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**Citation for published version:**

Pryce, JE, Coffey, MP, Brotherstone, SH & Woolliams, J 2002, 'Genetic relationships between calving interval and body condition score conditional on milk yield' *Journal of Dairy Science*, ???volume??? 85, ???journalNumber??? 6, ???pages??? 1590-1595.

**Link:**

[Link to publication record in Edinburgh Research Explorer](#)

**Document Version:**

Publisher final version (usually the publisher pdf)

**Published In:**

*Journal of Dairy Science*

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## Genetic Relationships Between Calving Interval and Body Condition Score Conditional on Milk Yield

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### ABSTRACT

Body condition score (BCS) is a useful tool in assessing the energy status of dairy cattle. Previous research has shown that it is heritable and genetically correlated to reproductive performance. Currently, interest exists in developing selection indexes for fertility that include BCS information. Before such indexes are developed, it is important to assess the genetic covariance between BCS and fertility after fully accounting for the covariance of both traits with milk yield, as indices to predict selection responses require knowledge of these (co)variances. In the present study, calving interval (CI) was used as a measure of reproductive performance. The genetic correlations between BCS and CI before and after genetically adjusting for milk yield were  $-0.48$  and  $-0.22$ , respectively. Thus, cows with low BCS have longer CI, which is exacerbated by high levels of milk production. Using selection index theory, we showed that selecting for milk yield alone will result in an increase of 768 kg of milk, an increase of 4.46 d in CI and a reduction of 0.41 BCS units for every standard deviation change in the index. Restricting BCS to no genetic change, whereas still selecting for milk yield will result in an increase of 653.1 kg of milk per standard deviation of the selection index. However, CI will still continue to increase at a rate of 3.20 d per standard deviation of the selection index. The selection indices used here are not optimum, in that they are not economically driven and do not consider all traits that contribute to profitability. However, they demonstrate that, even though restricting BCS may be seen as an attractive way of limiting reliance of body tissue mobilization to fuel milk production, this is unlikely to result in improvements in CI, although the rate of increase in CI will be reduced.

(**Key words:** calving interval, body condition score, milk yield)

(**Abbreviation key:** CI = calving interval; MY = milk yield.)

### INTRODUCTION

Studies using national data have shown that genetic correlations between fertility and production are generally unfavorable (for reviews see Rauw et al., 1998; Pryce and Veerkamp, 2001). To halt or slow the decline in fertility while increasing genetic merit for production, fertility must be included in breeding goals. Current selection programs focus on production, with many placing some emphasis, in the past, on angularity or dairy character. Detrimental effects on fertility from selection for yield have been compounded by additional selection pressure on a decrease in BCS (estimates of the genetic correlation between BCS and measures of angularity are from  $-0.47$  to  $-0.77$ ; Veerkamp and Brotherstone, 1997).

Service information can be useful to calculate measures such as days to first service and nonreturn and conception rates, and several countries already have genetic evaluations based on this information (Interbull Bulletin 18, 1997). However, in one of the milk recording systems operating in the UK, approximately 15% of herds had 90% of service information missing (H. Kadarmideen, personal communication, 2001). There are a variety of reasons for this; for instance, farms may have their own on-farm fertility monitoring scheme and record service information for their own use without transcribing it to the milk recording system. However, it is compulsory for calving dates to be recorded in the United Kingdom; therefore, compared to many other measures, calving interval data is very reliable. In the absence of suitable service records, a selection index based on calving interval is a good first step towards genetic evaluations for fertility given data constraints. As BCS has been shown to be a genetically linked to measures of reproductive performance (Pryce

Received July 2, 2001.

Accepted January 21, 2002.

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et al., 2000; Veerkamp et al., 2001) augmenting reproductive information, such as calving interval, with BCS may be desirable.

Evidence suggests that incremental increases in feed intake cannot match the extra requirement for milk production in early lactation and that the shortfall comes from mobilization of body tissue (e.g., Van Arendonk et al., 1991). Furthermore, there are concerns that a consequence of considerable body tissue mobilization is reduced health and fertility (Harrison et al., 1990; Waltner et al., 1993).

