Relationships Between Fertility and Production in Holstein Dairy Cattle in Different Lactations

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ABSTRACT

Record of Performance and Dairy Herd Improvement Corporation production records of Ontario Holstein cows were merged with breeding receipts of three Ontario AI units from September 1981 through December 1985. Relationships between fertility and production in the first three lactations were investigated for 97,368 daughters of 3806 sires in 22,768 herd-hear-seasons of calving. Fertility traits were days from calving to first insemination, number of inseminations per conception, and days open. Production traits were age and month of calving adjusted 305-d milk and fat yields and fat percentage. Multiple-trait maximum likelihood was used to estimate variances and covariances. Heritabilities for the first three lactations were .18, .18, and .19 for milk yield; .20, .19, and .19 for fat yield; and .58, .52, and .48 for fat percentage. Heritabilities of fertility traits ranged from .03 to .06. Genetic and phenotypic correlations between fertility and production traits in all three lactations were essentially 0. Genetic correlations between different lactation production traits ranged from .2 to .65. Repeatabilities of fertility traits ranged from .05 to .16 in different lactations. Repeatabilities for production traits in different lactations ranged from .51 to .77. Genetic and phenotypic correlations between fertility and production in the subsequent lactation and between production and subsequent lactation fertility were also very low or zero.

Received October 31, 1988.
Accepted March 21, 1989.

INTRODUCTION

Economic returns of dairy farms are dependent upon milk production and reproductive efficiency. Milk production from dairy cattle depends, at least in part, on reproductive activity, because the more frequently a dairy cow calves the greater is the amount of milk produced in her lifetime. Therefore, conception and calving at regular intervals are of great importance in maintaining efficient milk production.

Reproductive failures accounted for 16% of all disposals of Holsteins in the United States (18) and for 21% in Canadian Holsteins (4), ranking second to production as a reason for disposal. The possibility of high milk production causing lowered fertility has concerned dairy farmers.

Many estimates of genetic relationships between milk yield and various measures of fertility in dairy cattle from field data (2, 8, 13, 14, 19, 28) suggest a substantial antagonism between high yield and fertility. In contrast, other studies (3, 17) have found a very small association of yield with fertility. Designed selection experiments (9, 24, 29, 36) have not reported any antagonism between reproduction and production in initial generations; however, the results for later generations are not available. In summary, some uncertainty exists about the genetic relationships between yield and fertility.

Most published reports on fertility traits from field data have not used the most appropriate method of analysis. Cows reaching second or later lactations have normally been culled based on their early production and reproductive performance. Freeman (6) recommended the use of mixed-model multiple-trait analyses of obtain estimates of the relationship between production and reproduction.

The purpose of this study was to estimate heritabilities, and genetic correlations between different measures of fertility and production

TABLE 1. Measures of fertility and production traits along with numbers of observations in different lactations.

	Lactation number		
Trait	1	2	3
Production traits			
Breed class average-milk[1]	97,368	36,341	9876
Breed class average-fat	97,368	36,341	9876
Fat percentage	97,368	36,341	9876
Cow fertility traits			
Days between calving and first insemination	97,368	36,341	9876
Days open	46,322	12,007	1821
Number of inseminations per conception	46,322	12,007	1821

[1]Breed class average = The 305-d yield expressed as a percentage of the least squares mean for the appropriate age and month of calving.

using multiple-trait maximum likelihood (ML) in order to account for bias from sequential cow selection for cows with missing observations in later lactations.

MATERIALS AND METHODS

Data

Ontario Dairy Herd Improvement Corporation (ODHIC) and Record of Performance (ROP) lactation records of Holsteins born since 1975 were provided by the Livestock Production Division of Agriculture Canada. Data were kept on cows calving since December 1980 with valid sire identification and whose first record occurred before 40 mo of age. Daughters of US sires were eliminated due to a lack of breeding receipt information on these sires. The edited production records were merged with approximately 1.14 million computer-recorded breeding receipts from three Ontario AI units from September 1981 through December 1985.

Conception was determined by the birth of a calf and initiation of the next lactation. embryonic death and short-term abortions were not considered conceptions because such events were not recorded. Cows with breeding before the 25th d postpartum were removed, and at least 265 d were required between last breeding and subsequent calving. Production records of a cow were considered unmatched with breeding receipts if more than 295 d elapsed between last breeding and subsequent calving; except cows with no subsequent calving were considered open. the final matched data set contained 143,585 lactation records from 97,368 daughters of 3806 sires in 22,768 herd-year-seasons of calving. Two seasons of calving were March through August and September through February. Numbers of observations for each fertility and production trait in all three lactations are given in Table 1. Thus, 18 traits were analyzed. Number of inseminations per conception equalled the number of breeding receipts with at least 2 d between consecutive breeding dates.

