The Genetic Relationship between Calving Interval, Body Condition Score and Linear Type and Management Traits in Registered Holsteins

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ABSTRACT

The trend to poorer fertility in dairy cattle with rising genetic merit for production over the last decade suggests that breeding goals need to be broadened to include fertility. This requires reliable estimates of genetic (co)variances for fertility and other traits of economic importance. In the United Kingdom at present, reliable information on calving dates and hence calving intervals are available for most dairy cows. Data in this study consisted of 44,672 records from first lactation heifers on condition score, linear type score, and management traits in addition to 19,042 calving interval records. Animal model REML was used to estimate (co)variance components. Genetic correlations of body condition score (BCS) and angularity with calving interval were −0.40 and 0.47, respectively, thus cows that are thinner and more angular have longer calving intervals. Genetic correlations between calving interval and milk, fat, and protein yields were between 0.56 and 0.61. Records of phenotypic calving interval were regressed on sire breeding values for BCS estimated from records taken at different months of lactation and breeding values for BCS change. Genetic correlations inferred from these regressions showed that BCS recorded 1 mo after calving had the largest genetic correlation with calving interval in first lactation cows. It may be possible to combine information on calving interval, BCS, and angularity into an index to predict genetic merit for fertility.

(**Key words:** calving interval, body condition score, energy balance)

Abbreviation key: CI = calving interval, **VCE** = variance component estimation.

INTRODUCTION

Dairy cattle breeding goals in most countries have placed most emphasis on production traits over the last several decades. At the same time, a decline in average

conception rates has been observed. The decline in phenotypic trend has been reported to be around 0.45% per year in conception rate in the United States between 1975 and 1997 (1, 7) and 1% per year in the UK between 1975 and 1998 (27). Most published genetic correlation estimates between milk yield and measures of fertility are unfavorable (18, 24, 25, 31). Fertility is an economically important trait. In the UK the cost of increasing calving interval (**CI**) by 1 d has been calculated at £4 per day (excluding culling costs) (30) and in France 20FF per conception rate unit (3).

To halt, or at least slow down, this rate of decline, fertility should be included as part of the breeding goal. This is not straightforward because fertility is difficult to define. Fertility in dairy cattle breeding can be considered as having two components: 1) a measure of time, such as onset of estrus, and 2) a measure of the ability of the cow to conceive at first or second insemination. Thus, selection criteria need to reflect both of these aspects. Index traits are needed to predict genetic merit in both of these goal traits and should be measurable on a large enough number of daughters per sire to achieve sufficient accuracy in bull proofs. The extent to which the breeding goal requirements can be fulfilled in selection programs very much depends on what is currently recorded and what is economically feasible to record. Where accurate insemination data are available, genetic evaluations of fertility may be based on measures calculated from this information. Several countries already produce such genetic evaluations for fertility. Denmark, Finland, Norway, and Sweden have traditionally placed more emphasis on health and fertility traits and provide genetic evaluations of female fertility. Lindhe and Philipsson (20) give a review of the fertility indexes used in each Scandinavian country. France, Germany, Israel, and the Netherlands also provide genetic evaluations for sires based on the fertility of their daughters. In France, PTA for female conception rates have been published for sires since July 1998 (4), in Germany, fertility indexes have been calculated since 1995 using nonreturn rate 90 d after first insemination and expressed as both a paternal and maternal trait (22). Conception status calculated as one divided

by the number of inseminations until pregnancy is evaluated in Israel (D. Hojman, personal communication). In the Netherlands an index for female fertility has been developed that includes both the interval between calving and first insemination and nonreturn at 56 d (11).

In the United Kingdom, several milk-recording organizations record insemination dates. The final insemination date provides a date for the start of the dry period and a 'due to calve' date. Some milk recording organizations also provide an additional optional service for monitoring within-herd fertility, which requires all service dates to be recorded. Therefore, United Kingdom national data consists of a mixture of all insemination dates, some insemination dates, and just the insemination date leading to the pregnancy. Consequently, calculations from service dates are unreliable.

