Prediction of Average Daughter Performance from Sire Proofs for Use in Linear Programming Sire Profit Models

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ABSTRACT

When linear programming is used to rank sires on daughter profits, coefficients of input are required for representative daughters of each sire. Within herd-year-season regressions of daughter's actual 305-day milk, fat percent, days open, 2-min milk yield adjusted for total yield, total milking time, and body weight at birth and first calving on sire's proofs for production, conformation, milking speed, and nonreturn rate were computed from progeny data from 71 Canadian Holstein-Friesian artificial insemination sires, to provide these coefficients. Coefficients of determination for prediction equations were .23 to .71. A production function was fitted for milk production and days open. First lactation 305-day milk was predicted from sire's milk rating and linear and quadratic terms of size ratings. Fat percent proof and its squared term predicted daughter's fat percent. Days open was predicted by milk and fat proofs. Milk yield in the first 2-min of milking, adjusted for milking yield, was predicted by proofs for milking speed and the quadratic term for fat percent. Total milking time was obtained from 2-min yield by regression (−.3837) of total milking time on 2-min yield. Daughter's body weight at first calving was predicted from sire's size proof, as was birth weight. Milk yield was curvilinearly associated with days open.

Incidence of mastitis was derived indirectly from regression (.00172) on sire's milk proof for milk.

INTRODUCTION

Proven artificial insemination (AI) dairy sires are rated in Canada for traits by best linear unbiased prediction (BLUP), estimated transmitting ability (ETA), and these have widespread use and acceptance by industry. In addition, since 1964 dairy sires have been rated on an approximation of dairy profit, referred to as a production dollar difference. This approximation is under review, and one alternative is a dairy farm linear programming model to rank sires on profitability of an average daughter. Because sire evaluations are independent for each trait, little is known about the correlated effect of a sire's merit for a number of traits on daughter's performance for any single trait or for total dairy merit. The merit of a sire for a single trait, measured on his daughters, may be defined as a function of the sire's ETA for a number of measurable traits that may affect the trait in question. Therefore, for estimating average daughter performance for linear programming models to rate sires on profitability, development of prediction equations should consider all available ETA of each sire.

Although the sire's ETA is defined as an estimate of the relative mean of an infinite number of future daughters, the relationship between a sire's ETA for production, type, milking speed, and reproductive traits and his daughter's actual performance for milk yield, fat percent, days open, birth weight, body weight, and milking speed has not been the subject of study. One study that compared profitability of cows of high, medium, or low ETA for milk (1) revealed a linear relationship between ETA for milk and gross returns, but ETA for milk had a curvilinear relationship with days dry and days open.

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Thus, high milk proofs need not mean necessarily favorable production for other traits, and high milk yield among daughters need not be influenced necessarily by sire's superiority for milk alone but also may be influenced indirectly by sire's proofs for other characteristics.

Our purpose was to measure the magnitude and direction of the effect of sire proofs for a number of important traits on their daughters' performance for economic traits taken singly in the form of prediction equations. Equations derived in this fashion are also useful in economic modeling.

MATERIALS AND METHODS

Seventy-one Canadian Holstein-Friesian sires had official proofs for type traits, production traits, and milking speed with 55% or higher repeatability based on daughters in five or more herds and nonreturn rates for a minimum of 20 daughters in at least 10 herds. Production records consisting of 305-day milk yield in first lactation, fat percent, and days open following calving between 1968 and 1978 were drawn from Canadian Holstein-Friesian Records of Performance (ROP) herd files. Daughter records in first lactation of the 71 sires were chosen randomly to have approximately equal numbers of observations per sire by our drawing records at more frequent intervals for sires with fewer daughters than for sires with larger numbers of daughters. Daughters of each sire were chosen randomly so that an average of 800 records was obtained per sire from a data set containing 98,118 records, irrespective of the herd in which the record was made. These records included more recent daughter records gathered after sires were proven. From the resulting data set of 56,800 daugher records, those having lactation lengths less than 100 days and first calving age less than 15 mo or greater than 36 mo were removed, reducing the data to 44,196 records. Days open is not recorded routinely in ROP records but is computed indirectly by subtracting a standard 283-day gestation from the interval between first and second calivings. For the analysis involving days open, only approximately one-half of the 44,196 heifer records had days open available, because remaining heifers had not had their second lactations entered into the file. With these restrictions, 22,392 daughter records of days open were available for analysis. Body weight records in first lactation of 7,672 daughters of the 71 sires obtained from Dairy Herd Improvement files; 582 birth weight records of all parities from the Elora Dairy Research Centre, University of Guelph files; 1,281 2-min milk yield records and 392 2-min and total milking time records from field data files collected by the University of Guelph were also available.

