The Effects of Inbreeding on the Lifetime Performance of Dairy Cattle

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ABSTRACT

The effects of inbreeding on the lifetime performance of dairy cattle were examined using data for production, somatic cell score, and linear type for all Holstein cows that were scored between 1983 and 1993. The results of fixed and mixed animal models differed. Relative net income adjusted for opportunity cost for the 2,610,123 cows with an 84-mo opportunity for herdlife was depressed by $14.79 for fluid market pricing and by $12.40 for manufacturing pricing per 1% increase in inbreeding. Mixed model estimates of depression per 1% of increase in inbreeding were +0.55 d for age at first calving, –6 d for days of productive life, and –4.8 for days in milk. Inbreeding decreased the mature equivalent production of milk, fat, and protein during first lactation by 27, 0.9, and 0.8 kg and the lifetime production of milk, fat, and protein by 177, 6.0, and 5.5 kg, respectively, per 1% increase in inbreeding. Inbreeding had little effect on conformation traits. The effects of inbreeding were cumulative, and effects on lifetime profit functions were relatively larger than the effects on lactation traits. Registered cows had higher levels of inbreeding and larger standard deviations than did grade cows. Inbreeding in registered cows depressed relative net income adjusted for opportunity cost for fluid and manufacturing prices by $24.43 and $21.78, respectively; income was depressed $9.43 and $9.02, respectively, for grade cows. The difference between registered and grade cattle is likely due to the incomplete pedigree information in grade animals. Inbreeding among cows in this study was not high on average, but economic losses represented a significant cost to the producer.

(**Key words**: inbreeding, relative net income, lifetime performance, mixed models)

Abbreviation key: **DPL** = days of productive life, **OC** = opportunity cost, **RNI** = relative net income, **RNIOC** = RNI adjusted for OC.

INTRODUCTION

Interest in the lifetime performance of dairy cows has increased as operating margins continue to narrow for dairy producers. One to 3 yr of production are required for a dairy farmer to recover costs of rearing a cow (8) and to begin to generate a positive income flow. Longer productive life could increase returns if it reduced the number of cows for which rearing costs were never recovered or if it increased the income generated by those cows for which rearing costs were repaid. The trait is important enough that national genetic evaluations are now available (22).

Selection for improved lifetime economic performance or any other aggregate genotype increases the relationships among bulls in AI service (9, 16), as the most desirable genotypes tend to be found in a few individuals. Young and Seykora (27) and Short and Lawlor (16) have shown that relationships between animals in the US Holstein population and inbreeding in Holsteins have increased in recent years. The time frame involved corresponds to a period of genetic improvement in production brought about largely by the heavy use of highly selected bulls as sires of sons in AI (5). Inbreeding has become an important consideration among the large population of Holsteins in the US.

Inbreeding decreases cow survival (2, 9), single lactation production (2, 6, 7, 9, 10, 16), and reproductive performance (2, 6, 7, 9, 28) and may increase SCC (11). The literature shows that inbreeding has little effect on type traits (9, 12, 16, 19, 28). The combined economic effect of inbreeding depression on these traits across a cow lifetime is unknown. These separate performance measures can be combined to estimate the economic impact of inbreeding on total lifetime performance using functions such as lifetime relative net income (**RNI**) (3, 13, 20).

Estimates of inbreeding for cows included in the genetic evaluations for production in the US are now routinely available (26). Although complete pedigree

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Received December 30, 1997.
Accepted June 11, 1998.

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information is required for accurate calculation of inbreeding coefficients, only a valid birth date, calving date, and sire identity are required for genetic evaluations. Estimates of inbreeding must be based only on what is known or on reasonable assumptions. Wiggans et al. (26) assumed that the relationship between known and unknown parents or between two unknown parents was the same as that between known animals that were born during the birth year of the most recent parent, regardless of identification status. For unknown parents, a birth year 3 yr prior to the birth year of the animal in question was assumed. Inbreeding estimated in such a manner is near 0.0 with little variance. Animals in the national data sets with two known parents could have incomplete information existing more remotely in their pedigree, which could cause an underestimation of inbreeding for that animal. In effect, animals credited with low or zero inbreeding could be highly inbred, but such inbreeding would be unrecognized because of the relationships that were lost through missing pedigree information. The most frequent errors would be small underestimates of actual inbreeding. Rarely would the approach of Wiggans et al. (26) overestimate inbreeding and then only by small amounts.

