ABSTRACT

Dairy sires were ranked for overall merit by an average daughter's contribution to farm net profit. Biological characteristics of sires and economic factors of a dairy farm were linked by linear programming. Availability and constraints of resources were in the model. Average daughter's returns over variable costs attributable to sire proofs for several traits was the measure of sire's net merit. The index of total economic merit for sires was the amount of change of net profit by milking progeny of different sires. Ranking considered sire's contribution to milk yield and feed intake of daughters caused by variations of proofs for milk, fat percent, and size, sire's nonreturn rate, veal calf sales of the offspring, and labor costs of slow versus fast milking daughters. Size of quota for daily milk shipments, cow housing capacity, labor for milking, and milk tank capacity were critical in determining ranking and forced greater emphasis on traits other than milk yield. Correlations between sire ranking on returns over variable costs and sire proofs were highest for milk and significant for fat percent, milking speed, size, and nonreturn rate. These traits had high standard partial correlations with and explained most of the variation of the index of total economic merit. This method aims at maximizing farm profits and may be applied to rank dairy sires on a national basis or to select sires for specific dairy farm operations. Production dollar index ratings on the same sires were closely correlated (−.87 to −.96) with profit index ranking but are potentially misleading if constraints exist that limit maximum milk output per farm.

INTRODUCTION

High milk yield and high milk fat percent are important to the economic success of any dairy operation. However, profit derived from milk yield and fat percent may be influenced by other factors attributable to the herd's reproductive performance, milking speed, feed intake and efficiency, conformation, and susceptibility to common diseases such as mastitis. The goal in animal breeding is to improve total performance of the herd to maximize economic gains within the farm production unit. This requires the consideration of several animal attributes as well as other economic factors.

The approach to multiple trait selection was discussed as early as 1935 by Lush. However, formulation of a selection index based on several traits was in 1942 by Hazel and Lush (11). Using profit as the aggregate genotype, Hazel (10) developed a selection index to measure net merit of young boars and gilts. Breeding values for each of several traits were weighted by relative economic weights which Hazel defined as the "amount by which profit may be expected to increase for each unit of improvement in each trait." No major strides in further development of multiple trait selection have been achieved since the inception of Hazel's (10) selection index approach. Several reports have been published (1, 5, 16, 19, 20, 22, 23, 25) that have dealt with 1) the influence of more than one trait on the net merit of an animal, 2) linear and nonlinear relationship...
between net merit and individual traits, and finally, 3) importance of and association between net returns (as against gross returns) and several traits in selection goals. Everett (8) studied the influence of several variables on income over investment in semen and developed predictors of sire differences in income over investment for field application by a multiple regression approach. Andrus and McGilliard (1) predicted profitability of cows as the difference between lifetime income and expense expressed per year. Burnside et al. (2), reported that gross returns for milk increased linearly as pedigree estimated transmitting ability (ETA) for milk of the cow increased. However, high producers with high ETA for milk gave greater gross returns only by having longer lactations and calving intervals. Miller and Pearson (15) reviewed the literature on selection criteria, profit equations, selection indexes, and other economic aspects of selection and concluded that there was overemphasis on single trait selection in setting out selection goals. They further attributed conflict of defining selection goals, difficulty of predicting economic traits, and lack of data to estimate profitability and economic efficiency as obstacles to using economics in defining breeding goals.

Dairy producers are faced with the task of choosing sires for artificial insemination that will produce the most profitable offspring. When estimates of sires' breeding values for all economically important traits are available, it is then appropriate to evaluate sires on their average daughter's profitability within the production possibilities of a dairy farm.

Objectives were 1) to estimate total economic merit and rank Canadian AI (artificial insemination) dairy sires within the framework of a dairy farm model, 2) to study the effect of certain production limitations on ranking of these sires, and 3) to measure variation of sire indexes of total economic merit caused by the sires' genetic merit for the different traits measured so as to ascertain the relative importance of these traits for determining profitability.

