RELATIONSHIPS AMONG ESTIMATED NET INCOME, HERDLIFE AND LINEAR TYPE TRAITS IN DAIRY CATTLE

by

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(ABSTRACT)

Opportunity cost of postponed replacement (OC) is the income forfeited by keeping a cow for an extra day and is estimated by the income produced by an average replacement. The effect of adjusting a measure of net income, relative net income (RNI), for OC (RNIOC) by lactation was studied.

After edits, the data set consisted of 2,982,001 Holstein cows. Prediction factors were developed for RNI and days of productive life (DPL) so that OC could be estimated from cows with shorter herd life opportunities. Within-herd correlations of RNI estimated from 84 month herdlife opportunity with that predicted from cows still alive at 36, 48, 60 and 72 months were .46, .59, .72 and .76, respectively and predictions reflected phenotypic trends of increased net income over time. Corresponding correlations for predicted 84 month DPL at the same ages were .28, .36, .41 and .47 and predictions conflicted with phenotypic trends of decreased herdlife over time. Total OC for cows with 84 month opportunity were raised by an average of $34 when OC was estimated specific to each lactation.

The 433,116 cows with classification records and 84 month herdlife opportunity were used to estimate genetic and phenotypic (co)variances among type traits, production, and months in milk (MIM), RNI and RNIOC with a multiple trait sire model. Production information from all cows in classified herds indicated that classified cows are not a random sample of cows in those herds.

Heritability of RNIOC (.17) was higher than RNI (.12), but the genetic correlation between the traits was high (.97). Heritability of MIM was .06. Genetic correlations of MIM to the yield and linear type traits were less than .31 in absolute value. Evaluation of net merit using economic weights developed with RNIOC was more accurate than indirect prediction of MIM. Approximate reliability of a first crop AI sire evaluation for net merit is .65 compared to .42 for MIM.

Abstract

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Review of Literature

Introduction

A method of correctly weighting available sources of information in the estimated breeding value of an animal, for either a single trait or an aggregate genotype such as a measure of profit, was proposed by Hazel in 1943. This method, called selection index, has been the basis for a tremendous amount of research towards the refinement of breeding value estimation using single trait indexes. As a result, national genetic evaluations for a variety of traits are routinely published in the US by several sources.

The definition of the breeding goal for an aggregate genotype and the relative weighting of the breeding values in the genotype for dairy cattle has also been studied by many researchers. The general conclusion of the research using profitability or economic efficiency as the breeding goal has been that the production traits should be the primary focus of selection. However, indices which also include other traits, usually survival and/or conformation, have been estimated to be more efficient than indexes which include production only.

While genetic evaluations for stayability are conducted in the Northeast US, most selection for longevity is practiced indirectly using conformational type traits. Selection for type traits occurs at both the Artificial Insemination (AI) stud and farm levels and has been implicated as one of the major sources of reduced genetic gain for production. The overall effect on survival from the intense selection for type traits would appear small at best, especially considering that a reasonable method of measuring type traits, the linear scale, has existed only for the last 9 years.

Very recently, multiple trait methodology has been used to estimate breeding values for survival from the genetic and environmental relationships among survival and the linear type traits. While this application of multiple trait methodology is important for evaluation purposes, it does not indicate which linear type traits are most important to survival on a genetic basis. Proper weighting of survival with other traits in the aggregate genotype considering the genetic and economic relationships is also needed.

Review of Literature

Although the estimated breeding values for dairy cattle, routinely calculated and published in the United States (US) by the Department of Agriculture (USDA), are for production traits such as milk, fat and protein yields, it is generally agreed that the goal of genetic progress should be an economic measure. Pearson and Miller (48) discussed the application of the selection index, as outlined by Hazel (35), to dairy cattle in pursuit of an economic goal.

The first step needed in the development of a selection index is the choice of an objective function. While selecting cows on the basis of total lifetime net income is intuitively appealing, several arguments have been made for basing selection on other measures. Two measures which have been proposed by Harris (34) are the ratio of lifetime totals for income and expense or income and days of productive life. As pointed out by Pearson and Miller (48), the ratio of income/expense would be the choice if decisions were made at the national level, where the system is closed with both supply and demand being finite and in equilibrium.

Because selection decisions in the US are made at the individual producer level in a free market, the objective function of total net income or net income per day of productive life is more realistic (48). Arguments can be made for and against either measure. Total net income does not discriminate between cows with different rates of income. This can be corrected for somewhat by applying a discounting factor to returns, but is still a problem when facilities have limited capacity.

Net income per day has very non-linear properties over the range of possible values for length of productive life. The non-linearity occurs for cows with a very short productive life, such that a cow with only one day of productive life is twice as bad as the cow which produces for only two days. Further, as noted by Van Arendonk (66), net income per day is not applicable to dairy cattle because there are differences among cows for length of productive life. Replacement theory requires that an identical replacement to the current producing unit be available or that length of life be constant among all units for comparisons to be made on average profitability (66).

As an alternative, Van Arendonk (66) proposed adjusting net income functions for the opportunity cost of postponed replacement (OC). OC can be envisioned as involving the same basic principle used in the discounting of the returns from an investment. Returns from an investment are often discounted to reflect that the investor has the opportunity to invest the monies in another manner, such as in a bank, and receive an average return.

Likewise, OC discounts returns from a cow to reflect that she could have been culled at any time and replaced by a heifer. Cows which have long herdlife but low net income per year are penalized by OC to reflect that the replacement heifer would have generated more net income. This has an overall effect of de-valuing herdlife relative to production because cows must do more than just cover fixed costs to accumulate net income. Further, adjusting the net income function for OC effectively gives credit to cows that are culled to reflect that they will be replaced. The combination of these two properties would seem to give net income adjusted for OC the best features of both total net income and net income per day.

Research with Net Income Functions

Net income functions are phenotypic measures which contain both genetic and management factors leading to differences in profitability. Studies using net income as a measure of performance have provided much insight to optimizing management decisions for factors such as age at first freshening (30,31,42) and culling (17,47,49,50,64,65). However in developing a selection index, the part of the objective function which is due to genetic differences is the focus as it becomes the breeding goal.

The goal of research with net income functions is to determine the traits which are economically important and can be combined in a selection index to achieve the breeding goal. As reviewed by Pearson and Miller (48), most research studying the importance of traits to net income or efficiency differ in the method of estimation and the number of variables examined. As a result, most studies could either be classified as small, with very complete information per cow, or large, with only a few variables considered on cows from many different herds.

Some studies that would be classified as small and complete would be Andrus and McGilliard (4), Balaine et al. (5,6), Bertrand et al. (9), and Gilmore (32). Each of these studies is rather complete for actual return and expense data of the cows studied. However, all are limited in the sense that the numbers of cows studied are relatively small (<200) and limited to a single herd. Because management has such a large effect on lifetime net income (47,49), a larger cross-section of systems would be desirable in deciding which traits are of economic importance.

Perhaps the greatest use of the smaller studies could be in validating the accuracy of larger studies that use only those variables available through the Dairy Herd Improvement Association (DHIA) testing program. An example of this application is the work of Tigges et al. (62), who studied the effectiveness of the net income function Relative Net Income (RNI) in describing the true net income of the cows in the data of Balaine et al. (5,6). By describing 95% of the variation in true net income with the net income function, Tigges et al. (62) showed that studies dealing with net income could be conducted on a larger scale with reasonable accuracy.