Calving interval defined as the number of elapsed days between two consecutive calvings is more likely to be recorded accurately, because lactation 'start dates' are required by milk recording organizations, and birth dates of calves are now required by UK law. Consequently, of all the measures of fertility available on a large number of animals (which is a prerequisite for national genetic evaluations), CI is the least likely to be affected by data quality issues. However, CI is only available for animals with two or more calving dates. This makes it of limited use as a selection tool for breeding companies, whose decisions on bulls are based on information available early in their daughters' lactations or from juvenile predictors. Furthermore, only the most fertile and productive animals calve for a second time, so CI data are already censored for the trait of interest, namely fertility. Thus, information from correlated traits available earlier than CI may be useful.

Body condition scoring involves tactile and visual appraisal of the amount of tissue cover in the lumbar region of the vertebrae and around the tail head (21). Veerkamp (32) suggested that successive measures of BCS may be a useful indicator of energy balance as the shortfall in energy obtained from food is believed to come from mobilization of body tissue reserves. Indeed, the genetic correlation between milk yield and BCS has been estimated to be –0.37 (33). Several studies have shown that cows are in negative energy balance during the first weeks of lactation, as is often the case with lactating mammals (2, 12). In a traditional 365-d calving interval system, the ideal period for rebreeding is around 80 d postpartum, which coincides with peak milk production and the nadir of negative energy balance (1).

Linear type traits are measured in most international breeding programs and are predominantly related to dimension, and are thus less likely to be as highly correlated to fertility as the effects of body tissue mobilization. Nevertheless, some of these traits may provide additional information.

Until now, field data on BCS has not been available to allow an investigation of the relationship between reproductive measures and BCS. The first objective of this study was to estimate genetic parameters for BCS, linear type traits, and CI using nationally recorded data. The second objective was to investigate the genetic relationship between BCS recorded at different months of lactation and CI.

MATERIALS AND METHODS

Data

Body condition score has been recorded routinely by Holstein UK and Ireland (HUKI, formerly Holstein-Friesian Society of Great Britain and Ireland) since January 1996 as part of its linear type classification scheme. HUKI also record 15 linear type traits, two management traits (temperament and milking speed), and a locomotion score for each registered cow put forward for type classification. All traits including BCS are recorded once per lactation on a linear integer scale of 1 to 9. It is obligatory for herds participating in the scheme to have all heifers assessed. Because farmers can choose which cows to have assessed in later lactations, we restricted our analysis to first-lactation records. Lactation records are collected by HUKI under these circumstances: 1) a completed lactation record is received from a milk recording organization, 2) an incomplete lactation record is received (sold, died, culled, etc.), 3) a calf is born and registered.

The CI was calculated as the difference in days between the start of the second lactation and the start of the first. Nonpedigree cows were removed from the data set and it was restricted to a minimum of five daughters per sire and 20 cows per herd-visit. Calving intervals were also restricted between 300 and 600 d. Calving intervals less than 300 d may have arisen as a result of abortions or other abnormal occurrences. Those greater than 600 d were also considered to be unrepresentative of the national dairy herd. These may occur for a number of reasons. For example, when a herd participates in embryo transfer programs, donor cows are often flushed several times during a lactation, thus extending CI. Also, a number of herds may have attempted to deliberately extend calving intervals, adopting 18-mo calving intervals; at present this is not common practice in the United Kingdom. The final data set consisted of records collected from January 1996 until July 1998. There were 44,674 records on BCS, production, type, and management traits. Of these, a total of 19,042 also had records on CI. The pedigree file included 92,003 ani-

mals. All animals had sire information, and the majority of cows had dam identifications as well. Pedigrees for as many of the dams and sires as possible were also included in the pedigree file.

Condition scores and linear type and management traits were scaled by the ratio of the standard deviation of the scoring field officer to the mean standard deviation of all field officers, to account for range differences between field officers (5, 19).

Estimation of Genetic Parameters

Genetic parameters were estimated using restricted maximum likelihood method. The variance component estimation (**VCE**) package (15) was used to estimate (co)variance components. The VCE allows for unequal design matrices and missing observations.