The sire's average daughter 305-day milk yield, fat percent, and days open were predicted in separate analyses by the following model from sire proofs for production traits, type traits, milking speed, and nonreturn rates free of environmental variations common to individual herds:

\[ Y_{ij} = a + h_i + \sum_{t=1}^{n} b_t x_{tij} + e_{ij} \]

where

- \( Y_{ij} \) = an observation (305-day milk yield, fat percent, or days open) on the \( j \)th daughter in the \( i \)th herd-year-season,
- \( a \) = a constant common to all observations,
- \( h_i \) = effect of the \( i \)th herd-year-season where the observation was measured; fixed,
- \( b_t \) = partial regression coefficient of daughter observation on sire's proof for the \( t \)th trait,
- \( x_{tij} \) = the proof for the \( t \)th trait of the sire of the \( j \)th daughter,
- \( e_{ij} \) = random residual in each herd-year-season, \( N(0, \sigma_e^2) \).

Sires were mated randomly to cows in different herd-year-seasons. Herd-year-season effects were absorbed and regression coefficients estimated. To obtain the best prediction equation, the backward elimination procedure (3) was used. Sire proofs for 3 production and 11 type traits plus milking speed (2-min milk yield) and nonreturn rate and their squared terms entered the equation initially. At each stage of elimination, the variable with the lowest nonsignificant \( (P>.05) \) partial F was removed. Predicted first lactation yield and percent fat could be used to compute gross returns for production.

For estimating mean body weight and milking speed of each of the 71 sires' daughters, the same model was used where \( Y_{ij} \) were
weights at first calving and 2-min milk yields, respectively. Body weights of daughters may be used to estimate feed intakes and costs as well as salvage value of culls. Two-minute milk yield may be used to estimate labor costs for milking. The 1,281 2-min milk records and 7,672 body weights in first lactation were regressed on sire proofs in separate analyses. Total milking time per milking was estimated by regressing total milking time among daughters on their estimated 2-min milk yield. Only 392 paired observations of 2-min milk and total milking time were available for prediction of total milking time from the cow’s 2-min milk yield. Year-season effects were ignored as data were collected over 3 mo. If total milking time is measured in the field rather than 2-min yield, it may be the observation; thus, the second prediction equation will not be necessary.

Not all heifer calves are required for replacements in well-managed dairy operations, and male calves traditionally are sold at a few days of age. Body weight at birth is the key determinant of returns in this situation. As no large data sets were available, 582 birth weight records from single normal calvings in two seasons were analyzed for each sex by the same model as above. However, because the volume of data was small, birth weights from all parities of dam were used, and an effect of parity of dam was added to the regression model. A theoretical derivation was made on regression of incidence of mastitis on sire’s milk proof as no field data on the incidence of mastitis among daughters were available. Diagrammatically the relationship is:

\[
\text{Sire} \quad \quad a \quad \quad \text{Daughter} \\
\begin{align*}
g &= 2t \\
p &= \rho \\
\end{align*}
\]

where:
- \(g\) = genotype of sire for milk,
- \(t\) = ETA of sire for milk equal the sire’s proof,
- \(p\) = phenotypic probability of incidence for mastitis of a daughter, and
- \(a\) = relationship between sire and daughter; \(0.5\).

Correlation between \(p\) and \(g\) is:

\[
p = \rho \sqrt{h}
\]

where:
- \(\rho\) = genetic correlation between milk yield and probability of mastitis infection, and
- \(h\) = square root of heritability of the probability of mastitis infection.