Sigurdsson and Jonmundsson (17) studied the effect of incomplete pedigree data on estimates of inbreeding coefficients among Icelandic dairy cattle and reported an average inbreeding coefficient of 1.82% when the animals were required to have at least sire, dam, and one grandparent identified. When a minimum of four generations of complete pedigree information was required, the average inbreeding coefficient was 2.70%. Studies of inbreeding depression could be affected dramatically by the completeness of pedigree data.

The objectives of this research were to estimate the effect of inbreeding on RNI from fluid and manufacturing milk markets and on those traits related to lifetime performance. The effects of inbreeding in registered and grade populations were examined as a check of the impact of complete pedigree information on the estimates of inbreeding depression.

MATERIALS AND METHODS

Data for the study included all cows classified by the Holstein Association (Brattleboro, VT) from 1983 to 1993. Linear scores adjusted for age for all 14 type traits and adjusted final scores were provided by the Holstein Association for these animals. Inbreeding coefficients and actual lifetime production data were from the USDA-Animal Improvement Programs Laboratory (Beltsville, MD) for all cows in those herds that were classified during the same period. Major edits removed cows with a herdlife opportunity less than 84 mo, cows that did not calve for the first and last time in the same herd, cows with calving intervals under 270 or over 730 d (9 to 24 mo), cows with first calving ages under 548 or over 1096 d (18 to 36 mo), and cows without protein information for every lactation. These edits removed 41.9, 5.3, 6.6, and 6.6% of the original animals, respectively. Because these edits were sequential, a different order of edits would affect the percentages. The largest data set used in this study included over 2.6 million cows (Table 2). Of these, 1,188,777 or 45.5% were registered, and 1,421,346 or 54.5% were grade.

RNI Calculation

The RNI function that was used for the 84-mo herdlife opportunity was similar to that used by Weigel (23).

$$\begin{aligned} \text{RNI} = {} & \sum_{i=1}^{n}\left[\sum_{j=1}^{3}\text{component}_{ij}(\text{Value}_j - \text{Cost}_j)\right] \\ & + (\text{number of lactations})(\text{net value of a calf}) \\ & + \text{net salvage value} \\ & - (\text{total days in milk})(\text{daily expenses per day in milk}) \\ & - (\text{total days dry})(\text{daily expenses per day dry}) \end{aligned}$$

where summation is over j components (fluid, fat, protein) and i lactations initiated before the end of the 84-mo opportunity length. Economic values were the same as those used by Weigel et al. (25). Feed costs for production of milk, fat, and protein were based on information of Dado et al. (4). Cows that were milked three times daily were included in the study, and the daily expenses were increased to \$3.53/d for additional labor and facilities costs of milk harvesting. Daily expenses included labor costs for milking and handling of lactating cows and lower costs during the dry period when less labor input is required. Feed costs for body maintenance are included in daily expenses for days lactating and dry. Fixed costs for facilities are also included in daily expenses. Actual milk production for lactations of up to 305 d in length were used. Therefore, days dry, as used in this function, included DIM beyond 305. Days dry was calculated as the difference in calving interval and DIM; the maximum value was 305 d.

TABLE 1. Costs and values for yield traits used in the calculation of relative net income in fluid and manufacturing markets for both 84- and 60-mo herdlife opportunity.

Trait	Cost	Value	
		Fluid	Manufacturing
	($/kg)		
Carrier	0.02	0.254	0.116
Fat	0.567	1.28	1.28
Protein	1.02	. . .	3.00
SCC[1]		0.0055 (<100,000 cells) 0.0022 (<250,000 cells)	± 0.0042[2]

[1] Applies to 60-mo data set only. Details of how premiums were applied appear in the text.

[2] Per 100,000 cell deviation from 500,000.

