (NS), and pregnant 63 days after the start of the breeding season (PR63). The start of the breeding season for each herd was defined as the first service date recorded in that herd; start of breeding dates were available for both years of the study. Pregnant 63 days after the start of breeding was chosen to identify cows which conceive relatively early in the breeding season, an attribute conducive to a successful compact spring calving system. A total of 2,705 primiparous cows had identified first service records and parentage information. In Ireland most farmers use artificial insemination for the first 6 weeks of the breeding season and natural mating thereafter. Ninety two percent of farmers participating in the study observed cows more than twice daily for estrus during the breeding season, while 99% of farmers used tail paint and/or a vasectomized bull as an aid to estrous detection. This facilitated accurate recording of all services. Beginning 40 to 50 days after the start of the breeding season all herds were visited on three or four occasions, at approximately 40-day intervals, to perform pregnancy diagnosis by trans-rectal ultrasound imaging (Aloka 210D*II, 7.5 MHz). Cows at least 28 days inseminated and subsequently not observed in estrus were scanned to confirm pregnancy. Subsequently, all cows in the study were determined to be pregnant or not by rectal palpation of the entire herd at least 56 days after the end of the defined breeding season. Hence all cows were at least 56 days served. No pregnancy diagnosis was carried out thereafter as part of the study. No cognisance was taken of further losses beyond this point.

A single SCC figure per lactation was derived as the arithmetic mean of the natural logarithm of monthly SCC test day records. No restriction was placed on the number of SCC tests per lactation so as to avoid any selection bias against cows culled for high SCC in early lactation as suggested by Heringstad, Klemetsdal and Ruane (2000). The distribution of the mean SCC variable was normal.

Cows with missing values for any variable were coded as such, but remained in the analyses for the rest of the variables. The final data set consisted of 3,058 primiparous cows of which 2,224 had linear type trait records. A total of 2,104 animals had information on both type traits and fertility records. The additive genetic relationship matrix included 8,280 animals (i.e., includes animals with records and their pedigree).

Data analysis

A complete multivariate analysis for all traits simultaneously was not computationally feasible. For this reason, a series of multivariate analyses were carried out using a variance component estimation package (Neumaier and Groeneveld, 1998). Firstly, three separate multivariate analyses were undertaken within groups of related linear type traits – the body-related traits (stature, chest width, body depth, angularity, rump angle, rump width and body condition score), the udder-related traits (fore-udder attachment, rear-udder height, udder support, teat placement side view, teat placement rear view and teat length), and the feet and miscellaneous traits (rear legs side view, foot angle, locomotion, temperament and ease of milking). Subsequently, correlations between each group of related type traits with all other traits were estimated singly by including the trait of interest in the multivariate analysis and the additive genetic and residual covariance matrices were re-estimated.

Herd-year-season groups were formed. Season was defined as month of calving. Herd-year-season groups with less than four cows had their records moved into an adjoining season group from the same herd-year to facilitate a more accurate estimate. North-American Holstein percentage of the cows in the present study varied from 0% to 75% with an average of 60%. However, the maximum Holstein percentage a cow on the study may have is 75% as the maternal grand dam was assumed to have 0% Holstein genes. The latter assumption was made because most maternal grand dams were unknown. In addition the base population in Ireland prior to the mid-eighties was predominantly British Friesian.

The following linear animal model was used for the multivariate analyses:

$$Y_{ijp} = \mu_p + HYS_j + \sum_{t=1}^{2} b_t Hol_i^t + DIM + \sum_{m=1}^{2} b_m SOB_i^m + \sum_{n=1}^{2} b_n EOB_i^n + a_i + e_{ijp}$$

where:

Y_{ijp} = observation for trait p on animal i,
μ_p = overall mean for trait p,
HYS_j = fixed effect of herd-by-year-by-month-of-calving interaction (j = 1 to 302),
$\sum_{t=1}^{2} b_t Hol_i^t$ = fixed effect of a quadratic polynomial regression for the percentage of Holstein genes,
DIM = fixed effect of a linear regression on days in milk at assessment,
$\sum_{m=1}^{2} b_m SOB_i^m$ = fixed effect of a quadratic polynomial regression for the number of days between calving and the start of the breeding season,
$\sum_{n=1}^{2} b_n EOB_i^n$ = fixed effect of a quadratic polynomial regression for the number of

days between calving and the end of the breeding season,
a_i = random additive genetic effect,
e_{ijp} = random residual term.

The linear regression on days in milk was only included for the linear type traits and the quadratic regression on calving to the start of the breeding season and the quadratic regression on calving to the end of the breeding season were only included for the fertility traits. Age at calving was not included in the model as accurate date of birth information was not available for all animals in the data. Nevertheless, herds included in the present study operated a compact calving season and thus the variation in age at calving is expected to be minimum.

The effects of alternative selection indexes on the accuracy of selection were investigated using selection index theory (Hazel, 1943). The genetic and phenotypic parameters used in all index calculations were those estimated in the present study.

Results

The least squares means, genetic standard deviations, heritability estimates and coefficients of genetic variation are given for all 19 type traits in Table 1. Mean milk yield was 4596 kg; the standard deviation for milk yield was 703 kg. Heritability estimates for the body-related type traits were largest (0.24 to 0.43). Heritability estimates for the udder-related type traits varied from 0.11 to 0.38 while heritability estimates for type traits related to feet and legs varied from 0.14 to 0.19. The largest genetic variation existed for the body-related type traits; the coefficient of genetic variation for the body-related type traits was greater than 0.14 for all of these traits.