The statistical models used to estimate (co)variance components were:

$$P_{ijkl} = \mu + HY_i + m_j + \sum_{q=1}^{3} \beta_q x_{qklm} + a_n + e_{ijklmn}$$

$$T_{ijkl} = \mu + HV_i + m_j + \sum_{q=1}^{4} \beta_q x_{qklmn} + a_o + e_{ijklmno}$$

Where P = CI, milk, fat, or protein yield; T = BCS, type, or management traits; HY = herd-year of calving; HV = herd-visit of the HUKI officer; m = calendar month of calving; x_1 = age at calving in months; x_2 = age at calving in months squared; x_3 = percentage of North American Holstein genes; x_4 = month of lactation; a = random effect of animal; e = residual error term.

All statistical models included age at and calendar month of first calving. In addition, the month of lactation was included in the type trait and BCS model. A phenotypic adjustment of BCS for production was done by fitting the deviation of milk yield from herd-year contemporaries.

Ideally, (co)variance components would have been estimated using a multivariate model, i.e., fitting all the traits simultaneously, as this would account for covariances between traits. However, running such a model would take considerable computing resources. So, instead the analysis was done using a series of bivariate models, always including CI. Breeding values for BCS and CI were estimated using PEST, which is prediction and estimation software and part of the VCE suite (15, 16). The genetic parameters used to estimate breeding values were from univariate models estimated in VCE.

Estimation of the Relationship between CI and BCS Change

Heifers were scored for body condition only once during first lactation (at type appraisal), so it is impossible to investigate the phenotypic relationship between CI and BCS change across lactation. However, one way to investigate the genetic relationship between CI and BCS at different months after calving or BCS change is by using sire EBV for BCS recorded in different months of lactation. Sire EBV for BCS calculated by Jones et al. (19) were used in the present study. These authors used a sire model and random regression methodology to estimate genetic parameters for BCS recorded in 12 mo of lactation. The data set used by Jones et al. (19) was collected by HUKI over the period January 1996 to December 1997; thus, because it overlaps with the data set used in the present study, two data sets will have animals in common.

Daughter records of CI were regressed on sire EBV for BCS over the first 10 mo of lactation. Because most cow lactations are 305 d, those longer than 10 mo may be atypical of the population and, moreover, were based on relatively few records. The CI was also regressed on the difference between BCS EBV in mo 1 and EBV in mo 2, 3, and 4. In addition CI was regressed on EBV for BCS averaged over mo 1 to 10 of lactation. Genetic correlations were then inferred from these regressions. The data was restricted to cows that had CI between 300 and 600 d and sires with breeding value for BCS. The analysis was done using ASREML (14) fitting herd-year and month of calving as fixed effects and proportion of North American Holstein genes, age at calving, and sire breeding values as covariates. The model was as follows:

$$CI_{ijkl} = \mu + HY_i + m_j + \sum_{q=1}^{4} \beta_q x_{qklmn} + e_{ijklmn}$$

Where HY = herd-year of calving; m = calendar month of calving; x_1 = age at calving in months; x_2 = age at calving in months squared; x_3 = percentage North American Holstein genes; x_4 = BCS EBV; e = residual error term.

RESULTS

The distribution of CI in the raw data is shown in Figure 1. Estimates of the effect of month of calving on CI and BCS are presented in Figure 2. Heifers that calve from January to May have longer than average CI, the longest being in January and February. BCS at the time of classifying is lowest for heifers that calve in November through February.
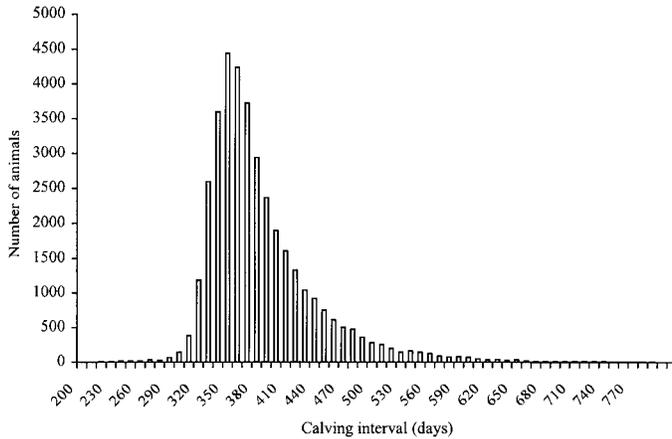
Figure 1. Distribution of calving interval.