Adjustment of RNI for somatic cell information was made using cows with herdlife opportunity of 60 mo and with average SCC available for all lactations. Somatic cell adjustment in the fluid market was a two-tiered process that was made per kilogram of milk produced in each lactation. The highest premium was $0.0055/kg for milk with SCC fewer than 100,000 cells. A second-tier premium was $0.0022/kg for milk with fewer than 250,000 SCC. Adjustment for SCC in the manufactured market (25) used a base of 500,000 cells and gave a $0.0042 bonus or penalty per kilogram of milk for each variation of 100,000 cells from that base of 500,000 cells. All costs, values, and SCC penalities or premiums affecting milk sales are shown in Table 1.

Calculation of Opportunity Cost

Opportunity cost (**OC**) must be estimated for and applied to every lactation initiated within the 84-mo herdlife opportunity for each cow. For cows born in earlier years, OC was a ratio of the average for 84-mo RNI to days of productive life (**DPL**) for those animals calving for the first time during the year in question. The DPL was the interval between the date of freshening for the last lactation in the herdlife opportunity plus DIM for that lactation (with a maximum of 305 d) and the date of first calving (24). The OC must be estimated for cows that were born in more recent years when no cows with 84-mo herdlife opportunity had their first calves. We calculated OC per day (within herd) for the actual years of data and predicted the ratios (RNI/DPL) for later years using linear regression. This method produced means and standard deviations of the OC per day that were more similar to those for actual years of data than the approach of Weigel et al. (24). Total OC was then calculated per lactation by multiplying the OC per day by the calving interval.

Estimation of Inbreeding Depression

The effects of inbreeding were estimated from a fixed model and a mixed model. The fixed model was applied to all data, and PROC GLM of SAS® (14) was used to analyze with herd-year of first calving absorbed. The model was as follows:

$$y_{ij} = \mu + hy_i + \beta(F_{ij} - \bar{F}_i) + e_{ij}$$

where

y_{ij} = trait recorded on animal j in herd-year i of first calving,
μ = overall population mean,
hy_i = fixed effect of herd-year of first calving i,
β = regression of trait being examined on inbreeding coefficient,
F_{ij} = inbreeding coefficient for animal j in herd-year of first calving i,
$\bar{F}_i$ = average inbreeding coefficient for herd-year of first calving i, and
e_{ij} = unexplained variation for animal j calving for the first time in herd-year i.

A similar animal model, analyzed by multitrait derivative-free REML (1), was used to estimate the heritabilities and inbreeding depression. Terms in this model are as previously described with the addition of a_{ij}, which represents the random animal effect of cow j first calving in herd-year i $(0, A\sigma_a^2)$.

$$y_{ij} = \mu + hy_i + a_{ij} + \beta(F_{ij} - \bar{F}_i) + e_{ij}.$$

The relationships between animals for mixed model analysis were calculated from the data samples that were analyzed with augmentation by paternal grandsire information from the July 1996 USDA-DHIA genetic evaluation and maternal grandsire information when the animal's sire-identified dam appeared in the original data set. The complete data set for the 84-mo herdlife opportunity was partitioned to avoid missing data points for certain traits as mixed model analysis requires all traits to be present for all animals. Samples of the data, which were necessary for analysis by multitrait derivative-free REML (1), included all cows in randomly selected herds.

RESULTS AND DISCUSSION

Profit functions including SCS used a herdlife opportunity of 60 mo. When SCS was not included, a herdlife opportunity of 84 mo was used, and subsets were formed to include cows with SCS in first lactation, cows calving a second time to generate a first calving interval, and cows with linear type data. Table 2 shows the number of cows and herds involved in each data set along with pedigree information and means and standard deviations of the inbreeding coefficients. The highest average inbreeding coefficient was for the data of herdlife opportunity of 60 mo. Cows in this data set were from the most recent birth years of the study, which was a result of requiring SCS information in RNI adjusted for OC (**RNIOC**) calculations. Higher estimates for inbreeding are consistent with the findings of Sigurdsson and Jonmundsson (17) as these cows would tend to have more generations of pedigree information available from which to estimate inbreeding than would cows with earlier birth dates. A base date of 1960 was used in the calculation of inbreeding coefficients used in this study (26).