The heritability estimates and the associated errors (s.e.) across the various multivariate analyses for the fertility traits and somatic cell counts were all ≤0.07 [IFS (0.05; s.e.<0.012), NS (0.04; s.e.<0.016), PRFS (0.03; s.e.<0.013), PR63 (0.05; s.e.<0.019) and SCC 0.07 (s.e.<0.02)].

Correlations among type traits

The phenotypic and genetic correlations among the different type traits are summarised in Table 2. The phenotypic correlations tended to be weaker than their corresponding genetic correlations although the signs of the correlations were generally the same. A strong negative genetic correlation existed between angularity and body condition score (BCS) (–0.84) while a strong positive genetic correlation existed between chest width and BCS (0.77). Genetically stronger cows (taller, deeper cows with low pins) tended to have stronger fore-udder attachments and stronger udder support; these animals also tended to have a higher locomotion score and were more docile and exhibited a faster speed of milking.

A strong genetic correlation existed between udder depth and fore-udder attachment (0.92); cows with shallow udders possessed tighter fore-udder attachments. Cows with genetically stronger, shallower udders had more sickled rear legs, with low foot angles; these animals were faster milkers.

A strong negative genetic correlation existed between foot angle and rear legs, side view (–0.88) indicating that cows with a steep foot angle tended to have straighter rear legs; there was also a tendency for these cows to be more docile.

Correlations of type traits with milk production and body weight

Genetic correlations between all type traits (except BCS, udder depth and teat length) and milk yield were positive (Tables 3, 4, and 5). Genetic correlations between either stature, chest width, body depth, rump angle, rump width or BCS

Table 2. Phenotypic† (above diagonal) and genetic (below diagonal) correlation (s.e. of genetic correlation in parentheses) between the type traits

Trait‡	Trait‡																		
	STA	CW	BD	ANG	RA	RW	BCS	FUA	RUA	US	UD	TPR	TPS	TL	RLS	FA	LOCO	TEMP	EASE
STA		0.38	0.52	0.30	0.06	0.54	0.08	0.13	0.19	0.10	0.18	0.05	0.12	0.13	0.00	0.09	0.07	0.14	0.12
CW	0.37 (0.056)		0.54	–0.24	0.04	0.58	0.58	–0.01	0.01	–0.05	–0.16	0.00	0.09	0.11	–0.05	0.11	–0.01	0.05	–0.03
BD	0.61 (0.041)	0.80 (0.043)		0.30	–0.04	0.49	0.11	–0.02	0.20	0.14	–0.25	0.06	0.24	0.13	0.05	–0.02	–0.03	0.14	0.10
ANG	0.41 (0.050)	–0.36 (0.062)	0.25 (0.057)		–0.07	0.05	–0.61	0.02	0.39	0.35	–0.01	0.15	0.27	0.04	0.13	–0.07	0.00	0.43	0.27
RA	0.02 (0.054)	–0.07 (0.097)	–0.38 (0.087)	–0.24 (0.052)		0.03	0.08	–0.07	–0.15	–0.05	–0.05	–0.02	–0.03	0.02	0.01	–0.04	0.06	–0.04	0.01
RW	0.68 (0.049)	0.65 (0.058)	0.75 (0.049)	0.17 (0.066)	0.17 (0.089)		0.31	0.05	0.14	0.03	–0.04	0.03	0.13	0.12	0.03	0.04	–0.01	0.07	0.06
BCS	0.07 (0.057)	0.77 (0.043)	0.28 (0.071)	–0.84 (0.033)	0.14 (0.074)	0.31 (0.073)		0.02	–0.18	–0.24	–0.05	–0.05	–0.10	0.04	–0.17	0.11	0.04	–0.04	–0.18
FUA	0.82 (0.050)	–0.10 (0.087)	0.15 (0.087)	0.44 (0.094)	0.21 (0.119)	0.43 (0.108)	–0.13 (0.093)		0.27	0.17	0.50	0.28	–0.08	–0.18	–0.04	0.06	–0.06	0.11	0.07
RUA	0.46 (0.060)	0.13 (0.076)	0.53 (0.061)	0.74 (0.052)	–0.49 (0.075)	0.40 (0.075)	–0.35 (0.081)	0.35 (0.081)		0.45	0.10	0.29	0.25	0.01	0.04	0.01	–0.08	0.17	0.17
US	0.22 (0.084)	–0.17 (0.089)	0.25 (0.088)	0.81 (0.060)	–0.23 (0.108)	0.05 (0.105)	–0.62 (0.088)	0.31 (0.113)	0.75 (0.099)		0.11	0.36	0.23	–0.02	0.04	–0.02	–0.01	0.12	0.14
UD	0.54 (0.061)	–0.44 (0.086)	–0.20 (0.066)	0.34 (0.080)	0.00 (0.093)	–0.11 (0.077)	–0.28 (0.087)	0.92 (0.030)	0.17 (0.081)	0.25 (0.116)		0.14	–0.26	–0.14	–0.06	0.09	0.01	0.02	0.06
TPR	–0.18 (0.053)	–0.02 (0.055)	0.03 (0.059)	0.24 (0.060)	0.02 (0.085)	0.02 (0.075)	–0.12 (0.063)	0.40 (0.071)	0.54 (0.060)	0.54 (0.059)	0.15 (0.062)		0.25	–0.20	0.02	–0.02	0.03	0.10	0.11
TPS	–0.17 (0.073)	0.19 (0.064)	0.21 (0.070)	0.19 (0.067)	0.11 (0.087)	0.13 (0.099)	–0.18 (0.072)	–0.39 (0.070)	0.22 (0.057)	0.22 (0.066)	–0.59 (0.043)	0.46 (0.040)		0.02	0.06	–0.01	0.06	0.10	0.11
TL	0.08 (0.048)	–0.05 (0.037)	–0.03 (0.033)	0.08 (0.027)	–0.14 (0.057)	–0.27 (0.032)	–0.09 (0.031)	–0.22 (0.117)	0.16 (0.059)	0.01 (0.056)	0.01 (0.084)	–0.32 (0.066)	0.06 (0.084)		0.00	0.01	0.03	0.05	–0.01
RLS	–0.03 (0.067)	–0.06 (0.091)	–0.02 (0.069)	0.10 (0.114)	0.04 (0.074)	0.00 (0.092)	–0.37 (0.107)	0.50 (0.093)	0.32 (0.077)	0.36 (0.076)	0.32 (0.085)	0.19 (0.074)	0.16 (0.060)	–0.09 (0.086)		–0.56	0.01	–0.04	0.04
FA	0.27 (0.085)	0.22 (0.078)	0.18 (0.082)	0.02 (0.087)	0.02 (0.104)	–0.02 (0.116)	0.19 (0.089)	–0.25 (0.082)	–0.27 (0.063)	–0.41 (0.062)	–0.16 (0.076)	–0.10 (0.062)	–0.23 (0.060)	–0.01 (0.102)	–0.88 (0.044)		–0.02	0.08	0.11