One limitation of RNI, found in the work of Tigges et al., was that the positive relationship between milk yield and incidence of mastitis was not accounted for with the profit function. The result was that the high milk cows were given too much credit by the net income function, which also caused the variability in net income to be overestimated. This problem was consistent with the findings of Bertrand et al. (9) in a study of the net income of two lines of cows selected to be divergent for milk production. The conclusion in both papers is that cows with higher genetic ability for milk production also have the highest lifetime net income, but accounting for incidence of mastitis, perhaps through an indicator such as somatic cell count (SCC), would be preferred.

Selection for total net income

While most of the research with net income functions has dealt with determining the traits which are suitable for inclusion in the index of selection for total lifetime net income, it should be noted that some researchers have recommended selecting for only the trait of net income. Lin and Allaire (42) and Strandberg (61) have both shown selection for an economic trait to be more efficient than index selection or selection for milk yield alone. Several arguments have been made against selection for the trait of lifetime net income (Hoeschele, VPI & SU class notes) including:

1. Differences in prices over time or across regions cause

problems with parameter estimation and genetic evaluations.

2. There is a loss in flexibility and information when the single trait of net income is used. Not only does net income have a lower heritability than many of the component traits, it is no longer possible to separate traits out for re-weighting for different selection goals.
3. Application of early economic measures is often problematic and less concise than combining information from traits individually. For example, evaluation of net income through first lactation favors cows with the undesirable characteristic of high days open.

While Beaudry et al. (8) and Balaine et al. (5) found that net income functions were somewhat insensitive to differences in prices for the traits included in the function, it can be argued that selection goals in the US have changed markedly in recent time. This type of change in the definition of net income (for example, including a new trait such as protein yield) would be difficult to implement in an evaluation for the single trait of lifetime net income. Similarly, differences continue to exist in the prices paid to producers in different regions of the US as well as abroad. Future changes in economic goals would seem inevitable due to potential developments in technology (such as improved efficiency in the separation of milk components) or government policies.

Identification of Economically Important Traits

In a study of 933 Holstein cows in Ohio institutional herds, Gill and Allaire (29,30,31) found that milk production, length of herdlife and age at first calving (favoring earlier calving) had strong genetic correlations with lifetime net income. Lin and Allaire (41,42) also found that milk yield and age at first calving were important factors in determining lifetime net income in a study of 1806 Holstein cows in 38 herds in California. However it should be noted that the heritability estimates for several of the traits studied were quite high and this may have inflated the importance of those traits to lifetime net income. Specifically, the estimates for age at first calving were .51 (31) and .18 (41), the estimates for profit to 41 months and over lifetime were .46 (42) and .26 (31), respectively. These estimates were from a mixed linear model analysis but may have been biased by requiring each cow to have 2 complete lactations or by the experimental design.

Beaudry et al. (8) found strong, positive correlations of lifetime total net income, estimated with the function Relative Net Income (RNI), with lifetime totals for milk yield and days of productive life (DPL) in a study of 176,902 Holstein cows. However the correlations varied for both total milk (.61 to .99) and DPL (.39 to .92) when lifetime net income totals were calculated using 3 different prices for both feed costs and product values in the RNI function. When net income was expressed per day of productive life (RNIPD), correlations were somewhat lower and much less variable across the different price levels for both lifetime milk yield (.45 to .50) and DPL (.45 to .46).

Smith (59) modified the costs charged for rearing and days dry in the net income function RNI, but found similar correlations for both lifetime milk (.97) and DPL (.89) as those reported by Beaudry (8) for the medium price levels (.96 and .86, respectively). In addition, Smith found that the correlation of age at first freshening decreased in magnitude as the length for the opportunity totals of RNI increased from 48 months (-.23), to 72 months (-.12) to lifetime (-.08). This trend was consistent with that found by Lin and Allaire (42), but of much smaller magnitude for both 72 month (-.39) and lifetime (-.29) totals.

Smith (59) also applied the concepts of discounting returns (DRNI) and opportunity cost of postponed replacement (RNIOC) to the net income function RNI. Discounting net income had little effect on phenotypic correlations among traits (59). Adjusting 72 month opportunity length net income totals for OC decreased the phenotypic correlation to total milk yield (.97 versus .88) and DPL (from .89 versus .78) compared to unadjusted net income. First lactation milk had a slightly higher correlation to 72 month RNIOC (.46) than with RNI (43). Thus, the impact of OC was to decrease the importance of herdlife and subsequent milk produced in later lactations as was expected from the simulation by Van Arendonk (66).

Van Arendonk (66) did not suggest a method of calculation, but noted that the choice of a value for the opportunity cost of postponed replacement becomes very important when assessing the importance of herdlife to profit. Smith (59) stated that, in principle, the opportunity cost should be equal to the returns that would have been generated by a replacement heifer under the same management conditions as faced by the cow.

Smith (59) used a within-herd Best Linear Unbiased Prediction (BLUP) analysis to arrive at an estimate of OC for each herd-year of first freshening. The average RNI and DPL of all cows freshening for the first time in the same herd-year was regressed on the average values of all years of the herd. The regression coefficient was of the form n/(n+k), with n equal to the number of first freshenings in the herd-year and k being the ratio of error to year within herd variances for the two traits. The OC was then expressed as per DPL by taking the ratio of the value obtained for RNI to that for DPL for each herd-year.

Although Van Arendonk (66) suggested that the calculation of opportunity cost be within herd, it could be argued that some population factors may influence the value. If the replacement heifer is seen as coming from the entire population of heifers of a given birth year, genetic trend of the population would have a direct impact on the opportunity cost. The importance of such refinements remains to be seen; there may be some validity to keeping the calculation as simple as possible.

Relationship of Type to Lifetime Net Income

Because intensity of selection for the type traits is substantial (75), researchers have tried for many years to delineate the relationship of the type traits and lifetime net income. Early research efforts dealing with type were hindered because the methods of evaluating type were not amenable to statistical analysis (13). The lack of a useful measurement of type traits may have been a contributing factor when Burnside et al. (12) concluded in a review article that type had little value for predicting what they regarded as the synonymous traits of longevity and lifetime profitability.

However, it was acknowledged by Burnside et al. (12) that minimum phenotypic requirements for some type traits are a reality and that some effort must be made to limit the decrease in these traits in practice. The emphasis of this point was directed towards the udder traits. Still, it was recommended that the industry allocate less resources to type evaluation and more effort to improvement of records for longevity evaluations, which is the supposed goal of selection for type.

A more objective method of evaluating conformational type was developed to aid in describing the biological form of the cow. Scoring individual type traits on a continuous, linear scale from one biological extreme to the other should allow for meaningful statistical evaluation of the importance of each trait. One of the first investigations using linear type traits was by Foster et al. (28), who used multiple regression techniques to evaluate the relationships between production, herdlife and the linear type traits as scored by an AI stud.

The part of the analysis by Foster et al. (28) for herdlife was somewhat preliminary due to small numbers of cows and short length of opportunity. The results did indicate that, for some of the linear traits studied, the optimum score for maximizing production was different from that which would maximize herdlife. This difference would seem reasonable, as it has been long hypothesized by dairy producers that cows which give large amounts of milk have decreased stayability. The non-linearity of the phenotypic relationships of some type traits with herdlife and milk production would also seem reasonable.