Estimates of inbreeding depression for RNIOC from each subset are shown in Table 3. Means for profit functions in the data for 84-mo herdlife opportunity were from –$16 to $178 in the fluid market and from –$12 to $185 in the manufacturing market. Differences between means were likely caused by the length of time that the cows were required to produce to be included in the specific data set. Means for the entire 84-mo herdlife opportunity group were nearly zero, reflecting adjustment for OC in both markets. Estimates of individual cow profitability in the fluid market were more variable. Weigel et al. (25) reported an average RNIOC in fluid markets of –$118 on cows that were scored and questioned whether optimum culling decisions were made for cows that were included in that study. The present study includes some cows that were not scored, cows milked three times a day, and slightly more recent calving dates.

Heritabilities of RNIOC for 84-mo herdlife opportunity ranged from 0.13 to 0.24 and from 0.12 to 0.20 for the fluid and manufacturing markets, respectively, in agreement with estimates of 0.14 to 0.18 by Weigel (23) and Weigel et al. (25). Fixed model estimates of inbreeding depression per 1% increase in inbreeding on RNIOC ranged from –$11 to –$15 for the fluid market and from –$10 to –$13 for the manufactured market. Mixed model estimates of inbreeding depression were larger, ranging from –$15 to –$22 for the fluid market and from –$12 to –$19 for the manufacturing market. The similarity of estimates of inbreeding depression from the two models seems to support the conclusions of Miglior et al. (10) that fixed model analysis of inbreeding is not greatly different from animal model analysis. However, mixed models utilize more information and appear to

TABLE 2. Characterization of pedigree status and inbreeding in full data sets and subsets created to study specific variables.

	Herdlife opportunity				
		84 mo			
Category	60 mo,[1] SCS required for all lactations	All cows	With first lactation SCS	With first calving interval	With linear type data
Animals	119,320	2,610,123	159,167	1,907,327	792,598
Herds	5706	18,166	11,967	18,158	14,119
Sires	11,060	58,998	11,615	52,833	32,406
Dams	104,886	1,767,873	138,815	1,377,384	610,277
Paternal grandsires	652	2190	681	2085	1394
Maternal grandsires	10,026	39,469	11,213	35,496	21,056
Inbreeding					
X, %	1.77	1.18	1.46	1.15	1.43
SD, %	2.25	2.07	2.11	2.02	2.15
	Subsamples for multitrait derivative-free REML analysis				
Animals	*	56,870	64,133	56,237	54,752
Herds	*	406	4838	564	910
Sires	*	5866	6691	6526	6471
Dams	*	38,977	55,789	40,576	43,325
Paternal grandsires	*	444	471	487	466
Maternal grandsires	*	3074	5947	3481	3261
Inbreeding					
X, %	*	1.09	1.47	1.12	1.47
SD, %	*	1.93	2.17	2.01	2.19

[1] The 60-mo data set was analyzed in its entirety by splitting the data set into two random halves, each containing complete herds.

TABLE 3. Comparison of means, standard deviations, heritabilities, and inbreeding depression for profit functions using fixed and mixed models.

	RNIOC,[1] Fluid milk market						RNIOC, Manufacturing milk market					
			Inbreeding depression[2]						Inbreeding depression[2]			
Data set[3]	$\bar{X}$	SD	Fixed model	Mixed model	SE[4]	h^2	$\bar{X}$	SD	Fixed model	Mixed model	SE[4]	h^2
60-mo[5] RNIOC												
With SCS adjustment	10	711	–9	–10	1.50	0.10	6	648	–8	–11	1.52	0.09
Without SCS adjustment	9	701	–9	–12	1.62	0.11	4	606	–8	–11	1.43	0.09
84-mo RNIOC												
All cows	–16	875	–11	–15	2.13	0.20	–12	737	–10	–12	1.80	0.18
First lactation SCS required	132	918	–14	–20	2.10	0.13	101	771	–13	–17	1.77	0.12
First calving interval required	178	943	–13	–20	2.14	0.24	185	764	–11	–17	1.75	0.21
Linear type data required	78	912	–15	–22	1.97	0.22	86	759	–13	–19	1.65	0.20

[1] Relative net income adjusted for opportunity cost.

[2] Number of cows in each data set are in Table 2.

[3] Inbreeding depression estimates are per 1% increase in inbreeding.

[4] Standard error of mixed model estimates of inbreeding depression.