Model

The model assumed for all 18 traits was:

$$Y_{ijkl} = u + HYS_i + G_j + S_{jk} + e_{ijkl}$$

where:

Y_{ijkl} = observation of l^{th} daughter of the k^{th} sire in the j^{th} genetic group in the i^{th} herd-year-season of calving;
u = overall mean;
HYS_i = fixed effect of i^{th} herd-year-season of first lactation calving;
G_j = fixed effect of j^{th} genetic group;
S_{jk} = random effect of the k^{th} sire in the j^{th} genetic group; and
e_{ijkl} = random error.

There were 16 sire genetic groups. The AI sires were grouped into eight groups (groups 1 to 8) on the basis of their birth dates. Non-AI sires were grouped separately into eight (groups 9 to 16) groups according to their registration number. Sires were assumed to be unrelated and randomly mated to dams. Dams were assumed to be unrelated and represented in the data by only one daughter and all heifers were assumed to have calved. Covariances between sire and error effects were assumed to be zero.

Methods

The maximum likelihood-related procedure (Method 2) outlined by Schaeffer (25) was used to obtain variance and covariance components. Starting values of heritabilities were .25 for milk and fat yields, .50 for fat percentage, and .05 for fertility traits. These values were assumed for all three lactations. Solutions to the mixed model equations (MME) were obtained using an iterative procedure (27). The convergence criteria for sire solutions was the sum of squares of changes in sire solutions divided by the sum of squares of the latest sire solutions. The solutions were assumed to converge when the convergence criteria (25) were less than or equal to .000001. The estimated sire variance-covariance matrix (VCV) was assumed to have converged if the value of the convergence criteria was less than or equal to 5%.

RESULTS AND DISCUSSION

The percentage of total calvings resulting from first services at various intervals after calving in different lactations are in Table 2. Calving rate of cows bred within 40 d postpartum was very low. Calving rate of cows with less than 60 d to first breeding was lower than the calving rate of cows bred for the first time at 61 to 90 d postpartum. Other studies (11, 36) also reported lower conception to early breedings. However, cows bred before 100 d had higher calving rates than cows bred later than 100 d postpartum. These results agree with recommendations that the optimum time to initiate breeding is between 60 to 90 d postpartum (2, 36).

Means and standard deviations for measures of cow fertility and production in different lactations are in Table 3. Cows in first lactation were bred for the first time 4 d later than cows in third lactation. Days open and number of inseminations per conception were calculated only if subsequent calving data were known. Days open of 119 d in first lactation corresponds to a 13-mo calving interval with an average gestation length of 280 d. Mean number of inseminations per conception were not different for the first three lactations. Third lactation cows tended to have lowest means and standard deviations for all three measures of fertility (2, 14). The lower number of inseminations per conception in this study as compared with others (2, 14, 20, 31) may either represent better management, or more likely, failure to report all breedings.

TABLE 2. Percentage of total calvings to first service at various intervals after calving in different lactations (Lact).

Interval to first breeding (d)	Total calvings to first service (%)		
	Lact 1	Lact 2	Lact 3
<40	1.2	1.0	.8
41–50	3.6	3.7	3.0
51–60	8.3	9.2	9.2
61–70	13.8	13.8	13.5
71–80	16.2	17.1	16.5
81–90	14.1	14.0	14.8
91–100	11.7	10.8	10.9
101–110	8.0	8.1	8.2
111–120	5.5	5.7	5.7
121–130	4.5	3.9	4.1
131–140	3.1	3.1	3.1
141–150	2.2	2.2	2.2
>150	7.8	7.4	8.0

Results in Table 3 indicate that fertility level in Ontario dairy herds is comparable with artificially bred Holstein dairy herds in Quebec (31), New York (7), and California (2). However, reproductive performance of Ontario herds failed to achieve a calving interval of 12 mo. A yearly calving interval requires an open period of no more than 90 d. Ontario dairy cows were taking 92 d from calving to first breeding. Failure of cows to come into estrus, poor conception rates, and inefficient estrus detection are important barriers to achieving a calving interval of 12 mo.