MATERIALS AND METHODS

Sire Subunit

A sample of 71 Canadian Holstein-Friesian AI sires was in the study to estimate the total economic merit of their daughters. The study used equations developed in (18) to predict milk yield, fat percent, days open, body weight at first calving, total time for milking, and probability of mastitis infection of daughters of the 71 sires as well as their progeny birth weights. Feed intake (barley, soybean oil meal, hay, and haylage) of the average daughter in first lactation of each sire was calculated from estimated milk yield, fat percent, and body weight. Income and production costs of an average daughter of each sire were estimated by the following equations and extended to an annual basis in the model.

Income

Milk returns were $33.03/hl of milk ($0.321/kg).

Fat differential was $0.3999/1 kg fat/hl of milk.

Veal value of calf was $1.02/kg live weight. The expected output was calculated as follows in kilograms of calf live weight.

\[ y_i = \sum_{t=1}^{n} b_t x_{ti} \times NRR_i \times SR \times P(1-R) \]

where

\[ y_i = \text{live weight (kg) at 1 wk of age of the calf by the } i\text{th sire's semen}, \]

\[ \sum_{t=1}^{n} b_t x_{ti} = \text{estimate of the } i\text{th sire's calf birth weight; } x_{ti} \text{ is the } i\text{th sire's proof for the } t\text{th trait (rump and size as in (18))}, \]

\[ b_t = \text{regression coefficient of the calf's birth weight on } x_{ti}, \]

\[ NRR_i = \text{nonreturn rate of the } i\text{th sire}, \]

\[ SR = \text{survival rate of calf up to 1 wk from birth; .85}, \]

\[ P = \text{proportion of calves of a particular sex, estimated as .48 and .52 for male and female calves, and} \]

\[ R = \text{proportion of calves retained as replacements each year; zero for male calves and .5 for female calves. The .5 for female replacements retained varies depending on cow turnover but was constant in this first lactation model.} \]

All inseminations were between 60 to 90 days postpartum, and calves did not change ap-
precisely from their birth weight in the 1st wk. Calf live weights were estimated separately for each sex from two production equations (18).

Salvage value was estimated. Beef value was $1.05/kg live weight. The following equation was used to estimate expected weight of a salvaged daughter.

\[ Y_i = \sum_{t=1}^{n} b_t x_{ti} \times P \times R \times SR \]

where:

- \( Y_i \) = live weight of the daughter of the \( i \)th sire in kilograms,
- \( \sum_{t=1}^{n} b_t x_{ti} \) = estimate of body weight of daughter of the \( i \)th sire; \( x_{ti} \) is the \( i \)th sire's proof for the \( t \)th trait; and \( b_t \) is the regression coefficient of the daughter's first calving weight on \( x_{ti} \) (18), as defined earlier. \( SR \) was set to 1. Differences in milk production, health, and other factors would not influence live weight of different sire progeny.

Costs

Feed costs were derived from the crops grown on the farm with associated costs, plus purchased protein supplement.

Labor cost for milking was $3.77/h. Total time required to milk daughters of different sires was estimated:

\[ t_i = bM_i S_i \times n \times 1, \]

\( M_i \) = estimate of 2-min yield of the \( i \)th sire's daughter;

\( b \) = regression of total time (min) per milking, on adjusted 2-min yield;

\( n \) = number of milkings per day, two; and

\( l \) = lactation length (in days); 305 days.

Cost per day open was calculated on the production function (18) where 305-day milk yield was a function of days open. The desired average days open in first lactation was 115 days, and anything beyond that would contribute to the costs. In keeping with economic principles, the slope of the production function at 115 days open was multiplied by the price per kilogram of milk to give the marginal value product of an additional day open beyond 115 days.

The loss per cow per infection of mastitis was associated with drugs and veterinary supplies ($3.04), milk loss ($113.86), milk discarded ($2.44), replacement loss ($19.35), and labor cost ($5.50) (6) by current prices.