[5] All cows with SCS data in all lactations; mixed model results are averages of results from two subsets of the data.

be more useful for estimating inbreeding losses. In all cases, profit functions for the fluid market are more variable, allowing for a greater chance for differences between cows caused by inbreeding.

Mean values for 60 mo RNIOC ranged from $4 to $10 and were slightly higher than the –$12.00 of Cassell et al. (3) and –$20 of Weigel (23) for a 60-mo RNIOC. Slight differences in the calculation of profit functions and in the cow populations involved could account for differences between the studies. Negative values for RNIOC could indicate a failure of breeders to recognize OC as an expense. Negative RNIOC values would be expected if the average heifer allowed to calve in the same year turned out to be more profitable than older cows actually retained by breeders. Estimates of inbreeding depression per 1% increase in inbreeding for a 60-mo RNIOC ranged from –$8 to –$9 and from –$10 to –$12 for fixed and mixed models, respectively. Averages of mixed model estimates of heritability ranged from 0.09 to 0.11. Heritability was higher for profit functions for the fluid market than for the manufacturing market. This result was likely caused by a greater emphasis on income in the fluid market from production traits. Production traits have higher heritabilities than other traits, such as length of productive life, which might be more important in herds with milk marketed for manufacturing purposes.

The use of SCC information in profit functions increased the average RNIOC slightly ($10 vs. $9), indicating that the somatic cell bonuses outweighed the penalties in the data studied. The somatic cell bonus and penalty system used would penalize a cow with high milk production and a high SCC while rewarding a cow with a high milk production and a low SCC. The impact on the lower producing cows would be less because fewer kilograms of product would be available for an increased or decreased value.

Estimates of heritabilities and inbreeding depression for production and type traits are in Table 4. Means and standard deviations were for the entire data sets (i.e., those analyzed using the fixed model) and were similar to other estimates in the literature. The means for data samples that were used in REML analysis (not shown) were comparable. Estimates of inbreeding depression on linear type traits from the fixed and mixed models were similar. Heritabilities for these traits were similar to estimates in the literature (15, 18), although the estimates for stature and for final score adjusted for age were slightly higher in this study. Estimates of heritability for lifetime performance traits were slightly higher than most estimates found in the literature (16, 21, 23). Mixed model estimates of inbreeding depression on the lifetime performance traits were at times almost twice those of the fixed model estimates. Several of the estimates of inbreeding depression (including age at first calving, days of productive life, and total DIM) from fixed model analysis were not significant ($P > 0.01$). Tests of significance were not performed on mixed model estimates of inbreeding depression. Inbreeding increased age at first calving and first calving interval less than 1 d and decreased the DPL and total DIM by 6 and 5 d respectively, per 1% increase of inbreeding. Our results for age at first calving agree with the findings of Bonzcek and Young (2), but our DPL results are lower. No comparable estimate for first calving interval or DIM was found in the literature.

Inbreeding decreased lifetime milk, fat, and protein by 177, 6, and 5.5 kg, respectively, per 1% increase of inbreeding. Estimates of inbreeding depression on mature equivalent production for first lactation from fixed and mixed models agree with recent estimates (16, 26). Miglior et al. (11) reported an increase in SCS of 0.012 units per 1% increase in inbreeding. Our results were not as large and were based on almost twice as many cows.

Impact of Complete Pedigree Information

Data sets were formed from the data for 84-mo herdlife opportunity from completely registered herds or grade herds to determine the effect of incomplete pedigree information on estimates of inbreeding depression. A subset of each of these data sets was formed by choosing random herds because the data sets were too large for analysis with REML. Inbreeding levels (Table 5) in registered herds were higher (1.67% vs. .57%) and more variable (SD of 2.24 vs. 1.60) than those in the grade herds. This result could be due to the method used to estimate inbreeding in cows with missing pedigree information rather than to differences in mating decisions made by herd managers.

Accurate calculation of inbreeding coefficients requires complete pedigree information from a reasonably remote base date. Of the grade cows in the study, 218,969 or 15.4% had no dam identification. The frequency of missing maternal granddam information was not calculated but could not be present more frequently than dam identification. Registered cattle had complete pedigree data available. Profit functions were similar for grade and registered cattle; values

TABLE 4. Means, standard deviations, fixed model, and mixed model analysis of inbreeding depression per 1% increase in inbreeding for production and type traits.