Milk and fat yields increased with lactation number, but fat percentage remained constant from first through third lactation. These trends were expected as a result of selection.

Heritabilities and Coefficients of Additive Genetic Variation

Literature estimates of heritabilities for cow fertility in different lactations ranged from .03 to .06 (2, 8, 10, 26, 33) (Table 4). Heritability

TABLE 3. Means and standard deviations of fertility and production traits in different lactation.

Trait[1]	Lactation 1		Lactation 2		Lactation 3	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
DCFI	94.92	36.18	91.22	32.10	90.48	31.69
DO	118.87	57.29	110.92	48.34	107.43	44.51
NICC	1.55	.91	1.55	.88	.1.54	.85
BCA-M	136.95	25.39	143.60	27.49	148.05	27.93
BCA-F	141.32	27.91	147.06	29.28	151.50	30.18
Fat %	3.80	.42	3.80	.44	3.80	.44

[1]DCFI = Days between calving and first insemination, DO = days open, NICC = number of inseminations per conception (cow), BCA-M = breed class average – milk, and BCA-F = breed class average – fat.

of milk yield was .18, .18, .19 in first, second, and third lactations, respectively, which are close to the generally accepted range of .20 to .25 (35). Heritabilities for milk and fat yields remained constant over the three lactations. Some studies (15, 22, 23, 32) have shown an increase in heritability for milk and fat yields with increase in lactation number, but comparable results have also been reported (34). Heritabilities for milk and fat yields in first lactation in this study were slightly lower than weighted averages reported by Maijala and Hanna (15).

The low heritability values for milk and fat yields were due to selection, because data covered the period 1981 to 1985 and selection prior to 1981 was ignored. If additive genetic relationships among sires were included in the analysis back to a base generation of 1960, then heritability estimates should be greater (30). Additive genetic relationships were not included in this analysis for computational reasons.

Heritability of fat percentage in first lactation was higher than in second and third lactations, due to an increase in error variance for fat percent in later lactations. Heritability of fat percentage in all three lactations was higher than some reports (15, 32).

Coefficients of additive genetic variation (CVA) were calculated as $[(4 \times \text{sire variance})^{.5}/\text{mean}] \times 100$. The CVA for measures of cow fertility (Table 4) in different lactations ranged from 6.5 to 12.7%. The CVA for number of inseminations per conception increased with lactation number. The CVA for production traits in different lactations ranged from 6 to 7% and remained constant across three lactations (8, 10, 21). Production traits had lower CVA than fertility traits, even though the heritabilities for production traits were much higher than for fertility traits. If selection for fertility were to be practiced, it should be on sire proofs based on large progeny numbers.

Fertility Relationships Within Lactation

Genetic and phenotypic correlations among fertility and production in the first three lacta-

TABLE 4. Estimates of heritabilities and coefficients of additive genetic variation (CVA%) for fertility and production traits in different lactations.

Traits[1]	Lactation 1		Lactation 2		Lactation 3	
	h^2	CVA%	h^2	CVA%	h^2	CVA%
DCFI	.05	8.28	.04	6.53	.04	6.54
DO	.03	8.77	.04	8.21	.05	9.00
NICC	.03	9.91	.04	11.02	.06	12.66
BCA-M	.18	6.33	.18	6.46	.19	6.54
BCA-F	.20	6.84	.19	7.04	.19	7.26
Fat %	.58	6.65	.52	6.66	.48	6.72

[1]DCFI = Days between calving and first insemination, DO = days open, NICC = number of inseminations per conception (cow), BCA-M = breed class average – milk, and BCA-F = breed class average – fat.

TABLE 5. Genetic correlations (above diagonal) and phenotypic correlations (below diagonal) among fertility and production traits[1] for the first three lactations (Lact).