Table 2. (continued)

Trait‡	STA	CW	BD	ANG	RA	RW	BCS	FUA	RUA	US	UD	TPR	TPS	TL	RLS	FA	LOCO	TEMP	EASE
LOCO	0.36	0.07	0.45	0.50	−0.59	0.37	−0.14	0.09	0.27	0.16	0.06	−0.03	−0.18	−0.04	−0.30	0.25		0.10	0.14
	(0.065)	(0.080)	(0.078)	(0.084)	(0.073)	(0.096)	(0.080)	(0.086)	(0.054)	(0.082)	(0.084)	(0.053)	(0.060)	(0.066)	(0.128)	(0.132)			
TEMP	0.25	0.01	0.21	0.27	−0.18	0.18	−0.14	0.07	0.49	0.05	0.03	0.06	0.00	0.00	−0.33	0.56	0.79		0.27
	(0.094)	(0.109)	(0.100)	(0.099)	(0.120)	(0.140)	(0.120)	(0.121)	(0.071)	(0.129)	(0.120)	(0.094)	(0.089)	(0.121)	(0.117)	(0.106)	(0.088)		
EASE	0.58	0.17	0.41	0.63	0.35	0.38	−0.34	0.38	0.46	0.50	0.37	0.09	0.22	0.15	0.55	−0.14	0.21	0.56	
	(0.081)	(0.089)	(0.092)	(0.078)	(0.097)	(0.104)	(0.083)	(0.099)	(0.100)	(0.112)	(0.079)	(0.066)	(0.065)	(0.107)	(0.077)	(0.112)	(0.120)	(0.112)	

†Standard errors of the phenotypic correlations ranged from 0.016 to 0.027.
‡See Table 1 for definitions.

and average BW were all moderate to strongly positive (Table 3) indicating that taller, wider, deeper cows in better condition tended to be heavier. The accuracy of selection on BW with a progeny group size of 50 half-sib daughters was 0.79 when the index included stature, chest width and rump width; this compares to an accuracy of 0.90 when BW was used alone with a progeny group size of 50.

Genetic correlations between BW and the udder- and leg-related type traits were all near zero with the exception of fore-udder attachment (0.40) and rear legs side view (0.21). The direction of the phenotypic correlations were generally the same as the genetic correlations although the strength of the correlations was lower than the respective genetic correlations (results not shown).

Correlations of type traits with fertility and somatic cell count

Genetically taller, wider, deeper more angular cows with high pins had lower genetic merit for pregnancy rate both to first service and 63 days after the start of breeding; these animals also tended to require more services (Table 3). Cows with genetically tighter fore udders and higher, shallower udders with stronger support also had lower pregnancy rate to first service and required more services (Table 4). Similarly, cows with shorter teats that were further apart from a rear view but closer together from a side view had inferior pregnancy rate to first service and required more services. Cows with straighter rear legs and a steeper foot angle were served later (greater IFS) and had inferior pregnancy rate to first service.

Wider, less-angular cows with more body condition and lower pins had lower SCC (Table 3). Similarly, cows with tighter fore-udder attachments and stronger udders

Table 3. Genetic correlations (s.e. in parentheses) of the body-related type traits with milk yield, body weight, fertility and somatic cell count

	Trait†						
Trait‡	MILK	BW	IFS	NS	PRFS	PR63	SCC
STA	0.42	0.63	–0.33	0.67	–0.64	–0.44	–0.09
	(0.050)	(0.015)	(0.075)	(0.106)	(0.200)	(0.100)	(0.078)
CW	0.24	0.80	–0.51	0.45	–0.44	–0.06	–0.39
	(0.044)	(0.026)	(0.104)	(0.080)	(0.112)	(0.077)	(0.135)
BD	0.36	0.68	–0.17	0.76	–0.75	–0.49	–0.06
	(0.050)	(0.024)	(0.086)	(0.094)	(0.157)	(0.101)	(0.111)
ANG	0.48	–0.10	0.37	0.26	–0.24	–0.48	0.33
	(0.045)	(0.035)	(0.083)	(0.170)	(0.215)	(0.107)	(0.075)
RA	0.24	0.29	–0.83	–0.31	0.31	0.42	–0.42
	(0.081)	(0.037)	(0.079)	(0.171)	(0.170)	(0.102)	(0.104)
RW	0.46	0.74	–0.53	0.80	–0.80	–0.22	–0.40
	(0.058)	(0.040)	(0.104)	(0.107)	(0.122)	(0.122)	(0.103)
BCS	–0.15	0.50	–0.53	0.13	–0.14	0.35	–0.57
	(0.055)	(0.024)	(0.109)	(0.116)	(0.122)	(0.056)	(0.099)