Semen costs were not included.

Dairy Farm Modeling Method

Static linear programming (LP of the IBM Mathematical Programming System Extended) farm models of farm firms were developed (3, 4, 7, 24). Of the five farm technology groups considered by these authors, the highest, referred to as Tech C model, was chosen because of its up-to-date dairy farming technology (milking parlors, automated cleaning, and feed handling). The model was modified to incorporate sires as activities linked to the other farm operations on a 1-yr planning horizon. The concept and association of various operations in the model is in Figure 1. The farm operation is subjected to various constraints; mainly land, labor, and barn space. Crops are either sold or used as feed. Week-old calves are purchased, raised together with home-born calves, and sold as yearlings for slaughter. An average daughter of each sire was treated as a separate activity in the LP model. This allowed direct comparison of each sire with respect to progeny output and associated costs.

The LP layout of the model treats sires as activities (Figure 2) within livestock activities. Columns represent operations of the farm and consist of input output coefficients associated with farm resources. These are linked to the objective function (prices and costs) by transfer rows.

In matrix notation, the static single period linear programming problem is stated generally as:

\[ \text{Maximize } Z = c'x \]

subject to \( Ax \leq b \)

and \( x \geq 0 \)

where

\[ Z = \text{net profit}, \]

\( c' = \text{an } 1 \times n \text{ objective function vector} \]
Figure 1. Diagrammatic representation of the dairy farm model.

consisting of net prices and costs of n farm operations including sire's daughters annual income and costs calculated above,

\[ x = \text{an} \ n \times 1 \ \text{vector of units of activities including number of units of sire's daughters,} \]

\[ b = \text{a} \ p \times 1 \ \text{vector of} \ p \ \text{levels of resources that were available,} \]

\[ A = \text{a} \ p \times n \ \text{matrix of technical coefficients where for sire activities these coefficients were daughters' estimated milk yield, fat yield, days open, feed ingredients required, body weight at first calving, calf birth weight, and probability of a mastitis infection. The size of the A matrix was 111 \times 190.} \]

The usual conditions of LP were linearity, additivity, divisibility, finiteness, single valued expectation, and risk (12). Resources in the model subject to limitation were dairy space, milking herd size, labor over 16 labor periods, land for permanent pasture, total tillable acreage, land for small grains, beans, and corn, market share quota (MSQ), field time, milk
tank capacity, and overhead expenses. The MSQ is an allocated quota for milk that each producer can supply annually. This is to ensure that total milk production will meet Canadian requirements and to allocate shares of the Canadian demand for milk among various producing regions. This quota is negotiable at the federal level in Canada.

With respect to ranking dairy sires on daughters' profitability, conditions were: 1) sire's daughter's performance was the outcome of mating the sire to an average cow in the year of study; 2) for comparing sires, all daughters in the herd were heifers in first lactations; 3) the probability of any one sire having a daughter in the herd was equal for all sires; 4) there was no interaction between sire activities; all sire progeny were treated alike; 5) all sires produced a daughter on which performance was measured; 6) herd dynamics, such as proportion of cows in second and later lactations in the herd, survival from one lactation to the next, and age distribution of cows and calves, were ignored.

The first base run of the model was to obtain optimal linear programming solutions. Herd size, marginal values of limiting resources, and farm net profits and marginal costs associated with the use of sires were calculated. Parametric programming (varying coefficients in the b matrix) was performed to investigate variation of sire ranking at different constraints affecting milking herd size and quantity of milk allowed to be sold by the farm (MSQ availability).