	DCFI	DO	NICC	BCA-M	BCA-F	Fat %
DCFI						
Lact 1		.28	−.08	.07	.10	.04
Lact 2		.21	−.04	.01	.03	.04
Lact 3		.12	−.02	.01	.01	.00
DO	.56		.14	.05	.06	.02
	.54		.09	.01	.03	
	.55		.04	.01	.00	.01
NICC	.01	.63		−.01	.01	.01
	−.10	.61		−.01	.01	.02
	−.06	.65		.01	.00	.00
BCA-M	.01	.01	.01		.55	−.38
	.01	.02	.02		.44	−.35
	.03	.02	.01		.30	−.21
BCA-F	.03	.02	.01	.79		.53
	.02	.04	.04	.80		.58
	.06	.05	.04	.78		.29
Fat %	.07	.04	.02	−.26	.34	
	.01	.02	.03	−.23	.31	
	.05	.06	.05	−.16	.38	

[1]DCFI = Days between calving and first insemination, DO = days open, NICC = number of inseminations per conception (cow), BCA-M = breed class average − milk, and BCA-F = breed class average − fat.

tions are in Table 5. Genetic correlations were generally positive. These estimates were forced positive because of a part-whole relationship among the measures of fertility; for example, days open contains days from calving to first breeding. Phenotypic correlations were larger than genetic correlations. The low negative genetic correlations between days from calving to first breeding and number of inseminations per conception indicate that all cows may require the same number of services to conceive irrespective of large or small intervals between calving and first insemination. Genetic correlations among cow fertility in second and third lactations were inclined to be lower than in first lactation, whereas the phenotypic correlations tended to be of the same magnitude and direction in all three lactations. Genetic correlations were lower than some literature values (2, 8, 33), but phenotypic correlations of days open with number of inseminations per conception and days from calving to first insemination were consistent with values reported by others (8, 33). The data analyzed in this report, which are biased by selection, are perhaps more representative of the dairy population. The results of analyses suggest no antagonism between production and reproduction.

Production Relationships Within Lactation

The relationships between milk and fat yields were large and positive. Phenotypic correlations of milk yield with fat yield were usually larger than genetic correlations. Genetic correlation between milk and fat yield in second lactation tended to be somewhat lower than in first lactation and lower yet in third lactation (8).

TABLE 6. Genetic correlations among the same traits in different lactations.

	Lactations		
Trait[1]	1 and 2	1 and 3	2 and 3
DCFI	.05	.02	.02
DO	.06	.02	.02
NICC	.03	.01	.01
BCA-M	.42	.21	.31
BCA-F	.46	.22	.34
Fat %	.65	.42	.52

[1]DCFI = Days between calving and first insemination, DO = days open, NICC = number of inseminations per conception (cow), BCA-M = breed class average − milk, and BCA-F = breed class average − fat.

TABLE 7. Genetic correlations among first lactation production traits and fertility traits in second and third lactations.

First lactation production traits	Fertility traits[1]					
	DCFI		DO		NICC	
	2nd	3rd	2nd	3rd	2nd	3rd
BCA-M	.01	.01	.01	.01	-.01	.01
BCA-F	.03	.01	.03	.01	.01	.01
Fat %	.03	.01	.02	.02	.02	.02

[1]DCFI = Days between calving and first insemination, DO = days open, NICC = number of inseminations per conception (cow), BCA-M = breed class average - milk, and BCA-F = breed class average - fat.

Fat yield and fat percentage were positively correlated. Genetic correlations between fat yield and fat percentage in first and second lactation were larger than phenotypic correlations. Genetic and phenotypic correlations between milk yield and fat percentage were negative, and genetic correlations were of greater magnitude in all three lactations.

Fertility and Production Relationships With Lactation

Most phenotypic correlations between fertility and production traits were positive but not different from 0. There was no apparent trend from first to third lactation. Genetic correlations between production and fertility traits in all three lactations were positive, but not different from 0. There was no evidence of antagonistic relationships between production and reproduction. The results were in agreement with the results from the initial generation of selection experiments (24, 29, 36) and with some reports with field data (3, 17). However, experimental results are not completed and only in later generations might one expect to see reproduction deteriorate. The results do not agree with those of some studies (2, 8, 10, 13, 14, 28, 33). These workers concluded a genetic antagonism between production and reproduction. However, if farmers were to inseminate high producing cows later than moderate or low producing cows or to breed high producing cows more frequently, this would automatically produce an antagonistic correlation between production and reproduction. Breeding high producing cows more frequently than low producing cows could also cause a false antagonism between production and reproduction. As well, failure to adjust for selection effects in estimating variances and covariances might affect results.

Relationships Between Traits in Different Lactations

Genetic correlations for fertility traits were positive and very close to zero (Table 6). Thus, fertility in different lactations may be influenced by different sets of additive genes. Jansen (12) reported moderate to high genetic correlations between fertility in different lactations.