†MILK = milk yield to day 240 of lactation; BW = average body weight; IFS = interval to first service; NS = number of services; PRFS = pregnant to first service; PR63 = pregnant 63 days after the start of breeding; SCC = somatic cell count.
‡See Table 1 for definitions.

with shorter, closer teats had lower SCC levels (Table 4). Cows with straighter rear legs and steep foot angles were genetically predisposed to lower average SCC during lactation. Quieter cows also tended to have lower average SCC during lactation.

Discussion

With a scale of 1 to 9, it was expected that the mean of each type trait would be approximately five and the phenotypic standard deviation would be 1.5. Based on the data from the present study the mean

Table 4. Genetic correlations (s.e. in parentheses) of the udder-related type traits with milk yield, body weight, fertility and somatic cell count

	Trait†						
Trait‡	MILK	BW	IFS	NS	PRFS	PR63	SCC
FUA	0.32	0.40	–0.52	0.36	–0.38	0.17	–0.25
	(0.133)	(0.075)	(0.119)	(0.079)	(0.090)	(0.066)	(0.082)
RUA	0.48	0.22	0.36	0.43	–0.29	–0.26	–0.16
	(0.086)	(0.087)	(0.146)	(0.060)	(0.104)	(0.073)	(0.086)
US	0.36	0.12	0.02	0.23	–0.15	0.12	0.45
	(0.108)	(0.114)	(0.126)	(0.085)	(0.154)	(0.113)	(0.110)
UD	–0.05	0.10	–0.57	0.24	–0.31	0.20	–0.07
	(0.090)	(0.061)	(0.058)	(0.059)	(0.103)	(0.046)	(0.057)
TPR	0.51	–0.01	0.38	–0.29	0.30	0.08	–0.28
	(0.066)	(0.056)	(0.107)	(0.033)	(0.067)	(0.056)	(0.041)
TPS	0.36	–0.05	0.57	–0.30	0.45	–0.12	0.06
	(0.044)	(0.035)	(0.091)	(0.045)	(0.087)	(0.060)	(0.055)
TL	–0.14	–0.23	0.28	0.02	0.30	0.03	0.31
	(0.064)	(0.085)	(0.126)	(0.083)	(0.060)	(0.096)	(0.075)

†See Table 1 for definitions.

Table 5. Genetic correlations (s.e. in parentheses) between the leg-related type traits and miscellaneous traits with milk yield, body weight, fertility and somatic cell count

	Trait†						
Trait‡	MILK	BW	IFS	NS	PRFS	PR63	SCC
RLS	0.21	0.21	-0.86	0.05	0.36	0.02	0.67
	(0.060)	(0.063)	(0.113)	(0.088)	(0.123)	(0.075)	(0.102)
FA	0.08	–0.02	0.84	0.01	–0.38	–0.30	–0.53
	(0.068)	(0.077)	(0.060)	(0.095)	(0.138)	(0.072)	(0.127)
LOCO	0.21	0.04	0.71	0.42	–0.32	0.16	–0.28
	(0.093)	(0.077)	(0.132)	(0.093)	(0.259)	(0.133)	(0.180)
TEMP	0.44	–0.02	0.74	0.23	–0.35	0.08	–0.42
	(0.077)	(0.086)	(0.176)	(0.178)	(0.281)	(0.095)	(0.178)
EASE	0.69	0.36	–0.18	0.36	–0.16	–0.15	0.24
	(0.060)	(0.104)	(0.248)	(0.149)	(0.212)	(0.098)	(0.170)

†See Table 1 for definitions.
‡See footnote to Table 3 for definitions.

of the re-scaled scores for each of the 17 type traits assessed by official HUKI classifiers varied from 4.1 to 5.8 and the phenotypic standard deviation varied from 1.1 to 1.6. Only BCS and fore-udder attachment had phenotypic standard deviations greater than 1.5. The standard deviation for ease of milking, which was assessed by each farmer, was only 0.8 which would indicate a reluctance of farmers to use the extremes of the scale.

The heritability of SCC was within the range of most recent estimates (for review see Heringstad *et al.,* 2000). Therefore, genetic selection for reduced lactation average SCC may be fruitful; this may have benefits in reducing the incidence of clinical mastitis (Philipsson, Ral and Berglund, 1995).

Body-related type traits

The heritability for the body-related type traits (stature, chest width, body depth, angularity, rump angle, rump width and BCS) varied from 0.24 (rump angle) to 0.43 (stature) and agree with previous reports from UK and Irish data sets (Brotherstone, McManus and Hill, 1990; Veerkamp and Brotherstone, 1997) and other international studies (Short, Lawlor and Lee, 1991; Pérez-Cabal and Alenda, 2002). The larger coefficients of genetic variation for the body-related traits also agree with previous reports; calculations on the results from Brotherstone *et al.* (1990) revealed coefficients of genetic variation varying from 0.11 (angularity and rump width) to 0.22 (stature).

The strong antagonistic genetic correlation between angularity and BCS (–0.84) questions the necessity of assessing both traits on the same animal since they appear to be genetically very similar, yet directly opposite traits; the phenotypic correlation between the two traits was also strong (–0.61). Veerkamp and Brotherstone, (1997) reported a similar genetic correlation (–0.77) between angularity and average BCS in cows and heifers; angularity in that study was measured on a scale of 1 to 9 while BCS was measured by a separate classifier on a scale of 0 to 5.