	Means and fixed model estimates				Mixed model estimates		
Variable	$\bar{X}$	SD	Inbreeding depression	SE	h^2	Inbreeding depression	SE
Age at first calving, d[1]	841	98	+0.44	0.18	0.11	+.55	0.18
Days of productive life[1]	909	587	–2.81	1.37	0.11	–5.96	1.40
Total milk, kg[1]	20501	14187	–95.49	33.35	0.13	–177.17	34.18
Total fat, kg	743	516	–3.25	1.21	0.13	–6.01	1.24
Total protein, kg	649	445	–2.93	1.05	0.13	–5.45	1.07
Total DIM	734	446	–2.58	1.04	0.12	–4.84	1.06
First lactation mature equivalent milk, kg	8794	1754	–18.74	3.41	0.33	–26.65	3.46
First lactation mature equivalent fat, kg	321	63	–0.66	0.12	0.34	–0.86	0.12
First lactation mature equivalent protein, kg	278	53	–0.59	0.10	0.28	–0.80	0.10
First calving interval, d[2]	402	68	+0.35	0.15	0.04	+0.31	0.15
First lactation SCS[3]	2.61	1.39	–0.002	0.003	0.16	+0.002	0.003
Stature[4]	30.9	8.7	–0.06	0.02	0.43	–0.09	0.02
Strength	29.1	7.8	–0.11	0.02	0.27	–0.11	0.16
Body depth	30.9	8.0	–0.14	0.02	0.32	–0.14	0.02
Dairy form	30.0	7.6	+0.01	0.02	0.24	–0.02	0.02
Rump angle	25.5	5.5	+0.01	0.01	0.38	–0.01	0.01
Thurl width	28.0	7.6	–0.10	0.01	0.23	–0.10	0.01
Rear legs-side view	27.5	7.2	+0.04	0.01	0.19	+0.04	0.01
Foot angle	23.8	7.0	–0.02	0.01	0.11	–0.04	0.01
Fore udder attachment	24.0	7.4	+0.09	0.01	0.23	+0.03	0.02
Udder height	26.1	7.8	+0.05	0.02	0.18	0.00	0.03
Udder width	25.9	7.9	+0.01	0.02	0.15	–0.02	0.02
Udder cleft	27.0	6.1	+0.08	0.01	0.16	+0.03	0.01
Udder depth	23.8	5.2	+0.10	0.01	0.27	+0.06	0.01
Front teat placement	24.2	6.7	+0.11	0.01	0.22	+0.05	0.01
Age-adjusted final score	80.4	3.9	0.0	0.01	0.32	–0.03	0.01

[1] For 2,610,123 cows for all production traits. Inbreeding depression significant for all traits except age at first calving, days of productive life, and total DIM ($P < 0.01$) in the fixed model.

[2] For 1,907,327 cows. Inbreeding depression was significant ($P < 0.01$) in the fixed model.

[3] For 159,167 cows. Inbreeding depression on first lactation SCS was not significant ($P > 0.01$) in the fixed model.

[4] For 792,598 cows for all linear type traits. Inbreeding depression was significant for all traits except rump angle, foot angle, and age-adjusted final score ($P < 0.01$) in the fixed model.

for grade cows were slightly more variable. Estimates of inbreeding depression for these traits were –\$9 in both markets for grade cattle, and comparable estimates for registered cattle were roughly 2.5 times larger at –\$24 in a fluid milk market and –\$22 in the manufacturing market. Inbreeding depression for other traits except type was 2 to 2.5 times more severe in registered herds than in grade herds. Heritabilities were higher in registered herds for all traits except age at first calving. For linear type traits, heritabilities were higher for registered herds, and inbreeding depression estimates were variable but small for both grade and registered cows.