Table 1. Number of records, means, phenotypic standard deviations (SDp), coefficients of genetic variation (CVa), heritabilities (h^2) and genetic correlation (rg) estimates for BCS, BCS adjusted for phenotypic milk yield (BCSm) and calving interval (CI).

	BCS	BCSm	CI
Number of records	44,622	44,622	19,042
Mean	3.9	3.9	385 d
SDp	1.3	1.3	45.3 d
CVa (%)	17	16	1.6
Heritability	0.28	0.25	0.022
SE of h^2	(0.01)	(0.01)	(0.005)
rg with CI	−0.40	−0.22	
SE of rg	(0.09)	(0.11)	

Means, standard deviations, and heritabilities for CI and BCS, and the estimates of genetic correlations between CI and BCS are presented in Table 1. BCS ranged between 1 and 9 and had a mean of 3.9. The mean for CI was 385 d, which is comparable to other studies of field data in the UK (e.g., 13, 24, 25). The heritability and coefficient of genetic variation for CI were 0.02 and 1.6%, respectively, which are smaller than reported in other studies (e.g., 26). The heritability of BCS was 0.28, and the genetic correlation between BCS and CI was −0.40. Genetically, thinner cows have a longer calving interval. This is partly because a longer CI is related to a higher milk yield, but even after adjusting for phenotypic milk yield, the genetic correlation between CS and CI is −0.22.

Genetic correlations between linear type scores, production, and CI are presented in Table 2. There were strong correlations of CI with milk, fat, and protein yields (0.56 to 0.61) in addition to angularity (0.47). Genetic correlations of CI with stature and body depth were moderate (0.26 to 0.33), indicating that taller, deeper cows have longer CI. Phenotypic correlations were all between −0.1 and +0.1.

The plot of BCS EBV versus CI EBV for 3770 sires that had daughters with both CI and BCS data is presented in Figure 3. The CI EBV ranged between −6.7 and +11.65 d, while BCS EBV ranged between −2.13 and 1.47 BCS units. The relationship between sire breeding values for CI and BCS appears to be linear.

Regression coefficients of CI on sire EBV of BCS at 10 mo of lactation, average EBV for BCS, and changes in EBV for BCS between different months of lactation are presented in Table 3. The regression of CI on EBV for BCS was greatest in mo 1 of lactation, −7.7 d. This was statistically significant at the $P < 0.001$ level. Genetic correlations were inferred by multiplying the regression coefficient by the ratio of the genetic standard deviations (23). Genetic correlations decreased from mo 1 (−0.88) to 10 (−0.39) and are shown in Table 3. The regression of CI on change in BCS EBV was greatest for the change between mo 1 and 2 of lactation (−4.9), although none of the regressions of CI on BCS change were statistically significant.
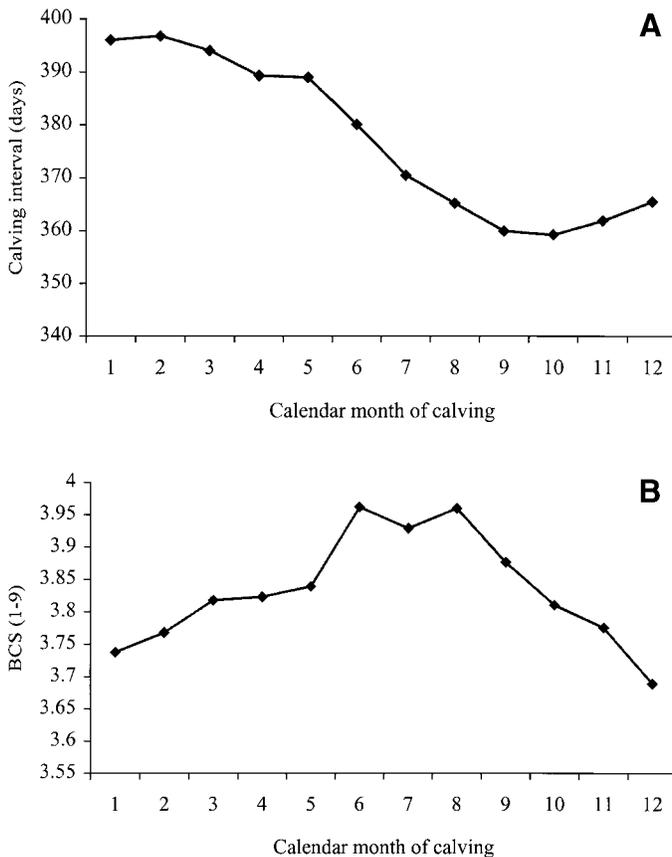
Figure 2. A, Effect of calendar month of calving on calving interval (CI). B, Effect of calendar month on BCS.