Net merit of dairy sires, defined here as an average daughter's expected returns over variable costs attributable to the sires' estimated transmitting abilities for a number of traits, was a sire's contribution to farm profit. An index of total economic merit (ITEM) of each sire was used to rank sires. The ITEM was the amount by which optimal LP net profit would be reduced (marginal cost) by a progeny of the sire used instead of the progeny of the most profitable sire. To estimate the relative influence of traits on ITEM, simple product moment and partial correlation coefficients were estimated between sire proofs and marginal costs of the 71 sires. Multiple linear regressions of marginal costs of sires on sire proofs and nonreturn rates, which were treated as independent variables, were used to estimate multiple correlation coefficients and, hence, estimate proportion of variation explained by each sire proof and nonreturn rate by a stepwise regression procedure.

RESULTS AND DISCUSSION

The production function for first lactation milk yield in 305 days and days open after first calving was in (18). For optimal days open of 115 days, price of milk at $.321/kg, and other costs ignored, cost per day open was estimated to be $1.13. The longer estimates of economic loss per day open (13, 21) compared to our study are explained by the higher price of milk.

The model selected a combination of sires that had wide variation of their merit for the different traits instead of a single sire when profit was maximized. This was because the model, after selecting the best sires, went on to include other sires as long as no resources constraints were at the limit. For the purpose of ranking sires, the model was forced to select a single most profitable sire for use on all cows in the herd. This was achieved by an additional constraint on number of daughters of these sires in the herd independent of the constraint on dairy space.

Sire Ranking in the Base Run (Model 1)

In the base run of the LP model, farm resources permitted 47.6 milking cows in the herd, which is a representation of an Ontario farm in terms of land, labor, and capital. All selected daughters were sired by Roybrook
Starlite (Reg. No. 308691), a top ranking Canadian sire for milk and fat yield. The most binding constraints on milking herd size were MSQ and dairy space, these having a shadow price (maximum price which the farm could afford to pay to acquire an extra unit of these factors) of $6.30 per unit of MSQ and $202.63 per unit of dairy space.

A sample of the 71 sires are listed in Table 1 together with their proofs, nonreturn rates, ranking on milk proof (ML), estimated milk yield of an average daughter (EM), revenue from milk sales (REV), and ITEM. These rankings were with reference to all 71 sires. The rank on ITEM was based on marginal cost associated with the use of the sire in place of the most profitable sire, in a dairy where MSQ was limiting (See ITEM-1 in Table 1). The EM was calculated by prediction equations as in (18) and was a function of sire proofs for milk, size, and (size) 2. Revenue from milk sales took into consideration estimated milk yield, fat percent, price of milk, and fat differential. Sire 308691 ranked on top for all criteria except EM where he did not differ significantly from the next ranking bull 315487 (5962.3 vs. 5961.9 kg). Generally, sires with high milk proofs were higher in the list, but because of economic importance of other traits, fat percent, size, and milking speed, some reranking occurred. Sire 303326, ranked 12th for ML, 12th for EM, and 10th for REV, was third in ITEM', ranking over several sires that were superior for ML. Sire 303326 was ranked third because a) his fat percent proof was high, b) his milking speed rating was substantially better than the next nine competitors, and c) his size proof was better (more nearly optimal) than all but sire 311497. A positive but moderate size proof not only had a favorable effect on milk yield (18) but also resulted in moderate feed intake in comparisons with sires with high proofs and good salvage value and veal calf value. These factors together with major farm constraints, especially MSQ, favored this sire. The MSQ restriction limited total milk output on the farm and costs such as the revenue from increased fat percent, beef, and veal or costs of feed and milk intake. Therefore, sires superior for these traits were favored even though these sires had lower milk proofs. By the same reasoning, sires with lower milk proofs were favored, even though these sires had higher milk