Incidence of mastitis was estimated by a regression equation. Let \(b_p g\) be the regression of probability of incidence of mastitis among daughters on genotype of the sire for milk. Then:

\[
b_{pg} = \rho \frac{\sigma_p}{\sigma_g} = \rho \frac{\sigma_p}{\sigma_g}
\]

\[
= \rho \frac{\sigma_p}{\sigma_g} \frac{\sigma_p}{2\sigma_t} \quad \text{change in mastitis incidence per kilogram of change in milk yield.}
\]

where:
- \(\sigma_g\) = standard deviation of \(g\),
- \(\sigma_p\) = standard deviation of \(p\), and
- \(\sigma_t\) = standard deviation of \(t\).

**RESULTS AND DISCUSSION**

Means and standard deviations of ETAs of the 71 sires are in Table 1. The sample of sires selected is about average for AI sires in use for milk and fat in the period of study, above average for conformation traits, and approximately average for milking speed, fat percent, and nonreturn rate. However, Table 2 shows that the sample of daughters selected for study may not be representative of progeny of these sires. In particular, heifers were lower than average for 2-min milk yield, 4.53 kg versus 5.10 kg measured in a larger group of Canadian records (13). The average 2-min milk yields in the sample of daughters of the 71 sires were for first lactations only whereas the larger sample included all lactation records; thus, age may explain the higher mean.

**Mixed Yield**

Prediction equations are in Table 3 (Equation [1]) together with coefficients of determination \((R^2)\). The response surface of the relationship between milk and size proofs (ETA) of sires
TABLE 1. Means and standard deviations (SD) of sire estimated transmitting abilities and non-return rates.

<table>
<thead>
<tr>
<th>Sire trait</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk proof (BCA)</td>
<td>4.30</td>
<td>4.61</td>
</tr>
<tr>
<td>Fat proof (BCA)</td>
<td>3.04</td>
<td>5.16</td>
</tr>
<tr>
<td>Fat percent proof, %</td>
<td>-0.04</td>
<td>0.09</td>
</tr>
<tr>
<td>Final score proof, points</td>
<td>1.15</td>
<td>0.92</td>
</tr>
<tr>
<td>Final class proof, points</td>
<td>3.59</td>
<td>3.63</td>
</tr>
<tr>
<td>General appearance proof, points</td>
<td>3.63</td>
<td>3.55</td>
</tr>
<tr>
<td>Dairy character proof, points</td>
<td>3.00</td>
<td>4.12</td>
</tr>
<tr>
<td>Capacity proof, points</td>
<td>3.10</td>
<td>5.08</td>
</tr>
<tr>
<td>Rump proof, points</td>
<td>3.06</td>
<td>5.82</td>
</tr>
<tr>
<td>Feet and legs proof, points</td>
<td>2.17</td>
<td>2.96</td>
</tr>
<tr>
<td>Mammary system proof, points</td>
<td>2.13</td>
<td>3.79</td>
</tr>
<tr>
<td>Fore udder proof, points</td>
<td>--</td>
<td>4.05</td>
</tr>
<tr>
<td>Rear udder proof, points</td>
<td>1.54</td>
<td>4.31</td>
</tr>
<tr>
<td>Size proof, points</td>
<td>4.63</td>
<td>6.58</td>
</tr>
<tr>
<td>Milking speed proof, min</td>
<td>-0.08</td>
<td>0.45</td>
</tr>
<tr>
<td>Non-return rate, %</td>
<td>67.19</td>
<td>3.15</td>
</tr>
</tbody>
</table>

and daughters' 305-day milk production is in Figure 1. There was a linear increase of daughters' milk production with increasing merit of sire for milk. Each unit increase of sire's milk proof resulted in an increase of 41.72 kg of milk in daughter's first lactation above an average cow. There was also a curvilinear relationship between daughter's milk yield in 305-days and sire proof for size. Daughters of sires having low proofs for size tended to produce less milk (although feed consumption for body maintenance also may be lower) than daughters of sires with similar milk proofs but positive and just above average proofs for size. Higher proofs for size will increase with milk yield at a decreasing rate, and milk yield will be depressed at higher proofs of size. However, feed consumption may continue to increase with size. The linear relationship between sire proofs for size and body weight of progeny is Equations [6], [7], and [8] in Table 3. A linear association between body weight and dry matter intake among dairy cattle has been described (16). Thus, we assumed that feed intake increases linearly with increasing body size. Our study, therefore, suggests that for sires with the same milk proofs, daughters of sires with low positive proofs for size will produce more revenue in first lactation than daughters of sires with high proofs for size.