However it should be noted that the actual change in herdlife from varying any of the linear traits was small, which may make any differences in the relationship of a linear trait to milk production and herdlife of small consequence. For example, the regression of phenotypic milk production on phenotypic udder depth score predicted that milk production is maximized at the udder depth score of 0, indicating that cows with the deepest udders give the most milk. A similar regression with herdlife found the optimum udder depth score to be the intermediate value of 24. However, the predicted herdlife for cows with a score of 0 for udder depth is only 80 days shorter than those cows with the optimum score of 24. Differences on the genetic scale would be further regressed.

Use of correlated traits, such as the linear type traits, for indirect selection on herdlife is of most benefit when the objective trait has a low heritability or cannot be measured early in life. This is the case for herdlife. Since production has a moderate heritability and can be measured cheaply at the same age, the utility of using linear traits as indirect predictors of production would seem to be of questionable value. However, because of the dependency between herdlife and production, it may be of value to know the relationship of each type trait with both production and herdlife.

If milk production and herdlife are the two main components of profit, it may be difficult to elucidate the relationship of profit with those type traits that have opposite sign correlations with milk production and herdlife. The correlations of these linear traits with net income would be dependent on the relative emphasis of herdlife to production in the net income function and on whether or not production had been accounted for in the model already. This was evident in the work of Cassell et al. (15) which related sire evaluations for Holstein-Friesian Association of America (HFAA) linear type traits to 72 month opportunity totals for DRNI in grade and registered Holstein cows.

The correlation to DRNI of several traits, most notably the udder traits, changed a great deal when DRNI was adjusted for the effect of Predicted Difference dollar value (PD$), which is a measure of the value of milk and milk components. It also should be mentioned that the correlations between the type traits and profit were dependent on registration status of the daughters. The apparent difference in philosophy of producers with either registered or grade cattle is an indication of how traits such as profit and herdlife are affected by management decisions.

Survival and Net Income

Survival is perhaps the non-production trait most consistently mentioned as being important to lifetime net income. Allaire and Gibson (3) estimated a relative weighting of 3.2:1 for production to production-adjusted herdlife. The relative value of milk to herdlife was further examined by Allaire (2) and found to be dependent on the ratio of cost of cow depreciation to fixed costs, with both costs expressed on a per cow per year basis. If this cost ratio is increased by 50%, the relative economic importance of milk to herdlife decreases to 2.2:1. Conversely, a 50% decrease in the industry cost ratio raises the importance of milk to 6.5 times that of herdlife.

In a simulation of the concept of OC, Van Arendonk (66) estimated a relative weighting of 5.92:1 for production:herdlife under economic conditions of the Netherlands. This ratio was much higher than the relative weighting of 1.65:1 when the profit function was not adjusted for OC. Previous work by Rogers et al. (49,50) had dealt with the increased revenue from reducing involuntary culling rates, rather than assigning a value to herdlife per se.

Obviously, the relative value of longevity is also dependent on the genetic and environmental relationships to production. Several papers have found a positive genetic correlation between production and stayability (26,19,67,22,51,53,61,76, 77). Estimated genetic (27) and phenotypic (27,45) trends for stayability are negative, which is in contrast to positive trends for milk. A possible reason for the apparent contradictory estimates of trends and correlations may be that herdlife trend estimates need to be corrected for changes in herd size, as suggested by Sattler and Dentine (56). Certainly many other factors exist which would also affect herdlife trends, such as herd terminations due to a decreasing national herdsize, improvements in heifer rearing practices, as well as changes in market values for replacement heifers and cull cows.

A more troubling potential reason for the discrepancy which has been put forth by Essl (25), and verified by Strandberg (61), is that the correlation between the traits may not be accurately estimated. Under the model presented, increasing phenotypic milk production causes the environment of herdlife to be positively biased, such that cows which give more milk are treated better or culled less. If this is the case, the estimated genetic correlation between the traits will be biased positively.

Strandberg (61) was unsuccessful in finding a method of correcting the restricted maximum likelihood (REML) estimates of the correlations between herdlife and milk yield. Until a solution is available, caution should be taken in making recommendations from research with field data.

Genetic Evaluation for Survival

The economic value of herdlife has led many researchers to seek improved genetic evaluation methods for this trait. Much of the early research defined the trait as stayability, which was measured as a binary trait for the ability to survive to various ages. Everett et al. (26) chose the traits of stayability to 36, 48, 60 72 and 84 months of life for investigation with least squares. The conclusion of the study was that 48 month stayability would be the best trait for sire evaluation because it is the earliest measure with high correlations with all later stayability traits.

Van Doormaal and co-workers (68) used a conditional probability function to plot the changes in the hazard value (probability of not surviving) over the life of Canadian Holsteins. The goal of this research was to document the most logical ages for evaluation of survival. Also, length of productive life was examined in hopes that it would be more informative than stayability because variation in age of first freshening is adjusted for.

The hazard plots for productive life were found to have more distinct peaks (periods of high hazard) and troughs (periods of low hazard) than the plots for survival over lifetime (68), making productive life the more desirable trait. Survival to 17, 30, 43 and 55 months of productive life were recommended as the most useful ages for evaluation due to the low hazard values at those times.

As noted by Smith and Quaas (60), when binary traits such as stayability to a fixed age are used, there is a loss of information because all cows which fail before the target date are treated as equal. Hence, several researchers (20,60,23,24,74) have sought methods to deal with herdlife on a more continuous basis.

DeLorenzo and Everett (20) compared the logistic transformation model to a linear model in mixed model analyses of survival to fixed ages. The logistic transformation is a nonlinear method of modeling a discrete response, such as survival to a fixed age, on a continuous underlying scale. A probability of survival to the fixed age is calculated for all cows with this method.

The heritability of survival from the logistic model, using approximated variances of the underlying normal scale, was estimated to be .28 for survival to 41 months and .26 for survival to 54 months (20). These estimates correspond to estiamtes of .12 and .15 on the phenotypic scale. Correlations between sire proofs for linear and nonlinear methods were not high (.61 to .70). Younger sires were found to rank much higher on the nonlinear scale, although a large, positive genetic trend for survival was estimated on both scales. It was reasoned that the nonlinear method was more accurate. The improved accuracy of the nonlinear method was thought to be especially important for herd-year-seasons where survival rates were high, which makes differences more difficult to detect. It was noted (20) that the nonlinear method was also more computationally demanding.

Smith and Quaas (60) extended the method of the hazard function to evaluate sires directly for the continuous measure of productive lifespan. Two potential definitions of failure were examined because the exact determination of failure with DHIA data was found to be difficult. Cows which were assumed to not have failed for each definition were treated as censored for the length of their records. The analysis was formulated on the hazard function from a Cox's regression model. As a distribution was not reported, it must be assumed that the non-parametric method of Cox was used. As with all non-normal analyses, estimation of variances and variance ratios (such as heritability) for either measure by Smith and Quaas were on the transformed scale, but were higher than previous estimates (.13 and .06).