| Sire no. | ML | FA | FPC | FS | FC | GA | DC | CA | RM | FL | MS | FU | RU | SZ | SPDP | NRR | ML | EM | REV | ITEM-1 | ITEM-2 | ITEM-1 | ITEM-2 |
|---------|----|----|-----|----|----|====|====|====|====|====|====|====|====|====|======|-----|----|----|-----|-------|-------|-------|-------|
| 308691  | 17 | 21 | .09 | 1  | 3  | 11 | -1 | 6  | -3 | 1  | -4 | 5  | 6  | .87 | 63  | 1  | 2  | 1  | 1    | 1     | 0     | 0     |
| 315487  | 15 | 15 | .07 | 2  | 5  | 4  | 17 | 7  | -4 | 8  | 2  | -3 | 5  | 5  | .60 | 58  | 1  | 1  | 2  | 2    | 8     | 8     |
| 303326  | 9  | 9  | .01 | 1  | 2  | 2  | 7  | 3  | 1  | -1 | -5 | -2 | 8  | .85 | 59  | 1  | 1  | 10 | 3    | 6     | 30    | 82    |
| 314226  | 10 | 9  | .04 | -1 | -8 | -8 | -3 | -2 | -6 | -1 | -11 | -8 | -14 | -3 | .00 | 69  | 8  | 8  | 7  | 4    | 5     | 39    | 82    |
| 317750  | 12 | 11 | .16 | 1  | 1  | 6  | 1  | -8 | 0  | 1  | -2 | 2  | 2  | -2 | 6  | .22 | 70  | 3  | 3  | 4  | 6    | 3     | 43    | 71    |
| 315196  | 11 | 9  | .07 | 0  | 0  | 0  | 3  | 2  | 2  | 2  | -2 | 0  | 3  | -4.7| 69  | 4  | 4  | 3  | 7    | 4     | 43    | 71    |
| 311497  | 10 | 7  | .09 | 2  | 7  | 7  | 6  | 10 | 4  | 6  | 3  | 6  | 14 | .23 | 69  | 8  | 7  | 9  | 11   | 7     | 47    | 88    |
| 298086  | 1  | 4  | .08 | 2  | 8  | 7  | 6  | 10 | 4  | 6  | 3  | 6  | 14 | .23 | 69  | 61 | 62 | 47 | 17   | 38    | 56    | 152   |
| 311885  | 11 | 8  | .09 | 1  | 3  | 3  | 6  | 1  | 3  | 1  | -1 | -1 | -1 | -1.04| 65  | 4  | 6  | 5  | 27   | 9     | 62    | 98    |
| 320957  | 12 | 2  | -.25| 1  | 5  | 5  | 3  | 1  | 2  | 0  | 5  | 2  | 3  | 3  | -.09 | 66  | 4  | 4  | 12 | 47   | 15    | 77    | 112   |
| 308231  | -1 | 0  | .03 | 0  | 0  | 1  | -1 | -5 | -5 | 1  | 2  | 3  | 1  | .65 | 69  | 65 | 65 | 64 | 38   | 62    | 73    | 178   |

\[ ML = \text{Milk proof}, \quad FA = \text{Fat percent}, \quad FPC = \text{Fat percent score}, \quad FC = \text{Final score}, \quad GC = \text{General appearance}, \quad DC = \text{Dairy character}, \quad CA = \text{Capacity}, \quad RM = \text{Rump}, \quad FL = \text{Feet and legs}, \quad MS = \text{Mammary system}, \quad FU = \text{Fore udder}, \quad RU = \text{Rear udder}, \quad SZ = \text{Size}, \quad SPDP = \text{Milk speed}, \quad NRR = \text{Nonreturn rate}, \quad ML = \text{Milk proof}, \quad EM = \text{Estimated milk yield}, \quad REV = \text{Revenue from milk sales}, \quad ITEM-1 = \text{Index of total economic merit in Model 1}, \quad ITEM-2 = \text{Index of total economic merit in Model 2}.\]
proofs as high as +11 were ranked low because of inferior proofs for fat percent, milking speed, and body size. Reranking was sometimes due to a low size proof and high fat percent proof (sires 320957 vs. 311885). Ranking on ITEM was because of good ratings for all type traits and milking speed offsetting demerits of a low milk proof as for 298086. High size and rump proofs favor veal production. Further, the MSQ restriction on total milk output favored sires that had a potential for veal production. Veal production is also a function of nonreturn rate which is above average for this sire.