Genetic correlations between milk yield and the body-related type traits may reflect past emphasis on milk production simultaneously with increased cow stature, width, depth and angularity in Holstein breeding programmes. The outcome is taller, wider, deeper cows that tend to be more angular and have less body condition. The signs of the genetic correlations between milk production and the body-related type traits estimated in the present study are not in full agreement with previous literature. Although most previous studies yielded positive genetic correlations between milk production and stature, body depth and angularity (Short and Lawlor, 1992; Brotherstone, 1994; Parke *et al.,* 1999; DeGroot *et al.,* 2002), some studies yielded negative genetic correlations between milk yield and chest width, rump width (Meyer, Brotherstone and Hill, 1987; Brotherstone, 1994) and rump angle (Brotherstone, 1994).

The moderate to strong genetic correlations between most of the body-related type traits and average BW is expected given that the body-related type traits reflect an element of size of the animal. Ahlborn and Dempfle (1992) and Parke *et al.* (1999) reported genetic correlations between stature and BW of 0.92 and 0.61, respectively. The ability of some body-related type traits to predict genetic merit for BW suggests that the inclusion of BW within a selection objective for Ireland may be achievable through the use of linear type traits as predictors of BW.

Genetically taller, wider, deeper, more angular cows with high pins had lower pregnancy rates and required more services. This disagrees with results from Pryce *et al.* (1998) who reported that cows with narrower chests had poorer conception rate to first service. Based on the genetic parameters estimated in the present study an increase in genetic merit for angularity by one unit would reduce the genetic merit for PR63 by five percentage points; the genetic standard deviation of PR63 was taken as 0.09%. The direction of the correlations with IFS reported in the present study agree with those from Royal *et al.* (2002) who regressed commencement of luteal activity on sire PTA for the various type traits.

Cows with genetically wider pins and sloping rumps are reported to be predisposed to a lower incidence of dystocia (Ali, Burnside and Schaeffer, 1984). Although calving ease was not included in the analysis the negative genetic correlation between rump angle and IFS and between rump width and IFS may be indicative of cows which had easier calvings; Thompson, Pollak and Pelissier (1983) reported that a reduced intensity of dystocia was associated with a shorter IFS.

The negative and positive genetic relationships, respectively, between SCC and chest width and between SCC and angularity agree with the signs of the regression coefficients reported by Pryce *et al.* (1998) between somatic cell score and sire PTAs for chest width and angularity. Similarly, Lund *et al.* (1994) reported a positive genetic correlation (0.37) between dairy character (a trait similar to angularity) and SCC. More angular cows with low body condition score may be indicative of cows in negative energy balance and may therefore be under greater metabolic stress. This may have deleterious consequences for their immune system making them more susceptible to mammary infections. Nevertheless, the economic benefits attainable from selecting towards coarser animals (i.e., lower angularity score) may be offset by reduced genetic gains in milk production due to the moderate correlation between angularity and milk production (0.48) reported in the present study; gains in all traits may be optimally achieved by including both traits (or related traits) in a selection index.

Udder-related type traits

The heritabilities for the udder-related type traits (0.13 to 0.38) agree with other estimates for udder-related type traits (Brotherstone *et al.,* 1990; Short *et al.,* 1991; Veerkamp and Brotherstone, 1997).

The strong phenotypic (0.50) and genetic (0.92) correlations between fore-udder attachment and udder depth indicate the possibility of reducing the number of type traits assessed on each animal with the loss of very little information. The strength of the correlation between fore-udder attachment and udder depth are slightly stronger than previous reports (Brotherstone *et al.,* 1990; Lund *et al.,* 1994; DeGroot *et al.,* 2002).

Genetic correlations between the udder type traits and milk production indicate that genetic selection for increased milk production alone will result in cows with tighter fore-udder attachments and stronger udders. Although Brotherstone (1994) also reported a positive genetic correlation (0.10) between udder support and milk yield, Brotherstone (1994) reported a negative genetic correlation (–0.29) between fore-udder attachment and milk yield; this was despite the strong genetic correlation between fore-udder attachment and udder depth (0.76) reported in the same study by Brotherstone (1994). Corroborating results of Brotherstone (1994), Norman *et al.* (1988) reported higher yields in cows with looser fore-udder attachments and deeper udders across five breeds of dairy cows. Differences between the present study and previous analyses on the correlations with milk production may be partly attributed to differences in the definition of milk yield; milk yield in the present study was cumulative 240-day yield estimated from predicted test-day records using smoothing splines. Mean lactation yield predicted in the present study (4596 kg) is considerably less than mean lactation yield reported by Norman *et al.* (1988); across five breeds the mean lactation yield varied from 5738 kg to 7096 kg. Differences in correlations between studies may also be due to Irish farmers placing greater selection emphasis on tighter udder attachments simultaneously with high milk yield.

The moderate genetic correlation between milk production and teat position indicate that selection on milk yield alone will result in teats that are closer together from the rear view, yet further away from a side view, the latter probably reflecting udder capacity. This may have practical implications for efficient milking, especially with robotic milking systems; Jagtenberg and van Scheppingen (1994) reported that cows with poor teat placement are unlikely to be compatible with robotic milking systems. Thus, a combined selection objective including teat placement may be warranted to alleviate the deleterious effects of selection on milk yield.