Ducrocq and co-workers (23) compared the hazard function from a Cox's regression to the Weibull regression model. It was thought that if the Weibull distribution was appropriate, computations would be made more easiliy than those required for non-parametric or semi-parametric analyses, as used by Smith and Quaas (60). Also introduced was the concept of herd rank for actual production as a factor in the analysis of length of productive life (LPL) to evaluate functional rather than true stayability.

The Weibull model was an appropriate approximation of Cox's semi-parametric model based on analysis of residuals and cross-validation with data splitting (23). Also, the estimated effect of lactation number, stage of lactation, and production within herd-year were plausible. Subsequent estimates of "pseudo-heritabilities" of LPL were found to be .085 for both true and functional (adjusted for herd rank on actual production) stayabilities (24).

The correlation between sire proofs for true and functional stayability of .80 suggested that the two definitions are measures of different traits (24). Further, the correlation with milk production differed for true (-.28) and functional (.13) stayabilities, with similar results found for survival to 48 months (-.48 versus -.33).

Ducrocq and co-workers (24) suggested that functional stayability is a more appropriate measure of a cow's ability to avoid involuntary culling than true stayability, which contains voluntary culling for milk yield. The separation of yield and survival is appealing from the standpoint of providing economic weights for different economic conditions. The adjustment for milk yield would seem to guarantee that bulls extremely high for milk yield have low evaluations for functional stayability, but a correlated reduction of fitness would seem reasonable as continued progress is made for milk production.

It could also be argued that survival has little value if production is not adequate, making functional stayability meaningless. Separation of production from stayability to provide a meaningful measure is very difficult with field data (61). Perhaps the best hope is for a measure of relative survival within production groupings.

Most recently, VanRaden and Klaaskate (74) have proposed that months in milk to 84 months of age (MIM84) be used as a measure of productive life. The goal was to develop national evaluations for survival that could use the more familiar linear methods for genetic evaluations. MIM84 of cows which were less than 84 months of age and still alive were treated as records in progress. As such, these records could be used in genetic evaluations by developing projection factors, expanding the variance of the projected records and finally giving them less weight in evaluations. This method has been incorporated in the genetic evaluations for the yield traits (73).

The maximum of 10 months in milk credit is given for each lactation in calculating MIM84. Although this feature was necessitated by limitations of data sources, it was also felt that the restriction rewarded cows with shorter calving intervals. The limit of 84 months was seen as a reasonable length of survival and allowed for a more normal distribution of records (74).

Best Linear Unbiased Prediction (BLUP)

Many statistical analyses dealing with biological traits are best described by a model including both fixed and random effects. For example, records on a population of dairy cows with one record per cow could be modeled in matrix notation as

$$y=X\beta+Zu+e \tag{1}$$

where

y is the vector of observations (records) of dimension 1xn,

β is the vector of fixed effects of dimension 1xp,

X is a known incidence matrix relating the n records to the p fixed factors (dimension nxp)

u is the vector of unknown random effects, in this case breeding values, of dimension 1xa,

Z is a known incidence matrix relating the n records to the a random factors (dimension nxa).

e is the vector of unknown random residual effects of dimension nx1.

The variances of **u** and **e** are **G** and **R** respectively, where **G** and **R** are known, nonsingular matrices. Henderson (37) derived a method to simultaneously provide a Best Linear Unbiased Estimator (BLUE) of the fixed effects and the Best Linear Unbiased Predictor (BLUP) of the random effects. Although important and useful for evaluation of both types of effects, the method is usually referred to as BLUP because of the emphasis placed on the random effects.

Henderson (37) also presented a very flexible algorithm that could be used to perform a BLUP analysis which he termed the mixed model equations (MME). The MME for the above model would be

$$\begin{bmatrix} X'R^{-1}X & X'R^{-1}Z \\ Z'R^{-1}X & Z'R^{-1}Z+G^{-1} \end{bmatrix} \begin{bmatrix} \beta \\ \hat{u} \end{bmatrix} = \begin{bmatrix} X'R^{-1}y \\ Z'R^{-1}y \end{bmatrix} \qquad [2]$$

These equations are then solved either directly by multiplying both sides by the inverse of the coefficient matrix of the left-hand side or iteratively. In most applications dealing with prediction of breeding values, the matrix **G** is equal to σ_a^2 **A** where σ_a^2 is the variance of breeding values and A is the additive genetic relationship matrix of animals. Both A and **u** can be augmented to predict breeding values for animals without records but having relatives with records.

Multiple Trait Evaluations

Henderson (37), and Henderson and Quaas (38) extended the MME to calculate the BLUP of breeding values in models with more than one trait. The data vector **y** now consists of subvectors $\mathbf{y}_i$ containing observations on the n animals for each trait i, i=1 to t. The **X** matrix is now of the form

$$X = \begin{bmatrix} X_1 & 0 & \cdots & 0 \\ 0 & X_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & X_t \end{bmatrix} \qquad [3]$$

The variances of **e** and **u** are now given by $\mathbf{R}_0 \otimes \mathrm{I}$ and $\mathbf{G}_0 \otimes \mathrm{A}$, with $\mathbf{R}_0$ and $\mathbf{G}_0$ being txt matrices of environmental and genetic (co)variances. The ⊗ denotes the direct product of two matrices, such that

$$R_o \otimes I = \begin{bmatrix} r_{11}I & r_{12}I & \cdots & r_{1t}I \\ r_{21}I & r_{22}I & & \vdots \\ \vdots & & \ddots & \\ r_{t1}I & \cdots & & r_{tt}I \end{bmatrix} \qquad [4]$$

where r_{ij}I represents the ijth element of matrix $\mathbf{R}_0$ as a scalar multiplier with the identity matrix. Computing solutions to the multiple trait MME is much more difficult than t single trait analyses because 1) the number of equations will become prohibitively large as the number of animals and traits increase, and 2) the proportion of non-zero off-diagonals is greatly increased, further increasing computational demands.

The motivation for utilizing a multiple trait evaluation is to either provide evaluations for animals that are not measured for a trait of interest, to increase the accuracy of evaluations for all traits of interest and to avoid selection bias from correlated traits. Both topics were reviewed in detail by Schaeffer (57). In the example presented, the MME for an animal model and two traits are solved, with all individuals being unrelated. The equations for predicting the breeding values for an individual can be shown to be equal to

$$\begin{bmatrix}\hat{a}_1\\ \hat{a}_2\end{bmatrix} = \begin{bmatrix}(g^{11}+r^{11})^{-1}(r^{11}(y_1-\hat{H}_1)+r^{12}(y_2-\hat{H}_2-\hat{a}_2)+g^{12}\hat{a}_2)\\ (g^{22}+r^{22})^{-1}(r^{22}(y_2-\hat{H}_2)+r^{12}(y_1-\hat{H}_1-\hat{a}_1)+g^{12}\hat{a}_1)\end{bmatrix} \qquad \textbf{[5]}$$

where

$\hat{a}_i$	is the predicted breeding value for trait i
$\hat{H}_i$	is the estimated herd effect for trait i
g^{ij}	is the ijth element of the inverse of the genetic (co)variance for the traits of $\mathbf{G}_o^{-1}$
r^{ij}	is the ijth element of the inverse of the

environmental (co)variance for the traits of $\mathbf{R}_o^{-1}$

The predicted breeding value for trait i for an individual can be divided into three components, all of which are all weighted by $(g^{ii} + r^{ii})^{-1}$. The components are the herdmate deviation for trait i which is weighted by r^{ii}, the environmental effect for trait j with weight r^{ij}, and the predicted breeding value for trait j, weighted by g^{ij}.