The goal of well-considered matings is to produce animals that are superior to those of the previous generation. The genetic superiority of the mating must be balanced, however, against any inbreeding depression that is generated. Losses from inbreeding can only be controlled when good pedigree information is available. A misidentified cow, accidentally bred to a half-sib bull, produces offspring with 12.5% inbreeding. Table 6 shows the production losses and Table 7 shows the conformation losses that an average heifer would incur because of 12.5% inbreeding. Values in both tables are based on mixed model estimates of inbreeding depression for registered cattle. Both tables also express inbreeding depression per 1% increase of inbreeding as a percentage of additive genetic standard deviations to identify those traits that are subject to the most severe impact of inbreeding. Genetically, RNIOC in the manufacturing market suffers the most from inbreeding, and inbreeding

TABLE 5. Comparison of means, standard deviations, and mixed model estimates of inbreeding depression and heritability for cows with 84-mo herdlife opportunity in registered and grade herds.

	Registered herds[1]					Grade herds[2]				
Variable	$\overline{X}$	SD	Inbreeding depression	SE[3]	h^2	$\overline{X}$	SD	Inbreeding depression	SE[3]	h^2
Inbreeding, %	1.67	2.24	. . .	. . .	. . .	0.57	1.60	. . .	. . .	. . .
RNIOC[4] fluid market, \$	–13	882	–24.43	1.87	0.23	–15	862	–9.43	2.50	0.17
RNIOC manufacturing market, \$	–11	743	–21.78	1.59	0.20	–13	721	–9.02	2.10	0.15
Age at first calving, d	839	94	+0.36	0.16	0.14	836	96	–0.20	0.21	0.15
Days of productive life	927	606	–13.07	1.27	0.13	906	570	–5.18	1.62	0.07
Total milk, kg	20,890	14,579	–358.41	30.34	0.15	20,870	13,985	–141.24	39.83	0.09
Total fat, kg	765	537	–13.17	1.12	0.15	756	507	–5.20	1.44	0.09
Total protein, kg	663	460	–11.41	0.96	0.14	659	437	–4.62	1.24	0.09
Total DIM	746	450	–10.30	0.96	0.13	734	434	–4.14	1.24	0.07
First lactation mature equivalent milk, kg	8967	1694	–37.15	2.95	0.41	8938	1799	–15.99	4.38	0.25
First lactation mature equivalent fat, kg	329	62	–1.20	0.09	0.36	325	65	–0.59	0.15	0.24
First lactation mature equivalent protein, kg	284	52	–1.23	0.10	0.39	281	54	–0.59	0.13	0.21
First calving interval, d	403	67.5	+.26	0.14	0.05	399	68	+0.21	0.20	0.02
First lactation SCS	2.56	1.37	–0.004	0.006	0.11	2.60	1.40	–0.001	0.006	0.07
Stature	32.6	8.6	–0.15	0.02	0.42	28.0	8.4	–0.95	0.02	0.30
Strength	30.1	7.8	–0.17	0.02	0.27	27.3	7.9	–0.10	0.02	0.20
Body depth	32.2	7.9	–0.20	0.02	0.32	28.8	8.1	–0.06	0.02	0.22
Dairy form	30.1	7.5	+0.01	0.02	0.24	28.8	7.9	+0.03	0.02	0.18
Rump angle	25.4	5.3	–0.03	0.01	0.31	25.8	6.1	+0.03	0.02	0.26
Thurl width	28.8	7.5	–0.01	0.02	0.24	26.8	7.7	–0.04	0.02	0.15
Rear legs-side view	27.0	7.1	+0.05	0.02	0.21	28.2	8.0	+0.04	0.02	0.13
Foot angle	24.1	6.7	–0.02	0.01	0.11	22.7	7.7	–0.02	0.02	0.08
Fore udder attachment	25.5	7.4	+0.01	0.02	0.21	21.1	7.0	+0.01	0.02	0.15
Udder height	27.0	7.6	–0.05	0.02	0.20	23.4	7.8	0.00	0.02	0.14
Udder width	26.7	7.6	–0.05	0.02	0.16	23.2	8.0	+0.01	0.02	0.11
Udder cleft	27.4	5.9	+0.03	0.01	0.18	26.1	6.6	+0.04	0.02	0.12
Udder depth	24.5	4.9	+0.05	0.01	0.27	22.5	5.6	+0.05	0.01	0.23
Front teat placement	25.1	6.4	+0.04	0.01	0.21	22.6	7.2	+0.05	0.02	0.17
Age-adjusted final score	81.5	3.7	–0.05	0.01	0.26	77.9	3.7	–0.01	0.01	0.17

[1] Represent random subsamples of complete herds from 257,449 original animals in 2223 herds.