In production systems in which the objective is to have an annual calving pattern, the period of insemination coincides with that of peak milk yield and the nadir of energy balance (Beam and Butler, 1999). Body condition score is an easy way to assess the energy status of an animal, and studies with BCS recorded as part of national type evaluation schemes in the United Kingdom and the Netherlands, show that the heritability of BCS is around 0.3 to 0.4 (Jones et al., 1999; Koenen et al., 2001). Several studies have shown a relationship between reproductive performance and measures of BCS. In a population of Holsteins in the Netherlands, Veerkamp et al. (2001) showed that the genetic correlation between BCS and calving interval and days to first service was between  $-0.44$  and  $-0.59$ . Pryce et al. (2000) estimated that the genetic correlation between BCS adjusted for stage of lactation and calving interval was  $-0.40$  in Holsteins in the United Kingdom. After adjusting for phenotypic milk yield, the genetic correlation was  $-0.22$ . However, making a phenotypic adjustment would result in both residual and genetic covariances being considered simultaneously and the interpretation may not be clear. BCS has been suggested as a possible selection criterion for improving fertility in dairy cattle, either by itself or in conjunction with reproductive data. Before developing fertility indexes that include BCS, it is important to know whether a genetic covariance exists between BCS and CI after the genetic effect of milk yield has been fully accounted for, i.e., do cows of low BCS have longer CI, regardless of their level of milk production.

Therefore, in this paper we estimate the genetic relationship between 305-d milk yield (MY), calving interval (CI) and BCS using a multivariate analysis. Using the genetic covariances and correlations, we adjusted the genetic correlation between BCS and CI for milk yield. In addition, we investigated responses to selection for BCS on CI, using selection index methodology considering both an unrestricted and restricted index framework.

## MATERIALS AND METHODS

### Estimation of Genetic Parameters

The dataset and genetic analysis models were the same as used by Pryce et al. (2000), and full details of

recording and data editing procedures are given there. In brief, BCS was recorded once in heifer lactations by Holstein UK and Ireland (HUKI) as part of their linear type classification scheme, information on MY and CI were also available. The final dataset consisted of 44,674 records on BCS and MY, of these, a total of 19,042 also had records on CI. The pedigree file included 92,003 animals. Genetic parameters were estimated using a multivariate animal model using a REML procedure to estimate variance components; VCE (Groeneveld and Kovac, 1990):

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

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

Where:

$P_{ijkl}$  is CI or MY,

$T_{ijkl}$  is BCS,

$HY_i$  is the fixed effect of the  $i$ th herd-year of calving,

$HV_i$  is the fixed effect of the  $i$ th herd-visit of the HUKI officer,

$m_j$  is the fixed effect of the  $j$ th calendar month of calving,

$x_1$  is age at calving in months fitted as a covariate,

$x_2$  is age at calving in months squared fitted as a covariate,

$x_3$  is percentage of North American Holstein genes fitted as a covariate,

$x_4$  is the covariate, months in lactation (difference between calving date and date of linear type inspection) fitted to BCS only,

$a_o$  is the random effect of animal fitted to BCS,

$a_n$  is the random effect of animal fitted to CI and MY, and

$e_{ijklm(n)}$  is the residual random error term.

### Conditional (Co)variances Between CI and Condition Score for MY

The covariance between calving interval and condition score adjusted for milk yield was calculated using the regression of BCS on MY, where  $\sigma_{MY,BCS}^2$  is the covariance between milk yield and condition score,  $\sigma_{MY,CI}^2$  is the covariance between milk yield and calving interval and  $\sigma_{MY}^2$  is the variance of milk yield. The variance of CI and BCS adjusted for milk yield ( $\sigma_{CI}^2$ ,  $\sigma_{BCS}^2$ ) and the covariance between CI and BCS both adjusted for milk yield ( $\sigma_{CI,BCS}^2$ ) were calculated as:

$$\sigma_{CI}^2 = \sigma_{CI}^2 - \frac{\sigma_{MY,CI}^2}{\sigma_{MY}^2}$$

$$\sigma_{BCS}^2 = \sigma_{BCS}^2 - \frac{\sigma_{MY,BCS}^2}{\sigma_{MY}^2}$$

$$\sigma_{CI^*,BCS^*}^2 = \sigma_{CI,BCS}^2 - \frac{\sigma_{MY,BCS}\sigma_{MY,CI}}{\sigma_{MY}^2}$$

Conditional (co)variances were estimated for both residual and genetic components.

Responses to selection were calculated using selection index theory. It was assumed that selection would be achieved through a progeny test of 100 daughters per sire (n = 100). In the first instance, responses and correlated responses to selection were calculated where it was assumed there was a single goal trait and index trait. For example, one scenario would be where the goal and index traits are both calving interval.