Obviously, the improvement in accuracy from utilizing a multiple trait evaluation will be dependent upon the heritabilities of the traits and the correlations between them. Table 1 contains the percentage reduction in prediction error variances (PEV) from a multiple versus single trait analysis adapted from Schaeffer (57).

From the values in Table 1 it is evident that the trait with the lower heritability almost always has the largest decreases in PEV through a multiple trait evaluation. Also evident is that higher correlations between the traits result in larger gains in accuracy, as would be expected given equation [5].

An interesting result is that PEV decreases as the absolute difference in the genetic and environmental

Table 1. Percentage reduction of variances of prediction error for a multiple trait analysis versus single trait analyses when all animals are measured for both traits, h^2_1 = .1 and h^2_2 = .25, where h^2_i = heritability of trait i. Adapted from Schaeffer (57).

Correlation between traits		Number of animals evaluated			
		10		40	
Error	Genetic	Trait 1	Trait 2	Trait 1	Trait 2
.1	.3	.92	.13	1.00	.14
.1	-.3	2.15	1.35	2.35	1.49
.1	.7	6.77	1.92	7.39	2.12
.1	-.7	9.46	4.72	10.32	5.21
.5	.3	.01	1.96	.01	2.16
.5	-.3	7.22	8.91	7.88	9.84
.5	.7	3.28	.07	3.58	.08
.5	-.7	18.79	15.93	20.51	17.58

correlations between traits increases. This should seem logical when one considers that the goal of genetic evaluations is to partition phenotypic deviations into genetic and environmental contributions. Having opposite sign genetic and environmental correlations between traits is more informative for genetic evaluations because there is a cleaner, or more nearly complete, partitioning of genetic and environmental effects.

The predicted increases in accuracy from multiple trait evaluations are based on the assumption that the estimated correlations are the true parameters. Not surprisingly, Schaeffer (57) found that the scenarios which produced the largest decreases in PEV from multiple trait evaluations are also at highest risk for increased PEV if the correlation values used are different from the true parameters. As a measure of the difference of estimated from true correlations, Schaeffer (57) used what he termed the absolute difference (AD) calculated as

$$AD = \left|(r_e - \rho_e) - (r_g - \rho_g)\right| \qquad \textbf{[6]}$$

where r_e and r_g are estimates of the true environmental and genetic correlations, ρ_e and ρ_g.

For the majority of the 101 scenarios of AD examined by Schaeffer (57), the AD was .5 or less which resulted in less than a 5% increase in PEV for either trait.

Because of the computational difficulty of performing a multiple trait evaluation, sire models are more feasible than animal models. The sire effects estimated from a two-trait model were solved for by Schaeffer (57) and separated into three parts. The first part of sire effect i for trait 1 is the contribution of progeny observations for trait 1 which is of the form

$$(n_{i.}+g^{11}/r^{11})^{-1}\left[\sum_{m=1}^{n_{i.}} y_{i1m}-\sum_{k=1}^{p} n_{ik}\hat{\beta}_{1k}\right] \qquad [7]$$

where

$n_{i.}$ is the number of progeny for sire i

p is the number of fixed effects

g^{11} is the first diagonal element of $(.25\mathbf{G})^{-1}$

r^{11} is the first diagonal element of $(\mathbf{R})^{-1}$

n_{ik} is the number of progeny of sire i with fixed effect level k

$\hat{\beta}_{1k}$ is the estimated fixed effect for level k on trait 1

The contribution from progeny observations on trait 2 represents the second part of the sire effect and is calculated as

$$(n_{i.}+g^{11}/r^{11})^{-1}(r_{12}/r_{22})\left[\sum_{m=1}^{n_{i.}} y_{i2m}-\sum_{k=1}^{p} n_{ik}\beta_{2k}-n_{i.}\hat{s}_{i2}\right] \qquad [8]$$

The third contribution comes from the sire solution for trait 2 and is of the form

$$-(n_{i.}+g^{11}/r^{11})^{-1}(g^{12}/r^{11})\hat{s}_{i2} \qquad [9]$$

Because part 2 is a sum of residuals, it will tend towards as $n_{i.}$ increases. The weighting for part 3 will tend toward zero as $n_{i.}$ increases. The result is that the evaluations for sires with large numbers of offspring would be unaffected by the correlations between traits and essentially be reduced to single trait evaluations. Conversely, the accuracy of evaluations for sires with small numbers of offspring would be increased due to the use of correlations among the traits.

Canonical Transformation

Because of the computational difficulty of performing multiple trait analyses, their application to large scale evaluations is limited. Methods of transforming the multiple trait equations to single trait equivalents were reviewed by Jensen and Mao (40). One of the transformations reviewed was the canonical transformation, which reduced the matrix of environmental correlations ($\mathbf{R}$) to the identity ($\mathbf{I}$) and the matrix of genetic correlations ($\mathbf{G}$) to a diagonal matrix ($\mathbf{D}$). This transformation is a result from multivariate theory which states that if both $\mathbf{R}$ and $\mathbf{G}$ are positive definite matrices, there exists a matrix $\mathbf{Q}$ such that $\mathbf{QRQ'}=\mathbf{I}$ and $\mathbf{QGQ'}=\mathbf{D}$. The elements of $\mathbf{D}$ are the eigenvalues of $\mathbf{RG}^{-1}$ and heritabilities of the corresponding traits on the transformed scale ($\mathbf{y}^{*}=\mathbf{Qy}$). The matrix $\mathbf{Q}$ contains the corresponding eigenvectors of the decomposition.

The advantage of this method is that the transformed traits are now uncorrelated, so that the multi-trait MME simplify to t single trait analyses. The resulting breeding value estimates are identical to those of a multiple trait analysis after they are transformed back to the original scale by multiplying by $\mathbf{Q}^{-1}$. One limitation of this method is that incidence matrices $\mathbf{X}$ and $\mathbf{Z}$ need to be identical for all of the t traits evaluated.

Van Raden et al. (70) employed this method of transformation in obtaining Residual Maximum Likelihood (REML) estimates of the (co)variance matrices between the linear type traits in Holsteins with a sire model. After estimating the (co)variances in the transformed scale in the k^{th} round of iteration, the matrices $\mathbf{G}^*_k$ and $\mathbf{R}^*_k$ are transformed back to the original scale and a new matrix $\mathbf{Q}_{(k+1)}$ was calculated. The matrices $\mathbf{G}_k$ and $\mathbf{R}_k$ are then transformed to the canonical scale with $\mathbf{Q}_{(k+1)}$ to begin a new round of iteration. The final estimates for the heritabilities and covariances between traits were found to be similar to previous estimates using different methods or smaller data sets (70).

The MME were then solved for the sire effects using these estimates and cow evaluations were approximated. Improvements in accuracy from using multiple versus single trait analyses were in agreement with expectations derived by Schaeffer (57). The largest improvements were seen in evaluations of the trait with the lowest heritability, foot angle, and for animals with small amounts of information. For cows with no relatives and one record per trait, the percentage increase in reliability ranged from 3% to 60%, with an average increase of nearly 23% for all traits where reliability is defined between the squared correlation of true and estimated breeding values (70). The percentage increase for bulls with 20 daughters ranged from 1% to 15% with an average of 5.6%, while the largest increase for bulls with 50 daughters was less than 5%.