The antagonistic genetic correlations between favourable udder conformation and PRFS disagree with Pryce *et al.* (1998) who found no genetic association between any of the udder-related type traits and conception rate to first service. The positive genetic correlations (0.13 to 0.26) reported by Pool *et al.* (2002) between udder depth and survival, adjusted for milk yield, in the first three parities in Irish cattle agree with the genetic correlation between udder depth and PR63 (0.20) reported in the present study.

The signs of the genetic correlations between the udder type traits and SCC are in close agreement with previous estimates of genetic correlations between udder type traits and SCC and mastitis (Boettcher, Dekkers and Kolstad, 1998; Mrode, Swanson and Winters, 1998; Rupp and Boichard, 1999). The positive genetic correlation between SCC and teat length (0.31) is stronger than a previous estimate (0.20) in primiparous cows (Rogers *et al.,* 1991). The increased SCC in cows with longer teats may be due to longer teats being more prone to injury from housing, handling and milking. Rogers and Spencer (1991) reported a tendency (although not significant) of increased linear slippage with longer teats; linear slippage during milking has been implicated as a cause of new infections to the udder (O'Shea *et al.,* 1975).

The strongest absolute genetic correlation with SCC involved udder support (0.45) indicating that animals with genetically stronger udder support were genetically predisposed to higher lactation average SCC level. The direction of the relationship between udder support and SCC agrees with Pryce *et al.* (1998) who reported a highly significant positive regression coefficient between udder support and both SCC on a transformed scale and incidence of mastitis.

Type traits related to feet and legs

The heritability for foot angle (0.17), rear legs side view (0.19) and locomotion (0.14) all agree with previous reports on Holstein-Friesian cows (Short *et al.,* 1991; Brotherstone *et al.,* 1990; Veerkamp and Brotherstone, 1997). Sound feet and legs are more important in grazing systems where emphasis is on superior locomotive properties to enable efficient grazing. The economic importance of including type traits associated with feet and legs in an overall breeding objective may therefore be greater in such systems.

The strong negative phenotypic (–0.56) and genetic (–0.88) correlations between rear legs side view and foot angle are stronger than previous literature estimates (Brotherstone *et al.,* 1990; Short and Lawlor, 1992; Degroot *et al.,* 2002) but nevertheless indicate the degree to which the two traits reflect similar characteristics of the legs. The low phenotypic standard deviation of locomotion (1.1 units) when coupled with the lack of strong phenotypic and genetic correlations between locomotion and either foot angle or rear legs side view suggests inaccurate assessment of the locomotion trait. However, Pryce *et al.* (1998) also failed to identify any significant relationship between foot angle and locomotion and between rear legs set (a trait similar to rear legs side view assessed in the present study) and locomotion; locomotion in that study was assessed as a binary (0/1) trait by the individual farmer. Similarly, Groen, Hellinga and Oldenbroek (1994) reported a weak correlation (–0.01) between rear legs set and feet and leg problems across 44 different farms in the Netherlands. Hence, questions should also be raised on the definition of the foot and leg traits and how they reflect the locomotive characteristics of the animal.

The weak genetic correlation between foot angle and milk yield agrees with previous studies (Brotherstone, 1994) although in the present study the correlation was less than twice the associated standard error. Cows with genetically straighter rear legs and steeper foot angles had a reduced chance of becoming pregnant to first service. The positive genetic correlation between foot angle and IFS disagrees with the sign of the genetic relationship between foot angle and the interval to commencement of luteal activity measured using progesterone assays (Royal *et al.,* 2002). However, the correlation between foot angle and IFS was very strong (0.84) and may be an artifact of the small data set in the present study; the standard error of the correlation was 0.06.

The unfavourable correlations between locomotion and fertility contrasts with previous reports comparing incidence of lameness with fertility; Pryce *et al.* (1998) showed that increased incidence of lameness was associated with longer IFS and poorer conception rate to first service.

Peeler, Otto and Esslemont (1994) found that if a cow became lame in the period before service there was less chance of observing oestrus. However, in the present study only one animal was assessed prior to 73 days in milk which was the average interval from calving to first service for the present study (Berry *et al.,* 2003). Therefore, locomotion post first service may not have had as much an influence as locomotion prior to first service.

Temperament and ease of milking

Heritability estimates for temperament and ease of milking were the lowest for the type traits investigated which is not surprising given that both traits were scored by the individual herdsmen; such scoring may not be consistent across herds. Nevertheless, the estimates of heritability for these traits were within the range of estimates reported in the review of Schutz and Pajor (2001).

The genetic correlation between temperament and ease of milking (0.56) is slightly larger than previous estimates (0.36 to 0.53) reported for other Holstein-Friesian populations (Foster *et al.,* 1988; Lawstuen *et al.,* 1988; Vischer and Goddard, 1995). The positive relationship is expected given the effect of fear, and the associated epinephrine and adrenal response, on oxytocin release and milk letdown (Schmidt, van Vleck and Hutjens, 1988).

The positive genetic correlation between temperament and milk yield and between milking ease and milk yield tend to agree with most other studies when account is taken of the different scales of measurement (for review see Schutz and Pajor, 2001); quieter, faster milking animals tend to produce more milk.

The negative genetic correlation between temperament and SCC may be attributed to elevated levels of blood cortisol (Hemsworth *et al.,* 1989) subsequently predisposing such animals to mastitis and other diseases. Lund *et al.* (1994) reported a strong negative genetic correlation (–0.96) between temperament and other diseases (i.e., nervous cows are predisposed to higher levels of disease occurrence).