Table 2. Biological extremes (scored on a scale of 1 to 9) of type and management traits, heritabilities and genetic correlation estimates of production, type and management traits with calving interval (CI).

Trait	1	9	Heritability (SE)	Genetic correlation with CI (SE)
Milk yield	. . .	. . .	0.50 (0.01)	0.61 (0.08)
Fat yield	. . .	. . .	0.42 (0.02)	0.56 (0.08)
Protein yield	. . .	. . .	0.47 (0.02)	0.57 (0.08)
Stature	Small	Tall	0.59 (0.01)	0.33 (0.10)
Body depth	Shallow	Deep	0.37 (0.02)	0.26 (0.12)
Chest width	Narrow	Wide	0.39 (0.02)	0.28 (0.09)
Rump angle	High pins	Low pins	0.33 (0.01)	0.07 (0.12)
Angularity	Coarse	Angular	0.33 (0.01)	0.47 (0.10)
Rump width	Narrow	Wide	0.32 (0.01)	−0.02 (0.12)
Rear leg set	Posty	Sickled	0.19 (0.01)	0.19 (0.11)
Foot angle	Low	Steep	0.16 (0.01)	−0.20 (0.12)
Foreudder attachment	Loose	Tight	0.19 (0.01)	−0.17 (0.12)
Rear udder height	Very low	Very high	0.23 (0.01)	0.07 (0.11)
Udder support	Broken	Strong	0.21 (0.01)	0.16 (0.11)
Udder depth	Shallow	Deep	0.30 (0.02)	−0.13 (0.01)
Teats rear	Wide	Close	0.28 (0.02)	−0.01 (0.01)
Teat side	Close	Apart	0.30 (0.01)	0.44 (0.10)
Teat length	Short	Long	0.33 (0.02)	0.09 (0.11)
Milking speed	Slow	Fast	0.06 (0.001)	0.25 (0.15)
Temperament	Nervous	Quiet	0.07 (0.001)	0.24 (0.14)
Locomotion	Poor	Excellent	0.06 (0.001)	−0.10 (0.14)

DISCUSSION

Genetic correlations between production and CI were higher than other field studies (e.g., 18, 24, 25). However, they were similar to genetic correlations between yield and the interval between calving and commencement of luteal activity (34). The interval between calving and luteal activity is believed to be free of management decisions and variation in heat detection rates, while the genetic correlation between production and CI may be inflated by management circumstances, such as high merit cows being given more chances to conceive than their lower yielding herdmates.

The genetic correlation between CI and BCS estimated using BCS records on all cows and CI on a subset of these, was moderate (−0.40). Therefore, cows that are thinner are more likely to have a longer CI. It is likely that cows are mobilizing body tissue to sustain milk production, so BCS or BCS change is likely to be closely related to energy balance. Cows in negative energy balance, particularly in early lactation, may be yielding milk at the expense of reproduction. After we adjusted for phenotypic milk yield the genetic correla-

Table 3. Regression coefficients (b) and associated standard errors (SE) of calving interval regressed on sire estimated breeding values for average BCS; BCS at mo 1 to 10 of lactation and BCS change between mo 1 and mo 2 to 4. Approximate genetic correlation estimates are inferred from the regressions.