Boldman et al. (10) also used this method to estimate (co)variances among the linear type traits and the traits of true (HLT) and functional (HLF) herdlife in Holsteins. Functional herdlife is defined as a measure of the cow's ability to avoid involuntary culling only. Because of the time constraints with measuring herdlife, very few current sires have daughters with observed herdlife. And, as previously mentioned, the canonical transformation is only possible when the incidence matrices **X** and **Z** are identical, such that the relationship matrix and the solution vector cannot be augmented to include sires without herdlife information. This restriction severely limits the application of multiple trait evaluations to herdlife.

To overcome this, Boldman et al. (10) first used the subset of cows which had both herdlife and linear type scores observed to estimate the matrix of genetic (co)variances among traits, **G**. Prediction of sire effects for those sires without herdlife information was then equal to

$$\begin{aligned}\hat{s}_n &= Cov(s_n, s)'\,[Var(s)]^{-1}\hat{s}\\ &= (g_{tn} \otimes A)'\,(G^{-1}A^{-1})\,\hat{s}\\ &= [(g_{tn}G^{-1})] \otimes I_q\ \hat{s}\\ &= (w_t \otimes I_q)\ \hat{s}\end{aligned} \qquad \textbf{[10]}$$

where

$\hat{\mathbf{s}}_n$	is the qx1 vector of predicted sire effects for herdlife
$\mathbf{g}_{tn}$	is the tx1 vector of sire covariances between herdlife and the t linear traits
$\mathbf{A}$	is the numerator relationship matrix among sires
$\mathbf{G}^{-1}$	is the inverse of the txt matrix of additive genetic (co)variances among the t linear traits
$\hat{\mathbf{s}}$	is the tqx1 vector of predicted sire effects for each of the t linear traits
$\mathbf{I}_q$	is the identity matrix of size q = the number of sires
$\mathbf{w}_t$	is a tx1 vector of weights for predicting the herdlife sire effect from the set of effects of the same sire on each of the t linear traits

which is equivalent to the solution from the multiple trait

MME with no records on herdlife. The vector of weights works for all sires without herdlife information, regardless of the amount of information from progeny or relatives through $\mathbf{A}^{-1}$, which has been accounted for in the MME when calculating $\hat{\mathbf{s}}$. Note that in the above formulae, data were ordered by sire within trait. If sire effects are ordered by trait within sire, sire effects for the trait of herdlife would be calculated as simply $\mathbf{w}_t'* \hat{\mathbf{s}}$, where $\hat{\mathbf{s}}$ is a tx1 vector of sire effects.

This same method of prediction of sire effects for herdlife was used by Harris et al. (33) for Guernsey cattle. Harris et al. (33) also noted that the resulting vector of weights were identical to partial genetic regression coefficients. As such, the weights from predicting the trait of profitability would be the economic weights of the traits, but would be dependent on the other traits included in **G**.

Chapter 2

Adjustment of a Net Income Function for Opportunity Cost of Postponed Replacement On a Lactation Basis

Abstract

Opportunity cost of postponed replacement (OC) is the income forfeited by keeping a cow for an extra lactation and is estimated by the income produced by an average replacement. The effect of refining a measure of net income, relative net income (RNI) adjusted for OC (RNIOC), by calculating an OC for each lactation was studied. After edits, the data set consisted of 2,982,001 Holstein cows from herds that had cows classified by the HFAA between 1983 and 1992. To utilize more recent data, prediction factors were developed for RNI and days of productive life (DPL) so that OC could be estimated from cows with shorter herd life opportunities. Within-herd correlations of RNI estimated from 84 month herdlife opportunity with that predicted from cows still alive at 36, 48, 60 and 72 months were .46, .59, .72 and .76, respectively. Corresponding correlations for predicted 84 month DPL were at the same ages were .28, .36, .41 and .47. Phenotypic trends indicate increased production and estimated net income from replacements over time. Because of these trends, estimating an OC specific to each lactation raised total OC for 84 month opportunity totals by an average of $34 compared to application of OC of herd-year of first freshening to all lactations.

Introduction

Profitability is not directly measured on dairy cattle in the US but various functions of DHI data have been used to estimate net income (29,31,46,66). Tigges et al. (62) compared the revenue estimated by one of these functions, relative net income (RNI), to that calculated from detailed cost and return receipts from a research herd. Tigges et al. (62) showed that research with net income functions and DHI records could be done with much larger data sets because RNI explained 95% of the variation in actual net income.

Van Arendonk (66) proposed adjustment of net income function totals for the opportunity cost of postponed replacement (OC). Opportunity cost was defined as the income forfeited by keeping a cow and not freshening a replacement heifer. Failure to adjust net income totals for OC in deriving economic weights was shown to over-emphasize the weight given to herdlife in a simulation study (66).

Smith (59) applied the OC adjustment to cows with 72 month herdlife opportunity. An OC was calculated for each herd-year of first freshening by regressing herd-year of first freshening averages for RNI and days of productive life (DPL) towards averages of RNI and DPL for all years of the herd. The regression coefficient was of the form n/(n+k), where n is the number of records in a particular herd-year of first freshening, and k is the ratio of error to variation among years within a herd for the respective trait. Predicted OC was then expressed per day (OCPD) by dividing RNI by DPL for each herd-year of first freshening.

Smith (59) applied the OC of a cow's herd-year of first freshening across her lifetime by calculating RNI adjusted for OC (RNIOC) as:

$$RNIOC_{hij} = RNI_{hij} - (DPL_{hij} * OCPD_{hi})$$

where RNIOC, RNI and DPL are totals for the j^{th} cow freshening for the first time in the i^{th} year of the h^{th} herd. Adjusting RNI for OC (RNIOC) decreased both the mean and the variance of RNI. In addition, RNIOC had a lower phenotypic correlation to DPL (.73) than did RNI (.84).

Smith's application of OC assumes the average replacement is the same for all lactations of a cow. Applying the same OC throughout a cows' life may not be accurate for longer opportunity lengths if significant trend for profit exists. A more precise method would be to calculate an OC for each lactation of the cow by using the averages of the replacements for that herd-year.

Timeliness of evaluations is the major obstacle with all lifetime measures. To evaluate cows with 84 month opportunity for RNIOC, replacements for each lactation would also need to be given 84 month opportunity. This requirement would limit the analysis to cows born approximately 11 years before the date of evaluation.

VanRaden and Klaaskate (74) applied techniques used in extending yield records to counter the required time lag for evaluation of months in milk to 84 months of age (MIM84). Records of cows still alive at ages less than 84 months of age were projected and given less weight in the evaluation.

The objective of this research was to investigate the effect of applying OC specific to each lactation for cows with up to 84 months of herdlife opportunity. Projecting RNI and DPL records of cows with shorter opportunity lengths to estimate OC will be investigated as a means to include more recent data in studies of lifetime performance.

Materials and Methods

The data included 4.6 million cows from herds which had some cows classified between the years 1983 and 1991. Edits required that breed be designated as Holstein, record was coded as usable for genetic evaluations, birth and calving dates were valid, age of first calving was between 18 and 36 months, all calving intervals were between 270 and 730 days, and the herdcodes for first and last records were the same. Numbers of cows removed for each edit are given in Table 2.