Genetic correlations between production traits in different lactations were all very differ-

TABLE 8. Genetic correlations among first lactation production traits and fertility traits in second and third lactations.

First lactation production traits[1]	Production traits[2]					
	BCA-M		BCA-F		Fat %	
	2nd	3rd	2nd	3rd	2nd	3rd
DCFI	.04	.01	.06	.02	.02	.01
DO	.03	.01	.05	.01	.03	.03
NICC	.01	.01	.01	.02	.01	.02

[1]DCFI = Days between calving and first insemination, DO = days open, NICC = number of inseminations per conception (cow), BCA-M = breed class average - milk, and BCA-F = breed class average - fat.

TABLE 9. Repeatabilities of fertility and production traits between different lactations.

Trait[1]	Lactations 1 and 2	1 and 3	2 and 3
DCFI	.11	.15	.16
DO	.08	.05	.09
NICC	.10	.06	.05
BCA-M	.58	.52	.60
BCA-F	.59	.51	.60
Fat %	.77	.70	.76

[1]DCFI = Days between calving and first insemination, DO = days open, NICC = number of inseminations per conception (cow), BCA-M = breed class average - milk, and BCA-F = breed class average - fat.

ent from unity, implying sire by age or parity interactions. The genetic correlations for production traits between different lactations were much lower than reported estimates (23, 32). This is probably caused, at least in part, by the relatively low number of cows that had time to complete all three lactations in the short time frame for data collection (about 4 yr). Sire rankings would therefore change somewhat with age or parity of cow. Adjacent lactations had higher estimates of genetic correlation than nonadjacent lactations. A genetic correlation of .42 between first and second lactation milk yield closely agrees with the "selection-free estimate" of .37 obtained by Ali (1).

Relationships Between Production and Subsequent Lactation Fertility

Genetic correlations between first lactation production traits and second and third lactation fertility traits are given in Table 7. Most of the genetic correlations were positive and very close to 0. The data revealed no evidence of genetic antagonism between production and subsequent lactation fertility traits. Selection for increased first lactation milk yield would not impair fertility in the current and subsequent lactations.

Relationships Between Fertility and Subsequent Lactation Production

Genetic correlations between first lactation fertility and second and third lactation production are in Table 8. No genetic antagonism was found between previous lactation fertility and subsequent lactation production traits.

Repeatabilities

Phenotypic correlations between the same trait in different lactations can be considered by definition to be estimates of repeatabilities. Repeatabilities estimated from the sire and residual variance and covariance components obtained by multitrait maximum likelihood were unbiased by selection (5). Repeatabilities (Table 9) for fertility traits were much lower than for production traits (7, 16). Fertility performance during one lactation may not be very repeatable in subsequent lactations. Thus, cows having some difficulty in conceiving in their first lactation may not repeat the same difficulty in later lactations.

Estimates of repeatability for each trait in Table 9 were quite similar. Fat percentage was more repeatable than milk and fat yields. Adjacent lactations had higher estimates of repeatabilities for production traits than nonadjacent lactations. Repeatability was not constant from one lactation to the next, although they were likely not significantly different.

CONCLUSIONS

Heritabilities of fertility measures were low, ranging from .03 to .06. Opportunities probably exist to express fertility in terms of other measures such as days to first estrus and degree of estrus expression. New variables are becoming available as a result of progesterone assays (Rapitta and Burnside, unpublished data). Progeny tests on large numbers of daughters may provide an opportunity for selection for fertility.

Genetic correlations between production and fertility traits were close to zero, indicating no genetic antagonism between production and fertility. Thus, correlated response in fertility from direct selection on production would be expected to be minimal. Genetic correlations between fertility and production traits for different lactations suggest that production and fertility in different lactations may partially be determined by different sets of additive genes.

Fertility is very lowly repeatable. Poor fertility in cows appears to be a management problem. Therefore, improvement must be brought about by improving management conditions that influence fertility. Inclusion of relationships among sires would have made the analysis much more difficult but would possibly have increased estimates of genetic variances and covariances. Correlations would not be expected to be greatly different from those in this study, except possibly correlations between fertility traits and milk and fat production.

ACKNOWLEDGMENTS

The award of a Commonwealth Scholarship to the first author by the Association of Universities and Colleges of Canada is acknowledged with gratitude. We also acknowledge research grants from the Natural Science and Engineering Research Council of Canada, the Canadian Association of Animal Breeders, and the Ontario Ministry of Agriculture and Food.

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