Conclusions

The results from this study indicate that considerable genetic variation exists for a range of type traits within this sample of the Irish Holstein-Friesian population. Herdsmen, however, should be encouraged/advised to consider the whole 1 to 9 scale of measurement when assessing animals for ease of milking and temperament. Genetic correlations between some type traits were very strong and indicate the opportunity of reducing the number of traits assessed on each animal. Moderate to strong genetic correlations were evident between most of the body-related type traits and average BW indicating the possibility of including type traits within a selection index as predictors of BW. Although moderate to strong genetic correlations existed between some type traits and the various fertility measures and SCC, the standard errors of the correlations were considerable in some instances. Thus, the true genetic correlations will vary somewhat around the estimates reported in the present study, the estimated correlations reported herein provide an indication of the direction and strength of the relationship between the traits.

Acknowledgments

The authors wish to acknowledge with gratitude Allied Irish Bank, the AI Managers Association, the Holstein-Friesian Society of Great Britain and Ireland, Dairy Levy Farmer Funds and EU Structural Funds (FEOGA) in financing the research programme.

The technical assistance of D. Cliffe, T. Condon and J. Keneally, and the guidance of Professor

Dorian Garrick in the initial stages of the study, are also acknowledged.

References

Ahlborn, G. and Dempfle, L. 1992. Genetic parameters for milk production and live size in New Zealand Holstein-Friesian and Jersey. *Livestock Production Science* **31:** 205–219.

Ali, T.E., Burnside, E.B. and Schaeffer, L.R. 1984. Relationship between external body measurements and calving difficulties in Canadian Holstein-Friesian cattle. *Journal of Dairy Science* **67:** 3034–3044.

Berry, D.P., Buckley, F., Dillon, P., Evans, R.D., Rath, M. and Veerkamp, R.F. 2003. Genetic relationships among body condition score, body weight, milk yield and fertility in dairy cows. *Journal of Dairy Science* **86:** 2193–2204.

Boettcher, P.J., Dekkers, J.C.M. and Kolstad, B.W. 1998. Development of an udder index for sire selection based on somatic cell score, udder conformation, and milking speed. *Journal of Dairy Science* **81:** 1157–1168.

Brotherstone, S. 1994. Genetic and phenotypic correlations between linear type traits and production traits in Holstein-Friesian dairy cattle. *Animal Production* **59:** 183–187.

Brotherstone, S., McManus, C.M. and Hill, W.G. 1990. Estimation of genetic parameters for linear and miscellaneous type traits in Holstein-Friesian dairy cattle. *Livestock Production Science* **26:** 177–192.

Coffey, E.M., Vinson, W.E. and Pearson, R.E. 1986. Potential of somatic cell concentration in milk as a sire criterion to reduce mastitis in dairy cattle. *Journal of Dairy Science* **69:** 2163–2172.

Crosse, S. 1986. 'Dairy Herd Management Information System — DAIRYMIS II'. Moorepark 25th Anniversary Publication, Part 2: Animal Health and Machine Milking, pages 325–361.

DeGroot, B.J., Keown, J.F., van Vleck, L.D. and Marotz, E.L. 2002. Genetic parameters and responses of linear type, yield traits, and somatic cell scores to divergent selection for predicted transmitting ability for type in Holsteins. *Journal of Dairy Science* **85**: 1578–1585.

Foster, W.W., Freeman, A.E., Berger, P.J. and Kuck, A.L. 1988. Linear type trait analysis with genetic parameter estimation. *Journal of Dairy Science* **71:** 223–231.

Groen, A.F., Hellinga, I. and Oldenbroek, J.K. 1994. Genetic correlations of clinical mastitis and feet and leg problems with milk yield and type traits in Dutch Black and White dairy cattle. *Netherlands Journal of Agricultural Science* **42:** 371–378.

Grosshans, T., Xu, Z.Z., Burton, L.J., Johnson, D.L. and Macmillan, K.L. 1997. Performance and genetic parameters for fertility of seasonal dairy cows in New Zealand. *Livestock Production Science* **51:** 41–51.

Hazel, L.N. 1943. The genetic basis for constructing selection indexes. *Genetics* **28:** 476–490.

Hemsworth, P.H., Barnett, J.L., Tilbrook, A.J. and Hansen, C. 1989. The effects of handling by humans at calving and during milking on the behaviour and milk cortisol concentrations of primiparous dairy cows. *Applied Animal Behaviour Science* **22:** 313–326.

Heringstad, B., Klemetsdal, G. and Ruane, J. 2000. Selection for mastitis resistance in dairy cattle: a review with focus on the situation in the Nordic countries. *Livestock Production Science* **64:** 95–106.

Jagtenberg, C.J. and van Scheppingen, A.T.J. 1994. Dieren selecteren op AMS. Inpasbaarheid automatisch melksystem stelt eisen aan de koe. *Landbouwmechanisatie.* **45:** 43–45.

Koenen, E.P.C. and Groen, A.F. 1998. Genetic evaluation of body weight of lactating Holstein heifers using body measurements and conformation traits. *Journal of Dairy Science* **81:** 1709–1713.

Lawstuen, D.A., Hansen, L.B., Steuernagel, G.R. and Johnson, L.P. 1988. Management traits scored linearly by dairy producers. *Journal of Dairy Science* **71:** 788–799.

Lund, T., Miglior, F., Dekkers, J.C.M. and Burnside, E.B. 1994. Genetic relationships between clinical mastitis, somatic cell count, and udder conformation in Danish Holsteins. *Livestock Production Science* **39:** 243–251.

Meyer, K., Brotherstone, S. and Hill, W.G. 1987. Inheritance of linear type traits in dairy cattle and correlations with milk production. *Animal Production* **44:** 1–10.