	b (SE)	Genetic correlation
Average BCS	−4.66 (1.95)*	−0.55
BCS1	−7.67 (2.16)***	−0.88
BCS2	−6.88 (2.11)**	−0.73
BCS3	−5.67 (1.99)**	−0.60
BCS4	−4.79 (1.89)*	−0.54
BCS5	−4.05 (1.83)*	−0.48
BCS6	−3.72 (1.81)*	−0.46
BCS7	−3.50 (1.80)*	−0.44
BCS8	−3.30 (1.80)	−0.41
BCS9	−3.14 (1.81)	−0.40
BCS10	−3.02 (1.80)	−0.39
BCS1-2[1]	−4.90 (7.03)	−0.06
BCS1-3[1]	−3.38 (4.10)	−0.11
BCS1-4[1]	−3.12 (3.26)	−0.16

[1]BCS1-2, BCS1-3, BCS1-4 are the differences between BCS at mo 1 and mo 2, 3, and 4 of lactation.

*$P < 0.05$.

***$P < 0.01$.

***$P < 0.001$.
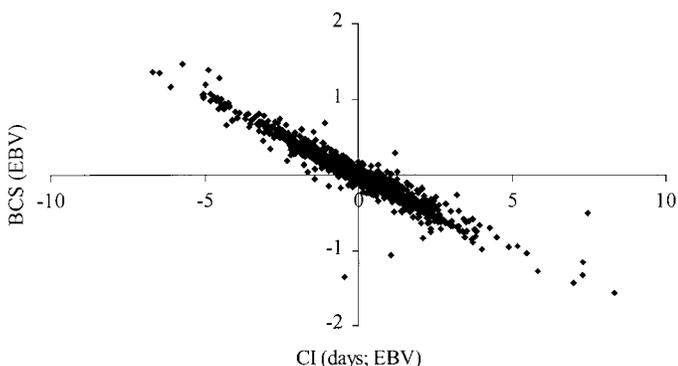
Figure 3. Estimated breeding values (EBV) of BCS versus calving interval (CI) for sires obtained from univariate analyses.

tion between BCS and CI was still negative (–0.22). Regardless of level of yield, cows with low BCS are more likely to have a longer CI, thus mobilization of body tissue plays a role in the genetic control of fertility. In the phenotypic study of Domecq et al. (12) conception at first service in multiparous cows was partly determined by the loss of BCS in the first month of lactation. Veerkamp et al. (34) showed that live weight and live weight gain have a strong negative genetic relationship with the interval between calving and commencement of luteal activity (cows in strong negative energy balance had poorer fertility). Lighter cows are expected to be in a greater negative energy balance because of the contribution of BCS to live weight (33, 34).

Genetic correlations inferred from the regression estimates of CI on BCS in mo 1 to 10 of lactation (Table 3), declined from –0.88 to –0.39. Genetic correlations estimated using regression coefficients tend to be sensitive to the genetic variances assumed, so the genetic correlation estimates presented here should be treated with caution. Despite this, it is clear that BCS recorded in mo 1 of lactation is more informative as an indicator of CI than BCS recorded in any other month of lactation. Heritability estimates of BCS are lower in early lactation than in later lactation and range from 0.20 in early lactation to 0.28 in late lactation (19). Genetic correlations between mo 1 of lactation and later months ranged from 0.63 in late lactation to 0.93 in mo 2 of lactation (19), indicating that BCS in mo 1 of lactation may be genetically different from BCS in later stages.

BCS recorded in mo 1 is also more important than BCS change between mo 1 and other months of early lactation. The genetic variance of BCS change between mo 1 and 2 was smaller than the genetic variance calculated for the change in BCS between mo 1 and 4. Thus, although the regression was largest for BCS change between mo 1 and 2, the largest genetic correlation was between CI and BCS change between mo 1 and 4.

It is possible that the regression analysis was not sensitive enough to detect changes in BCS between months adequately. Jones et al. (19) noted that the range in sire EBV for BCS at each month was narrow. Ranges in sire EBV for BCS change were narrower still, ranging between –0.13 and 0.16. A greater effect of BCS change may have been found if the change in BCS had been calculated weekly rather than monthly. However, obtaining a sufficient number of observations per week per sire would have been difficult.