Sire 314236 ranks high, however, has poor conformation characteristics and may be unprofitable in subsequent lactations. Ranking of such sires can be corrected when the model is extended for all lactations and stayability taken into consideration with coefficients linking production and possibly type with stayability.

The marginal cost for each sire is (ITEM) in Table 1. There was a rapid increase of the opportunity cost of using the second, third, and fourth ranking sires in contrast to sire 308691. Then the cost of using subsequent sires increased gradually indicating little change of profits.

**Sire Ranking when Market Share Quota is Not Limiting (Model 2)**

One of the limiting constraints in the base run was MSQ availability, which limited herd size to 47.6 milking daughters. To avoid interference by the restriction of a limit to milk production in the dairy farm on sire ranking, another set of optimal solutions was obtained by reducing the milking herd size to less than 47.6, namely 46. This allowed total milk output from the milking herd to be unaffected by the MSQ restriction.

Net farm profit in this run from 46 milking first calf daughters of the best sire was reduced to $65,482.64 from $66,800.69 in the previous solution. The shadow price for dairy space (floor space per milking cow or calf equivalent) remained the same at $202.63 and there was an MSQ stack (unused quota) of 9301.5 kg. Because the number of milking cows could be expanded, this variable assumed a shadow value of $846.36 per cow.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Model 1b</th>
<th>Model 2b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r$</td>
<td>$r'$</td>
</tr>
<tr>
<td>Milk proof</td>
<td>-.74**</td>
<td>-.62**</td>
</tr>
<tr>
<td>Fat proof</td>
<td>-.93**</td>
<td>-.11</td>
</tr>
<tr>
<td>Fat percent proof</td>
<td>-.43**</td>
<td>-.64**</td>
</tr>
<tr>
<td>Final score proof</td>
<td>.17</td>
<td>.01</td>
</tr>
<tr>
<td>Final class proof</td>
<td>.24*</td>
<td>-.06</td>
</tr>
<tr>
<td>General appearance proof</td>
<td>.27*</td>
<td>-.01</td>
</tr>
<tr>
<td>Dairy character proof</td>
<td>-.41**</td>
<td>.13</td>
</tr>
<tr>
<td>Capacity proof</td>
<td>.14</td>
<td>.00</td>
</tr>
<tr>
<td>Rump proof</td>
<td>.33**</td>
<td>.11</td>
</tr>
<tr>
<td>Feet and leg proof</td>
<td>.05</td>
<td>.04</td>
</tr>
<tr>
<td>Mammary system proof</td>
<td>.32**</td>
<td>.17</td>
</tr>
<tr>
<td>Fore udder proof</td>
<td>.33**</td>
<td>-.02</td>
</tr>
<tr>
<td>Rear udder proof</td>
<td>.23*</td>
<td>.09</td>
</tr>
<tr>
<td>Size proof</td>
<td>.06</td>
<td>-.67**</td>
</tr>
<tr>
<td>Milking speed proof</td>
<td>.03</td>
<td>-.92**</td>
</tr>
<tr>
<td>Nonreturn rate</td>
<td>.19</td>
<td>-.64**</td>
</tr>
</tbody>
</table>

1ITEM - Index of total economic merit.

bModel 1 = Milk output constrained, Model 2 = milk output unconstrained.

*P<.05.

**P<.01.
Ranking of sires under Model 2 and marginal costs are in Table 2 as ITEM-2. The obvious difference between the two ITEM rankings is that in the second ranking (Model 2), sires with high milk proofs were placed higher in the list although due consideration still was given to other traits as in the earlier case. For instance, sire 303326 moved down from the third to sixth position whereas sires 317750, 315196, and 314235 now have been rated superior to sire 303326, mainly because of their ability to produce more milk. Sires such as 311885 and 320957 were superior in their milk proofs but were ranked lower than sire 303326 because of their lower ratings for other traits. Sires such as 298086 and 308231 shifted to the 38th and 62nd positions.