Mrode, R.A. and Swanson, G.J.T. 1996. Genetic and statistical properties of somatic cell count and its suitability as an indirect means of reducing the incidence of mastitis in dairy cattle. *Animal Breeding Abstracts* **64:** 847–857.

Mrode, R.A., Swanson, G.J.T. and Winters, M.S. 1998. Genetic parameters and evaluations for somatic cell counts and its relationship with production and type traits in some dairy breeds in the United Kingdom. *Animal Science* **66:** 569–576.

Neumaier, A. and Groeneveld, E. 1998. Restricted maximum likelihood estimation of covariances in sparse linear models. *Genetics, Selection, Evolution* **1:** 3–26.

Norman, H.D., Powell, R.L., Wright, J.R. and Cassell, B.G. 1988. Phenotypic and genetic relationship between linear functional type traits and milk yield for five breeds. *Journal of Dairy Science* **71:** 1880–1896.

O'Shea, J., O'Callaghan, E., Meaney, W. and Crowley, C. 1975. Liner slip, impacts and mastitis. *Irish Journal of Agricultural Research* **14:** 372–375.

Parke, P. Jr., Kennedy, B.W., Dekkers, J.C.M., Moore, R.K. and Jairath, L. 1999. Genetic and phenotypic parameter estimates between production, feed intake, feed efficiency, body weight and linear type in first lactation Holsteins. *Canadian Journal of Animal Science* **79:** 425–431.

Peeler, E.J, Otto, M.J. and Esslemont, R.J. 1994. Inter-relationships of periparturient diseases in dairy cows. *Veterinary Record* **5:** 129–132.

Pérez-Cabal, M.A. and Alenda, R. 2002. Genetic relationships between lifetime profit and type traits in Spanish Holstein cows. *Journal of Dairy Science* **85:** 3480–3491.

Philipsson, J., Ral, G. and Berglund, B. 1995. Somatic cell count as a selection criterion for mastitis resistance in dairy cattle. *Livestock Production Science* **41:** 195–200.

Pool, M.H., Meuwissen, T.H.E., Olori, V.E.. Cromie, A.R., Calus, M.P.L. and Veerkamp, R.F. 2002. Breeding for survival and calving interval in Ireland. *Proceedings 7th World Congress on Genetics applied to Livestock Production* (August 19–23, 2002), Montpellier, France **29:** 135–139.

Pryce, J.E., Esslemont, R.J., Thompson, R., Veerkamp, R.F., Kossaibati, M.A. and Simm, G. 1998. Estimation of genetic parameters using health, fertility and production data from a management recording system for dairy cattle. *Animal Science* **66:** 577–584.

Pryce, J.E., Coffey, M.P. and Brotherstone, S. 2000. The genetic relationship between calving interval, body condition score and linear type and management traits in registered Holsteins. *Journal of Dairy Science* **83:** 2664–2671.

Rogers, G.W., Hargrove, G.L., Lawlor, T.J. and Ebersole, J.L. 1991. Correlations among linear type traits and somatic cell counts. *Journal of Dairy Science* **74:** 1087–1091.

Rogers, G.W. and Spencer, S.B. 1991. Relationships among udder and teat morphology and milking characteristics. *Journal of Dairy Science* **74:** 4189–4194.

Roxström, A., Strandberg, E., Berglund, B., Emanuelson, U. and Philipsson, J. 2001. Genetic and environmental correlations among female fertility traits and milk production in different parities of Swedish red and white dairy cattle. *Acta Agricultura Scandinavica* **51:** 7–14.

Royal, M.D., Pryce, J.E., Woolliams, J.A. and Flint, A.P.F. 2002. The genetic relationship between commencement of luteal activity and calving interval, body condition score, production, and linear type traits in Holstein-Friesian dairy cattle. *Journal of Dairy Science* **85:** 3071–3080.

Rupp, R. and Boichard, D. 1999. Genetic parameters for clinical mastitis, somatic cell score, production, udder type traits, and milking ease in first lactation Holsteins. *Journal of Dairy Science* **82:** 2198–2204.

Schmidt, G.H., Van Vleck, L.D. and Hutjens, M.F. 1988. 'Principles of Dairy Science' (2nd edition), Prentice Hall. Englewood Cliffs. NJ, page 61.

Schutz, M.M. and Pajor, E.A. 2001. Genetic control of dairy cattle behavior. *Journal of Dairy Science* **84** (E. Suppl)**:** E31-E38.

Short, T.H., and Lawlor, T.J. 1992. Genetic parameters of conformation traits, milk yield, and herd life in Holsteins. *Journal of Dairy Science* **75:** 1987–1998.

Short, T.H., Lawlor, T.J., and Lee, K.L. 1991. Genetic parameters for three experimental linear type traits. *Journal of Dairy Science* **74:** 2020–2025.

Thompson, J.R., Pollak, E.J. and Pelissier, C.L. 1983. Interrelationships of parturition problems, production of subsequent lactation, reproduction, and age at first calving. *Journal of Dairy Science* **66:** 1119–1127.

Veerkamp, R.F. and Brotherstone, S. 1997. Genetic correlations between linear type traits, food intake, live weight and condition score in Holstein Friesian dairy cattle. *Animal Science* **64:** 385–392.

Veerkamp, R.F., Koenen, E.P.C. and De Jong, G. 2001. Genetic correlations among body condition score, yield, and fertility in first-parity cows estimated by random regression models. *Journal of Dairy Science* **84:** 2327–2335.

Vischer, P.M. and Goddard, M.E. 1995. Genetic parameters for milk yield, survival, workability, and type traits for Australian dairy cattle. *Journal of Dairy Science* **78:** 205–220.

Received 10 February 2004