The genetic correlation between CI and angularity was 0.47, thus more angular cows have longer CI. As the genetic correlation between BCS and angularity is –0.84 (S. Brotherstone, 1999; unpublished results), the basis for the relationship of CI and angularity is likely to be the same as that between CI and BCS. Although

EBV for angularity at different months of lactation were not available, it seems probable that regressions of CI on angularity EBV at different months of lactation would be similar to those found between CI and BCS. Dadati et al. (8) estimated a genetic correlation of 0.43 between CI and dairyness (recorded subjectively, but subsequently transformed to an objective scale). In a more recent study where Scandinavian disease data and US type data were combined, Rogers et al. (27) found an approximate genetic correlation of –0.50 between dairy form (which is a trait similar to angularity) recorded in the United States and reproductive diseases recorded in Denmark. Cows that were more 'dairy' had a higher incidence of reproductive disorders. These authors suggested that selection for lower dairy form would only be reasonable if intense selection for milk yield is practiced simultaneously because the genetic correlation between dairy form and milk yield is high.

The genetic correlations between stature, body depth, chest width, and CI were unfavorable: taller, deeper cows had longer CI. The data used in the present study was from a breed society. It is possible that owners of pedigree cows prefer taller, deeper cows, and may give them more opportunities to conceive, although this is only likely to affect phenotypic correlations. However, results from a long-term selection experiment conducted by the University of Minnesota support the hypothesis that reproductive performance tends to be poorer in large versus small cows (17). In two lines selected for divergent BW yet equal merit for production, reproductive performance—defined as number of services (first lactation only) in favor of the small line— differed significantly, indicating that smaller cows may be more fertile. Dadati et al. (8) investigated the relationship between subjectively assessed type (converted to objective scores) and CI and found that chest floor and capacity were favorably related to CI, which was interpreted as 'stronger' cows had shorter CI. Pryce et al. (24) found significant regressions of sire PTA for chest width (evaluated using daughter records) on CI and conception at first service, with narrow chests being associated with a longer CI and poorer conception rate.

Calving interval is only available after a cow has calved for a second time, which makes it of limited use in progeny testing schemes in which information is required from either the early part of lactation or preferably from juveniles. Furthermore, CI data is highly selected for the trait of interest, namely fertility, because the least fertile cows will not calve for a second time. Data imputation techniques to predict a cow's CI using information from, e. g., relatives and the cows own production level, should in part resolve this problem, but more research into these techniques is needed. However, our results show that it may be possible to

predict CI using type and BCS that are available earlier in lactation and for many cows that fail to calve for a second time. Logically, the current investigation should be extended to examine the relationship between BCS, type traits, and other measures of fertility, such as commencement of luteal activity, because this measure is independent of heat observation and the subsequent decision to inseminate a cow (9, 10, 34).

In the long term, the availability of other measures of fertility may mean that a fertility index based on CI, BCS, and type is improved or replaced by other information. Subsequent to developing a fertility index, fertility also needs to be incorporated into an index of overall genetic merit as a goal trait, such as the UK's Profitable Lifetime Index (£PLI). £PLI currently includes production and lifespan measured in lactations and a phenotypic index of type traits most closely related to it (udder depth, teat length, fore udder attachment and foot angle; 6). Milk, fat, and protein yields and lifespan are weighted according to their economic values (29). This means that an economic value for calving interval needs to be calculated. Although some estimates of economic values of fertility are available, a serious problem is that they start exclusively from the premise of a failed insemination, whereas lengthening the CI may be a result of a delayed insemination, possibly associated with a high yield. In some circumstances extended lactations may be more economical. Thus, the economic optimum lactation length first needs to be resolved. This may be dependent on production systems, as it is possible that different systems would require high fertility at different times postpartum.

CONCLUSIONS

Given the rate of decline of fertility in dairy cattle which appears to be associated with the rise in genetic merit for production, it is suggested that a selection index to improve, or prevent a further decline in fertility needs to be developed. In the absence of suitable data to enable genetic evaluations of measures derived from service data, a fertility index based on CI, BCS, and type is attractive. Based on the current study, a multivariate procedure that includes CI, BCS, and possibly angularity could be used to estimate breeding values. Information from BCS and type would be used for animals that are either culled before completing their first lactation, or that have not had the opportunity to calve again. Thus, type and BCS information go part way to resolving the issue of selected CI data.

ACKNOWLEDGMENTS

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