[2] Represent random subsamples of complete herds from 449,343 original animals in 3540 herds.

[3] Standard error of mixed model estimates of inbreeding depression.

[4] Relative net income adjusted for opportunity cost.

depression is equal to 6.6% of the additive standard deviation for the trait. However, the profit function with the largest financial impact by inbreeding is RNIOC in fluid milk markets in which over $300 as measured by our profit function is lost from a half-sib mating. That profit function includes charges for opportunity cost, an accounting expense not actually paid by producers. The cumulative effect of inbreeding on the lifetime performance of dairy cows in these data was greater than in the effects on the individual traits contributing to lifetime performance. The impact of inbreeding on linear type traits was much less; losses were less than 2% of one additive standard deviation unit for most traits. Strength and body depth were affected more strongly, but not as much as the lifetime performance traits in Table 6.

CONCLUSIONS

Profit functions such as RNIOC continue to be useful in estimating the impact of selection and mating strategy on cow profitability. Inbreeding has a cumulative effect on the lifetime performance of dairy cows as it exerts a greater effect on lifetime profit than on the single lactation traits contributing to lifetime profit. Inbreeding levels in Holstein cows do not appear to be alarming at the present time, but estimates are higher in populations that have complete pedigree information. Estimates of inbreeding depression were greater for almost all traits for registered herds than for grade herds. We contend that this difference is not due to physiological differences between the two groups but, rather, to the more accurate estimates of inbreeding for registered animals.

The most important factors in avoiding inbreeding are maintenance and use of pedigree data when mates are assigned. In a registered herd, identification is mandatory. For the commercial producer, accurate identification is encouraged for DHIA testing and is required if the herds involved in young sire sampling are to contribute useful information for genetic evaluations. An additional financial incentive for grade herds to identify ancestry of cows is to avoid inbreeding, the economic consequences of which are documented in this report. The recognition of the relationships between potential parents prior to a mating can minimize inbreeding and the losses associated with it. Current trends toward increased relationships between influential sires and the heavy use of those bulls as sires of daughters indicate that inbreeding will become increasingly difficult to avoid in the future.

TABLE 6. Net losses for an average cow because of 12.5% inbreeding and depression per 1% increase in inbreeding expressed as a percentage of additive standard deviation (σ_a).[1]

Variable	Losses from 12.5% inbreeding	Inbreeding depression
		(% of σ_a)
RNIOC,[2] fluid market, $	–305	5.8
RNIOC, manufacturing market, $	–272	6.6
Days of productive life	–163	6.0
DIM	–129	6.3
Age at first calving, d	+5	1.0
First calving interval, d	+3.3	1.7
First lactation SCS	–0.05	0.96
First lactation mature equivalent milk, kg	–464	3.4
First lactation mature equivalent fat, kg	–15	3.2
First lactation mature equivalent protein, kg	–15	3.8
Total milk, kg	–4480	6.4
Total fat, kg	–165	6.3
Total protein, kg	–143	6.6

[1] Estimates were from mixed model analysis for registered cows with 84-mo herdlife opportunity.

[2] Relative net income adjusted for opportunity cost.

TABLE 7. Changes in conformation traits for an average cow from 12.5% inbreeding and 1% inbreeding depression expressed as a percentage of additive standard deviation (σ_a).[1]

Conformation trait	Losses from 12.5% inbreeding	Inbreeding depression
		(% of σ_a)
Stature	–1.88	2.7
Strength	–2.13	4.2
Body depth	–2.5	4.5
Dairy form	+0.13	0.3
Rump angle	–0.38	1.0
Thurl width	–0.13	0.3
Rear leg-side view	+0.63	1.5
Foot angle	–0.25	0.9
Fore udder attachment	+0.13	0.3
Udder height	–0.63	1.5
Udder width	–0.63	1.6
Udder cleft	+0.38	1.2
Udder depth	+0.63	1.9
Front teat placement	+0.5	1.4
Age-adjusted final score	–0.63	2.7

[1] Estimates were from mixed model analysis for registered cows with 84-mo herdlife opportunity.

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