Opportunity costs of sires was greater, although the trend was the same as when the MSQ was limiting.

Sire Ranking Without the Market Share Quota Constraint (Model 3)

A final run was without the MSQ constraint; that is, unlimited opportunity for milk production and sale and a milking herd whose size will be determined only by the availability of farm resources. The model increased herd size to 53.5 milking cows. The ranking did not differ from that of the second run with 46 milking cows. When the milking herd size was increased to just over 53.5, dairy space, milk tank capacity, and other constraints limited expansion, and sire ranking corresponded to the original run when MSQ was a limiting factor. Thus, many factors in dairy farm operations may restrict expansion of farm milk production and thus restrict or decrease emphasis on milk yield in sire choices.

Correlations Between Proofs and ITEM

Product-moment correlations (r) and partial correlation (r’) between sire proofs and sires’ marginal costs (ITEM) for both the first two models are in Table 2. The correlation, r, is the measure of relationship between sires’ marginal cost and sires’ ratings (proofs and nonreturn rate) for each trait taken individually, independent of the others. The partial correlation, r’, is the relationship between similar pairs of marginal costs and sire ratings, adjusted for variation of all other ratings. The sires’ milk proof had the highest correlations of both kinds, ranging from –0.62 to –0.94. Because ITEM start at zero and are progressively more positive as merit decreases, signs of significant correlations were chiefly negative. The simple correlation coefficient shows reduced association between milk proof and marginal cost when total farm output of milk was a restrictive factor in Model 1. Associated with this change, there was an increase of the simple correlation coefficient for fat percent proof. Trend was similar for standard partial correlation coefficients, although the corresponding change for milk proof was small.

A number of sire proofs showed significant association with marginal costs; however, apparent correlations were caused by inter-relationships between sire proofs. True economic relationships are given by the partial correlations where milk, fat percent, milking speed proofs, and nonreturn rate were significant (P > .01) for both herd situations. These were also the proofs selected in the prediction equations (18). Size proofs were negatively correlated with ITEM in Model 1 where the significant r’ absolute values increased except for nonreturn rate and milk proof. These changes suggest that when amount of milk quota limited total milk output, farm profits were maximized by continued high emphasis on milk proofs but with increased emphasis on 1) high fat percent ratings, 2) high milking speed ratings, and 3) high ratings for size.

The correlation coefficients between sires’ marginal costs and their 1979 production dollar index (PDI) (17), were –0.872 for Model 1 and –0.963 for Model 2. This was based on only 60 sires that had marginal costs as well as PDI. There was general agreement between sire rankings of the present study and PDI, especially when rankings were not affected by constraints such as MSQ in Model 2. This close association was mainly due to dependence of both ranking methods on sires’ milk proof. Milk proof had a high correlation coefficient of .947 with PDI and –.949 with marginal costs in Model 2. The coefficient between marginal costs in Model 1 and sire milk proof was lower (–.776) for the same 60 sires. These results indicate that the current economic index (PDI) available to dairy producers for ranking sires agrees well with our results based on total economic merit. However, the latter approach based on an
The standard partial regression coefficients of sires’ marginal values on their proofs and nonreturn rates are in Table 3. In Model 1 the relative importance of the traits in descending order were milk proof, fat percent proof, milking speed proof, size proof, fat proof, nonreturn rate followed by other type traits. Trend was the same in Model 2 except fat percent proof and nonreturn rate were ranked lower than some of the other type traits.

Most of the variation of marginal cost of sires was explained by milk proof (54.31 and 87.38%), fat percent proof (32.28 and 7.70%), and milking speed proof (6.19 and 1.75%) in Models 1 and 2, respectively, as in Table 3. The $R^2$ in both cases were almost 99%. There is further evidence here on redistribution of economic importance of the different traits when the milk quota restriction was made nonconstraining in Model 2.