Reports on prediction of daughter performance from sires' ETA are scarce. A linear association between cow's ETA based on pedigree and gross returns from milk yield was in (1). Other reports have been on the positive correlation between body weights and milk yield of cows. Miller and McGilliard (9) reported a within-herd correlation of .23 between body weight and milk yield and a genetic correlation of .33 in Holsteins. Though only 2% of the intra-herd variance in milk production was associated with body weight, these researchers estimated a partial regression of about 200 kg of milk per 100 kg increase in body weight. Similar reports on the association between body weight as a measure of size and milk production were in (2, 5), indicating that large

TABLE 2. Means and standard deviations (SD) for records of daughters and calves of sires studied.

<table>
<thead>
<tr>
<th>Trait</th>
<th>No. of observations</th>
<th>No. of herd-year-seasons</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>305-day milk, kg</td>
<td>44196</td>
<td>10594</td>
<td>5244.79</td>
<td>1066.47</td>
</tr>
<tr>
<td>Fat percent</td>
<td>44196</td>
<td>10594</td>
<td>3.73</td>
<td>.43</td>
</tr>
<tr>
<td>Days open</td>
<td>22392</td>
<td>5335</td>
<td>112.74</td>
<td>39.14</td>
</tr>
<tr>
<td>2-min yield (adjusted), kg</td>
<td>1281</td>
<td>115</td>
<td>4.54</td>
<td>1.63</td>
</tr>
<tr>
<td>Total time, min</td>
<td>932</td>
<td>11</td>
<td>5.03</td>
<td>2.23</td>
</tr>
<tr>
<td>Male calf birth weight, kg</td>
<td>295</td>
<td>15&lt;sup&gt;a&lt;/sup&gt;</td>
<td>45.15</td>
<td>6.04</td>
</tr>
<tr>
<td>Female calf birth weight, kg</td>
<td>287</td>
<td>15&lt;sup&gt;a&lt;/sup&gt;</td>
<td>42.00</td>
<td>5.16</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>7672</td>
<td>1773</td>
<td>525.56</td>
<td>63.42</td>
</tr>
</tbody>
</table>

<sup>a</sup>No. of year-season grouping from a single herd.
TABLE 3. Prediction equations of daughter performance derived from within herd-year-season regression on sires' proofs for various traits.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Equation</th>
<th>( R^2 ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>305-day milk, kg</td>
<td>[5244.79 + 4.7261 (milk proof) + 3.2921 (size proof) - 3.501 (size proof)^2]</td>
<td>65.23</td>
</tr>
<tr>
<td>305-day fat, %</td>
<td>[3.7336 + 1.2157 (fat% proof) + 1.1125 (fat% proof)^2]</td>
<td>52.73</td>
</tr>
<tr>
<td>Days open</td>
<td>[112.7359 + .0399 (milk proof)^2 + .0499 (fat proof)^2]</td>
<td>59.53</td>
</tr>
<tr>
<td>2-min yield, kg</td>
<td>[4.5269 + .9651 (milking speed proof) - 15.7242 (fat % proof)^2]</td>
<td>22.90</td>
</tr>
<tr>
<td>Total time, min</td>
<td>[5.0322 - .3837 (2-min yield adjusted for total yield)]</td>
<td>23.58</td>
</tr>
<tr>
<td>Birth weight, male, kg</td>
<td>[45.1525 + .1456 (rump proof) + .1581 (size proof) + .6153 (lactation number)]</td>
<td>25.85</td>
</tr>
<tr>
<td>Birth weight, female, kg</td>
<td>[42.0000 + .1140 (rump proof) + .1867 (size proof) + .5024 (lactation number)]</td>
<td>21.41</td>
</tr>
<tr>
<td>Body weight, 1st calving, kg</td>
<td>[525.5571 + 1.0206 (size proof) - 1.4656 (final class proof) + .7349 (fore udder proof)]</td>
<td>70.80</td>
</tr>
</tbody>
</table>

Cows tend to produce more milk than small cows. However, these reports were of a linear association of production with size. Relationship also has been curvilinear (14). Based on wither height at first calving, Naito et al. (10) grouped heifers as small (<132 cm), medium (135 ± 3 cm), and large (>138 cm). Their ranking on milk yield was medium, large, and small, which closely supports results of our study.