Additional edits required that herds were on test continuously for 72 months, had greater than 5 calvings per year, and milked 2X for the duration of the data. After edits, 2,982,001 cows with at least 33 months of herdlife opportunity remained.

Herdlife opportunity length is the number of months that the cow had the opportunity to live and was determined from the difference in the dates of last information from the herd and the birthdate for a cow in the herd. Minimum opportunity lengths of 48, 60, 72 and 84 months were included in this study.

Table 2. Percent and number of cows removed from data set and number remaining after different edits.

Edit	Percent Removed	Number Removed	Number Remaining
Invalid date of birth or calving, coded not usable for genetic evaluations or not Holstein	5.1	238,102	4,404,451
Milked 3 times a day (3X)	14.9	657,919	3,746,532
Age of first calving < 548 days	~0.0	1,910	3,744,622
Age of first calving > 1096 days	11.6	436,218	3,308,404
Calving interval < 270 days	~0.0	1	3,308,403
Calving interval > 730 days	0.9	28,478	3,279,925
Different first and last herdcodes	0.3	10,517	3,269,408

Production records were lifetime files of 305 day actual and mature equivalent (ME) yields for milk and fat. Since test day weights were not available, a record was included in its entirety if the record was initiated prior to the end of the opportunity length. A relative net income (RNI) total for each opportunity length was then calculated as:

RNI = (total product value * net percentage) + (number lactations * net value per calf) + net salvage value - (rearing cost) - (total days in milk * daily cost for maintenance feed, milk labor, fixed and operating expenses) - (total days dry * daily cost for maintenance feed, fixed and operating expenses)

Calculation of RNI in this study uses essentially the same variables put forth by Norman et al. (46). Total product value is the value of the milk and fat produced in the opportunity length period. This value was calculated using the same milk price of $12/cwt as Smith (59), but the fat differential was lowered to $.08 to reflect recent changes in component pricing.

The net percentage is the fraction of total product value left after accounting for cost of feed for production and the value of discarded milk. A net percentage of 72%

was used for this study with the derivation given in the Appendix.

Net value per calf and net salvage value were the same as those used by Smith (59). The net calf value of $100 assumes live calf values of $100 for bull calves and $200 for heifer calves. The average value of $150 is reduced by $50 to reflect costs of 10% death losses and $35 semen and breeding labor costs. Likewise, the average salvage value of $300 is based on an average cull cow price of $525 with adjustment for death losses and original cost of a heifer calf.

Feed cost for maintenance and gain of $.77/day are derived in the Appendix. Fixed costs and labor costs of $.57/day for a dry cow were taken from Smith (58) to arrive at a total daily cost of $1.34 for dry cows. Costs of milking labor and equipment increase the daily costs for a cow in milk to $2.80/day.

Rearing cost was based on the age of first freshening (AFF) as ((AFF - 790) * .99) + 987.5, where $987.5 is the cost of raising a heifer to 790 days assuming a $1.25 average daily cost and $.99 is the approximate average daily cost of a heifer between the ages of 18 and 36 months.

Two measures of herdlife were examined. Days of productive life (DPL) was the interval between the date of freshening for the last lactation in the herdlife opportunity plus days in milk for that lactation (with a maximum of 305 days), and the date of first calving. As with RNI, DPL included all days in milk of any lactation initiated before the end of the opportunity length for 48, 60, 72, and 84 months.

Months in milk (MIM) was calculated by the method proposed by VanRaden and Klaaskate (74). MIM totals were calculated for 36, 48, 60 and 84 months of age by summing the months in milk (with a maximum of 10.2 months per lactation) up to the appropriate age in months for each cow. Because records are truncated in calculating MIM for the different opportunity lengths, the DPL measure within the same opportunity length is not equivalent to the MIM measure plus the total days dry for the opportunity length. Days of productive life includes any extra days in milk beyond the opportunity length for the last lactation. Therefore, MIM considers the exact opportunity length specified while DPL and RNI use a slightly longer period that varies from cow to cow.

Multiple regression models utilizing information available at the end of first lactation and after 48, 60 and 72 month opportunity lengths were developed to predict RNI and DPL totals for longer opportunity lengths. Effects of herd-year of first calving were absorbed in the GLM procedure of SAS. All cows with 84 month opportunity that were alive at each of the respective times were used in development of prediction equations. Cows were classified as alive at end of prediction length period if more information for the cow was present in the data file or if herd information ended within 425 days of the last information on the cow. Because herd-year of first freshening effects were absorbed, intercepts of prediction equations were estimated by back-solving for the average effect herd-year of first freshening. Models to predict 72 and 60 month RNI and DPL totals from earlier information were developed in the same fashion.

The original edits required cows to be between 18 and 36 months of age at time of first freshening, which means that cows differing by up to 30 months of age could calve for the first time within the same herd-year. As a result, cows in the same herd-year of first freshening may have different herdlife opportunity.

In calculating means for herd-year of first freshening, cows with completed records (those with maximum opportunity length equal to or greater than the length being analyzed) were included in the herd-year mean with a weight of one. RNI and DPL totals of cows with shorter maximum opportunity length that were classified as dead were also considered complete and given a weight of one.

RNI and DPL totals were predicted for cows with shorter maximum opportunity length considered still alive using their maximum opportunity length totals. The predicted RNI and DPL totals were weighted by the square root of the within-herd coefficient of determination (R^2) in calculating the herd-year of first freshening mean.

The herd-year of first freshening averages for RNI and DPL were regressed toward herd averages of complete opportunity length records using the same method as Smith (59). The OC per day for each herd-year of freshening was then equal to the ratio of RNI and DPL. RNIOC was then calculated as:

$$RNIOC_{hi..} = RNI_{hi..} - \sum_{j=1}^{n} [(DIM_j + DDRY_j) * OCPD_{hk}]$$

where DIM is the total days in milk for the j^{th} lactation of n total lactations, DDRY is the total days dry preceding the j^{th} lactation for the i^{th} cow in the h^{th} herd, and OCPD is the OC per day for the k^{th} year within herd h. Days dry for the first lactation was zero. The OC for the next lactation was applied beginning with the first day dry of the previous lactation since the decision to postpone replacement was made at this time.

Results and Discussion

Prediction of Opportunity Totals

Within herd-year coefficient of determination (R^2) and coefficients of prediction for different opportunity length RNI totals from different ages are given in Table 3. Models using various combinations of the available variables were tested for each age of prediction (end of first lactation, 48, 60 and 72 months). Variables considered included AFF and the current lifetime total RNI, DPL, DIM, days dry and actual and ME milk accumulated through the age of prediction.

The current total RNI was the single best predictor of future RNI totals at all ages of prediction and was included with AFF and total DIM in all models for prediction from later ages. The resulting coefficients for RNI and AFF at all ages predict that cows that calve early and are profitable early in life tend to have higher RNI totals for longer opportunity lengths.

As expected from the part-whole relationships, coefficients of determination were highest when predicting RNI for the following opportunity length. As shown in Table 3, accuracy of prediction of 84 month opportunity RNI

Table 3. Multiple regression coefficients of prediction and coefficient of determination (R^2) within herd-year of first calving for predicting 60, 72 and 84 month opportunity totals for Relative Net Income (RNI) using variables available from cows with 84 month herdlife opportunity and alive at 36, 48, 60 or 72 months of age.