The correlated responses (CR) in each trait were calculated for milk yield, calving interval and condition score in turn. The intensity of selection was assumed to be one standard deviation change in the index:

$$CR = \frac{b'G}{\sqrt{b'Pb}}$$

where b is the vector of index weights:

$$b = P^{-1}G$$

A restricted index was used to investigate the responses and correlated responses when selection was for CI, BCS, and MY, with restrictions to zero genetic change being assumed for each of the other traits in turn and together. Note that the calculations could have been done using the variance and covariance estimates conditional on the restricted trait. Both methods would yield the same results assuming there are no rounding errors. The calculation method described by Cameron

(1997) was used to construct the restricted index. Both the restricted and unrestricted trait were included in the P matrix, and an extra G row and column were added to the phenotypic variance-covariance matrix between index traits corresponding to the restricted trait (Y), with the remaining diagonal element of the new matrix (NP) set to zero. The resulting matrix was 3 × 3 in dimension. A zero was also appended to the genetic covariance matrix between goal and index traits (NG: 3 × 1). The index weights were calculated in the same way as in a nonrestricted index.

$$NP = \begin{bmatrix} P & GY \\ G'Y & 0 \end{bmatrix}$$

$$NG = \begin{bmatrix} G & 0 \end{bmatrix}$$

### RESULTS

Genetic and environmental variances and covariances between MY, CI, and BCS are presented in Table 1. Selection for MY would result in a longer CI and lower BCS. The environmental covariance between BCS and CI was small (−0.011) and the environmental correlation was less than 0.001 suggesting that the relationship between CI and BCS is mediated entirely through genotype. Thus, managing or feeding for BCS would have little effect on CI in these data.

The genetic correlation between MY and BCS was −0.51 and between MY and CI was 0.67, while the genetic correlation between BCS and CI was −0.48. Parameters conditional on MY are presented in Table 2. After genetically adjusting the variances of and covariance between BCS and CI, the estimated genetic correlation between BCS and CI was −0.22. This is the same as the correlation estimated after the phenotypic adjustment for milk yield in the parameter estimation of Pryce et al. (2000), although clearly the advantage with the method here is that we have demonstrated the effect of disentangling environmental and genetic covari-

**Table 1.** Environmental and genetic variances and correlation estimates for milk (MY), calving interval (CI), and BCS.

	Phenotypic variance	Genetic variance	Genetic and environmental correlations above and below diagonal, respectively, heritabilities along the diagonal		
			MY	CI	BCS
MY	1,091,354	626,204	0.57 (0.02)	0.67 (0.08)	−0.51 (0.03)
CI	2057	51.2	0.05 (0.01)	0.025 (0.005)	−0.48 (0.01)
BCS	1.68	0.648	−0.03 (0.02)	0.06 (0.01)	0.39 (0.02)



**Table 2.** Genetic and environmental parameters for calving interval and BCS after adjustment for milk yield.

	Genetic	Environmental
Var CI	28.56	2001
Var BCS	0.48	1.03
Covariance	-0.825	0.041
Correlation	-0.22	0.0009

ances. The reason for the small effect on the correlation estimation is because the environmental covariance is small.

Table 3 shows responses to selection using both restricted and unrestricted selection indexes. When the goal is CI, a selection response of -5.23 d in CI would be achieved. Correlated responses in BCS and MY were 0.49 BCS points and -654.8 kg of MY (assuming selection for 1 SD change in the selection index, e.g., SD<sub>i</sub> = 1). Single-trait selection for BCS would result in a response of -3.30 d in CI. When MY was restricted in the index to zero genetic change, the response in CI was -1.12 d per SD<sub>i</sub>. When the goal was milk yield, the correlated response in CI and BCS were +4.46 d and -0.41 BCS units per SD<sub>i</sub>. Restricting CI to no genetic change, while still selecting for MY, would result in 402.4 kg of MY/SD<sub>i</sub> and -0.02 BCS units/SD<sub>i</sub>. Restricting BCS to no genetic change will still result in an increase in CI of 3.20 d/SD<sub>i</sub>. Restricting both CI and BCS to no genetic change resulted in 402.2 kg of MY/SD<sub>i</sub>.