Johansson (6) pointed out that many of the relationships between body size and milk production have been distorted by environmental covariances such as parity and age at first calving. Our study agrees with Johansson's conclusion, which was based on reports that the regression of milk yield in first lactation on body weight is distinctly curvilinear.

Fat Percent

The only proof that affected daughter's fat percent was the sire's fat percent proof as shown by Equation [2] in Table 3. As in Figure 2, fat percent among daughters increased at an increasing rate with the increase of sires' proof for fat percent. Both linear and quadratic terms were significant \( (P<.05) \) and explained 52.73% of the variation of fat percent among daughter records for fat percent.

Days Open

Daughters' days open were influenced by sires' proof for milk (Equation [3], Table 3). Though selection for milk and reproduction and systems of management are contributory factors, the relationship may reflect a potential for higher 305-day yields from heifers that stay open longer (1). This could be because low milk producers have fewer records on fertility traits as they are removed from the herd earlier than high producers. Thus, fertility measurements generally reflect reproductive efficiency of mainly the high producers. Also, high milk production enhanced the detrimental influence of low roughage content of diets on overall
conception rate and repeat breeding (8); hence, there was a positive relationship between milk proof and days open. One major difficulty in this analysis was that no sire proofs for days open were available for prediction. To establish a true relationship between 305-day milk yield and days open, a production function was developed. Milk yield as a function of days open was: 305-day milk yield (kg) = 5263.5544 + 10.7199 (days open) - .03128 (days open)^2. The $R^2$ was 58.4%. Herd-year-season effects were absorbed, and first and second degree polynomials were significant ($P<.05$). Figure 3 shows total product and marginal product curves. Milk production increased at a decreasing rate with increase of number of days open. The linear marginal curve shows a decrease of amount of additional milk produced for each progressive additional day open until 173 days after which margins are negative. Burnside et al. (1) showed a similar curvilinear trend when days open of cows during their first 36 mo were regressed on their ETA for milk and ETA squared. A curvilinear relationship between milk production and days open also was in (4, 7, 11), although those authors did not fit a production function.

Two-Minute Milk Yield and Total Milking Time

Two-minute yield was dependent on the sire's proof for 2-min milk adjusted for total yield and square of the sire's proof for fat percent as in Equation [4], Table 3. Equation [5], Table 3, indicates the regression coefficient for total time per milking on 2-min yield as predicted in Equation [4] was $-0.3837$. These results would mean sires with superior milking speed ratings produce daughters that spend relatively shorter time milking out. Sire proofs for other traits did not ($P>.05$) affect total milking time. The $R^2$ were small (.23). This indirect approach to prediction of total milking time, which is the trait of economic interest, is not accurate, and direct measurement of total milking time for sire rating seems desirable. Small samples of data also may have contributed to small coefficients of determination.

Body Weights

Birth weights and body weights of heifers at first calving were affected by sire's proof for size. Prediction equations also suggested calves with heavy birth weights were by sires with superior proofs for rump and size. Implications of selection for increased size of cow and calf on dystocia need study.
Incidence of Mastitis

The regression of incidence of mastitis on sires’ ETA for milk was .00172 based on the derivation above. A genetic correlation .30 was between mastitis incidence and milk yield, and heritability and phenotypic standard deviation of incidence of mastitis were taken to be .07 and .48 (15). Although the regression coefficient was small, the cost associated with infection is large and will be discussed in a subsequent paper on sire ranking.

DISCUSSION AND APPLICATION

Prediction equations were used to predict milk yield, fat percent, days open, total milking time, birth weights of calves, and body weights of first-calf heifers. These equations took into account total merit of the sire as expressed by sire proofs for a number of traits. The predicted average daughter performances of each sire were used then in a linear programming model (12). Additional research with larger numbers of observations on heifers for some traits and larger numbers of sires seems desirable if accurate economic rating systems for sires are to result and if a better understanding of interrelationships among dairy traits is desired. This study is restricted to daughter performance in first lactation, and additional complications arise in generalizing to performance for all lactations. Use of equations based on BLUP proofs and population means may offer a more direct approach to accurate economic models for cow and sire selection.

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