### General Discussion

One of the unique features of the ITEM system for ranking sires was that the LP was forced to solve for one sire for each farm herd situation rather than bringing a number of sires into the solution. In effect, the LP must select that sire that will maximize profits and rank all other available sires in descending order of overall profitability independent of other sires available. Otherwise, compromise ranking will result where sires with complementary proofs for different traits are brought into the solution for each farm herd situation. The ultimate goal is to apply such a procedure to rank Canadian sires on overall profitability; however, many of the conditions in developing the LP model must be examined before this application may take place. Further, implications of extending the planning horizon to greater than 1 yr and inclusion of more than

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**Table 3.** Relative importance of traits in determining dairy profits and proportion of variation in ITEM explained by sire proofs for different traits.

<table>
<thead>
<tr>
<th>Sire trait</th>
<th>Model 1 $^b$</th>
<th>% $^d$</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk proof, kg</td>
<td>1.122</td>
<td>54.31</td>
<td>1.094</td>
</tr>
<tr>
<td>Fat proof, kg</td>
<td>.167</td>
<td>.41</td>
<td>.046</td>
</tr>
<tr>
<td>Fat percent proof, %</td>
<td>.797</td>
<td>.3228</td>
<td>.371</td>
</tr>
<tr>
<td>Final score proof, points</td>
<td>.003</td>
<td>.01</td>
<td>.019</td>
</tr>
<tr>
<td>Final class proof, points</td>
<td>.051</td>
<td>.25</td>
<td>.099</td>
</tr>
<tr>
<td>General appearance proof, points</td>
<td>.006</td>
<td>.01</td>
<td>.013</td>
</tr>
<tr>
<td>Dairy character proof, points</td>
<td>.020</td>
<td>.01</td>
<td>.017</td>
</tr>
<tr>
<td>Capacity proof, points</td>
<td>.001</td>
<td>.213</td>
<td>.015</td>
</tr>
<tr>
<td>Rump proof, points</td>
<td>.020</td>
<td>.28</td>
<td>.022</td>
</tr>
<tr>
<td>Feet and leg proof, points</td>
<td>.007</td>
<td>.00</td>
<td>.004</td>
</tr>
<tr>
<td>Mammary system proof, points</td>
<td>.082</td>
<td>.47</td>
<td>.074</td>
</tr>
<tr>
<td>Fore udder proof, points</td>
<td>.004</td>
<td>.08</td>
<td>.019</td>
</tr>
<tr>
<td>Rear udder proof, points</td>
<td>.027</td>
<td>.15</td>
<td>.027</td>
</tr>
<tr>
<td>Size proof, points</td>
<td>.216</td>
<td>.56</td>
<td>.130</td>
</tr>
<tr>
<td>Milking speed proof, min</td>
<td>.276</td>
<td>.19</td>
<td>.147</td>
</tr>
<tr>
<td>Nonreturn rate, %</td>
<td>.105</td>
<td>.77</td>
<td>.057</td>
</tr>
<tr>
<td>$R^2$</td>
<td>98.91</td>
<td></td>
<td>98.98</td>
</tr>
</tbody>
</table>

$^a$ITEM = Index of total economic merit.

$^b$Model 1 = Milk output constrained, Model 2 = milk output unconstrained.

$^c$Standard partial regression coefficient of ITEM on sire proofs and nonreturn rate.

$^d$Percent variation in ITEM explained by sire proofs and nonreturn rate.
one lactation per animal should be considered with different proportions of cows of various parities. Some reranking could be expected for mature cows instead of heifers in first lactation due to factors such as variation of mature size, feed requirement, stayability, influence of age on production, reproduction, and resistance to mastitis.

ACKNOWLEDGMENTS

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