**DISCUSSION**

The genetic correlation between MY and CI was 0.67 (0.08), which is higher than most other studies in which estimates (between MY and CI) range from 0.22 to 0.59 (Campos et al., 1994; Hoekstra et al., 1994; Grosshans et al., 1997; Kadarmideen et al., 2000; Pryce et al., 1997). Thus, cows of high genetic merit for milk yield have poorer reproductive performance, and the same is generally true of environmental correlations, although these tend to be smaller. However, high production is not always detrimental to reproduction. Røxstrom et al. (2001) obtained favorable herd-year correlations be-

tween production and fertility, demonstrating that higher yielding herds have better reproductive performance. Thus, well-managed, high yielding herds can obtain good reproductive performance, although the high genetic merit cows within these herds likely have poorer reproductive performance than low genetic merit contemporaries.

Selection for production has led to a greater dependence on body tissue mobilization to support milk production in early lactation, as intake is not sufficient to sustain lactation in this period (Veerkamp, 1998). Thus body tissue mobilization and milk production are closely related. High genetic merit dairy cattle are more predisposed to body tissue mobilization, and reproductive performance is more sensitive to changes in BCS (Pryce et al., 2001).

The environmental covariance between BCS and CI was very small, thus it appears that in this dataset feeding and management had little effect on the relationship between BCS and CI. This could have been because BCS is measured only once in lactation. The effects of management and feeding on BCS and its relationship with reproductive performance may have been more evident if repeated BCS records were taken across lactation. However, as the data were collected as part of a national type classification scheme that assessed cows only once per lactation, repeat records were not available for individual cows. BCS measured more frequently in lactation could be useful, as this would allow measures of BCS change to be calculated. The change in energy status in early lactation denoted by a change BCS may be hypothesized to be more strongly related to reproductive performance. Pryce et al. (2001) used data from a research herd, where BCS was measured weekly. Cows of high genetic merit tended to be thinner and lose more BCS than average genetic merit cows, and the effect on reproduction of losing one unit of BCS was greater in the high merit than average merit cows. Thus, the propensity of high genetic merit cattle to use body tissue to fuel milk production appears to be partly responsible for lower reproductive performance.

The genetic correlations between BCS and CI before and after adjustment for milk yield were -0.48 and -0.22, respectively. Even though the genetic covariance

**Table 3.** Responses and correlated responses (CR) to selection when the goal is calving interval (CI), BCS, and milk (MY), using index selection, where 1) a selection is unrestricted, 2) one or both of the traits is restricted to no genetic change. Results are presented as selection responses per SD change of the selection index.

Goal traits restricted	CI				BCS				MY			
	None	BCS	MY	MY, BCS	None	CI	MY	MY, CI	None	CI	BCS	CI, BCS
CI (d)	-5.23	-4.06	-2.74	-2.50	-3.30	0	-1.12	0	4.46	0	3.20	0
BCS (1-9)	0.49	0	0.27	0	0.77	0.60	0.66	0.60	-0.41	-0.02	0	0
MY (kg)	-654.8	-514.6	0	0	-405.0	10.90	0	0	768.5	402.4	653.1	402.2

between both BCS and CI with MY is high, there is a genetic predisposition for cows of low BCS to have longer CI that is independent of MY. Milk yield is partly a product of energy output; a more accurate description of energy output would have been energy-corrected milk yield; however, this is not normally considered in genetic evaluations and the genetic correlation between milk yield and energy-corrected milk yield is likely to be high.

Using the genetic parameter estimates estimated in this study, the accuracy of a predicted breeding value for CI with and without BCS were calculated to be 62 and 69%, respectively, with reliabilities of 38 and 48%, assuming information on 100 daughters. An argument for excluding fertility from some countries breeding programs is the low accuracy of predicted breeding values for fertility. Yet, using BCS in combination with fertility measures would improve the prediction of fertility breeding values.

Selection indexes are useful when there are several traits affecting economic merit. They are also useful in determining the expected correlated responses in traits that are not in the goal, or in investigating the consequences of selecting for one trait, while restricting, or achieving a desired improvement in another trait. It is highly unrealistic that any dairy breeding program would restrict milk production to zero genetic change or omit it from the goal traits, but for completeness, we included responses to selection for all three traits. Our results show that when selection is for CI or BCS, the correlated response in MY is negative, which is expected as genetic correlations are unfavorable between CI and MY and BCS and MY. As expected, responses in BCS to selection on CI were positive (i.e., cows would have a higher BCS). The same was true for selection for BCS in that the correlated response in CI was negative, i.e., a shortening of CI. Selection for MY alone would result in an extra 4.46 d/SD<sub>i</sub> in CI and a decline of 0.41 BCS units/SD<sub>i</sub>. Restricting CI and to zero genetic change and BCS to zero genetic change (i.e., one at a time in the index) would still result in unfavorable responses in BCS and CI, respectively. Jones et al. (1999) suggested that restricting BCS within a selection index may have beneficial effects for fertility; however, in our study, CI would still continue to increase, albeit at a slower rate than when single-trait selection for MY is pursued. The rate of genetic progress in milk yield when CI and BCS are restricted is 51 and 85%, compared with selection for milk yield with no restrictions. Veerkamp and Brotherstone (1997) estimated that restricting BCS to zero genetic change when selecting on the UK national selection index PIN would result in genetic gain of 83% in genetic progress of milk yield

compared with selection on PIN where BCS is not restricted.

Deriving economic weights for all traits in a selection index is the desired strategy, but in circumstances in which it is difficult to derive an economic weight for the trait of interest, a restricted index approach may be attractive. Obtaining an economic value for CI is complicated because a 365-d CI is only optimal in some circumstances; there is growing interest in allowing cows to have extended lactations in some temperate countries as a way to manage high yielding dairy cows. Economic values are generally derived assuming the extra cost or benefit of an extra unit in the trait of interest. In the case of calving interval, this would be the cost/benefit of an extra day of lactation assuming a 305-d lactation and 60-d dry period. At present, little evidence exists to suggest that anything other than a 365-d CI is optimal, but management influences, such as oestrous detection rates affect the estimate of the economic weight (e.g., Stott et al., 1999). As for BCS, in some systems, there may be an extra benefit in carcass value from having cows of higher BCS.

Implied economic weights were calculated for the cases in which either MY was held constant, while CI was decreased or in which CI was held constant, while MY was increased. In these cases, the economic weights placed 7.1 and 5.2 times more value on CI than MY (both expressed per SD). Since the phenotypic SD for CI and MY were 45 d and 1044 kg, this places an approximate economic equivalence of 10 ds CI with 1500 kg of milk. This approximate equivalence seems to suggest that restricting CI in response to increases in MY is a management overreaction, unless a radical change in production system would be required to accommodate the increase in calving interval. However maintaining CS produced relatively small change in the rate of progress for MY. While relative economic values for CI less than 5:1 will still result in increases in CI with selection for MY, availability of genetic indices for CI and for other fertility traits will allow breeders to express and to manage their breeding goals in a way that is not possible otherwise.

There are also likely to be welfare benefits in improving or preventing further declines in both CI and condition score. However, quantifying the economic value of welfare benefits is not straightforward and requires development of methodology as an extension of the conventional economic framework for estimating weights. Olesen et al. (2000) describe a framework in which each trait is considered to have both a market and a nonmarket value; individual traits may differ in whether they have only one or both types of value. This approach raises two important issues, the first being the determination of the nonmarket (or ethical) values for traits.

For example, in dairy cattle, longevity potentially provides an integrated welfare measure incorporating all aspects of health and fertility that contribute to the culling of cows.

The restricted index method is useful for examining the borders of solution areas for genetic improvement, especially in traits with difficult to estimate economic values. Conventional bioeconomic models for calculating 'market' economic weights include a number of assumptions on, e.g., milk price, insemination costs, feed costs, and exist to enable economic values to be derived (Stott et al., 1999). Fine-tuning of these models will lead to either a single economic value for CI, which can be applied to a national index, such as the UK's Profitable Lifetime Index (£PLI; currently includes PTA for milk, fat, and protein yield in addition to a measure of longevity known as lifespan), or to several economic values which could then be used in a restricted index framework. Limitations in using CI are that only the most fertile cows have two or more consecutive calving dates and hence calving interval data, and that CI may be available too late to influence breeding company decisions on young bulls. Research into dealing with the aspects of bias in CI needs to be done, before producing a genetic index for fertility. Including BCS, milk, and CI into an index is a way in which bias can be reduced, as most of the animals culled on the basis of their reproductive performance will have this information. Research into optimal ways of combining this information to limit bias is currently under way.

As fertility in high yielding dairy cows is becoming a major concern, one positive step to improvement would be through selecting for the energy status of cows, using BCS or energy balance (Coffey et al., 2001). This would also have beneficial effects on other (and as yet unquantified) aspects of health.

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