Dependent Variable	Independent Variables					
	RNI1[1]	DIM1	AFF			R^2
RNI84	2.778	2.310	-0.683			.21
RNI72	2.524	1.906	-0.759			.26
RNI60	2.117	1.316	-0.799			.35
	RNI48[2]	DIM48	DDRY48	MEMLK48	AFF	R^2
RNI84	2.593	-0.226	-1.225	-0.060	-0.982	.35
RNI72	2.227	-0.285	-1.132	-0.047	-0.990	.45
RNI60	1.670	-0.232	-0.805	-0.026	-0.741	.64
	RNI60[3]	DIM60	MLK60	AFF	DPL60	R^2
RNI84	1.316	0.046	0.004	-1.298	-1.901	.52
RNI72	1.139	0.043	0.005	-1.054	-1.387	.71
	RNI72[4]	DIM72	MLK72	AFF	DPL72	R^2
RNI84	1.085	0.070	0.004	-1.078	-1.455	.58

[1] RNI1 = first lactation RNI, DIM1 = days in milk (DIM) first lactation, AFF = age at first freshening (days). 1,376,712 cows were used in development of models.

[2] RNI48 = 48 month opportunity total RNI, DIM48 = 48 month opportunity DIM, DDRY48 = 48 month opportunity total days dry (DDRY), MEMLK48 = 48 month opportunity total for mature-equivalent milk (pounds). 1,037,006 cows were used in development of models.

[3] MLK60 = 60 month opportunity total for actual milk (pounds), DPL60 = 60 month opportunity total for days of productive life (DPL). 734,376 cows were used in development of models.

[4] 492,765 cows were used in development of models.

(RNI84) was highest when using 72 month opportunity information (R^2=.58) and was lowest when using first lactation information (R^2=.21). Prediction of RNI72 from 60 months (.71) and prediction of RNI60 from 48 months (.64) gave higher within-herd coefficient of determination than prediction of RNI84 from 72 months. Either current lifetime totals for cows still alive at 72 months do not provide an accurate description of the current state of the cow or the remaining variation in future returns of such cows is more controlled by chance than at earlier ages.

Corresponding information from predicting DPL for various opportunity lengths are in Table 4. Variables used in prediction were current lifetime total for DPL, the months fresh in current lactation (FRESH), AFF, the months dry in current lactation (CMDRY) and the binary indicator for lactation status (DRY), with 1 denoting that the cow is dry or milking past 305 days. Predictors were similar to those used by VanRaden and Klaaskate (74) in predicting MIM84. Many of the same trends of RNI were observed in prediction of DPL, but accuracy of prediction was much lower for DPL.

Development of prediction models was needed to utilize cows with shorter opportunity lengths that are still alive; prediction is not needed for those cows that are considered dead. Projected herd-year averages for RNI and DPL for the

Table 4. Multiple regression coefficients of prediction and coefficient of determination (R^2) within herd-year of first calving for prediction of 60, 72 and 84 month opportunity totals for Days of Productive Life (DPL) using variables available from cows with 84 months of herdlife opportunity and still alive at 36, 48, 60 or 72 months of age.

Dependent Variable	Independent Variables					
	DIM1[1]	FRESH36	AFF	CMDRY36	DRY36	R^2
DPL84	4.704	-8.66	-0.890	13.77	8.0	.08
DPL72	4.158	-7.67	-0.885	14.32	1.0	.10
DPL60	3.311	-6.84	-0.868	14.35	-18.8	.14
	DPL48[2]	FRESH48	AFF	CMDRY48	DRY48	R^2
DPL84	4.541	121.48	3.517	132.30	1313.0	.13
DPL72	3.662	97.30	2.652	108.14	1039.3	.18
DPL60	2.340	58.24	1.366	69.11	599.7	.25
	DPL60[3]	FRESH60	AFF	CMDRY60	DRY60	R^2
DPL84	3.410	88.75	2.415	100.87	970.6	.17
DPL72	2.258	55.76	1.273	66.18	584.7	.24
	DPL72[4]	FRESH72	AFF	CMDRY72	DRY72	R^2
DPL84	2.075	50.94	1.113	59.77	552.1	.22

[1] DIM1 = days in milk in first lactation, FRESH36 = months fresh in current lactation at 36 months of age (= 0 if dry), AFF = age of first freshening (days), CMDRY36 = months dry after previous lactation at 36 months (= 0 if lactating), DRY36 = lactation status (= 0 if lactating, = 1 if dry). 1,376,712 cows with 84 month herdlife opportunity and still alive at 36 months used in development of models.

[2] DPL48 = 48 month opportunity total for days of productive life (DPL). 1,037,006 cows used in development of models.

[3] 734,376 cows used in development of models.

[4] 492,765 cows used in development of model.

different herdlife opportunities using those cows with shorter herdlife opportunities combine completed and predicted values. As the opportunity length of cows increases, the percentage of cows surviving decreases.

Tables 5-8 group cows into ranges of maximum herdlife opportunity of 72-83, 60-71, 48-59, and 33-47 months, respectively. These tables contain averages for all opportunity lengths. Averages of RNI and DPL totals for opportunity lengths longer than the maximum of the group contain both predicted values for cows still alive and completed values of cows classified as dead.

The standard deviations of RNI and DPL values increased as maximum opportunity length increased across the groups. The average weight given to records also increased with maximum opportunity length because of the higher accuracy of prediction and the greater percentage of cows classified as dead. However, in all but one case, the mean predicted value decreased as opportunity length increased.

As a result, cows in the 48-59 month opportunity group (Table 7) were predicted to have $203 more profit and 66 more DPL than cows in the 72-83 month opportunity group (Table 5) by the end of 84 months opportunity. Both the predicted and actual averages for RNI and DPL exceeded the actual averages of cows with longer opportunity lengths in all cases. Average year of first freshening increased with

Table 5. Characterization of 315,823 cows with between **72** and **83** months of herdlife opportunity length, including the distribution of predicted and actual totals of Relative Net Income (RNI) and Days of Productive Life (DPL), for different herdlife opportunity lengths.

Variable	Mean	SD	Minimum	Maximum
Opportunity length	77.6	3.4	72	83
Year of first freshening	87.3	1.2	81	89
Predicted RNI84	1114	1447	-1354	7999
Weight for RNI84[1]	.95	.06	.87	1.00
Predicted DPL84[2]	930	613	15	2013
Weight for DPL84	.80	.26	.47	1.00
RNI72[3]	872	1189	-1354	6909
DPL72	806	478	15	1861
RNI60	667	949	-1354	5638
DPL60	708	376	15	1556
RNI48	323	633	-1282	4478
DPL48	538	243	15	1185

[1] Weight given to the records in calculating the herd-year means for RNI and DPL and deviating the herd-year means from the overall herd means. RNI and DPL totals predicted for cows still alive were weighted by square root of R^2 given in Tables 3 and 4, respectively. Totals for cows classified as dead were given a weight of 1 and are included in this table.

[2] Predicted DPL84 total was required to be equal to or greater than the actual 72 month total for DPL.

[3] Totals for 72 months or less are actual totals because all cows had a minimum of 72 month herdlife opportunity.

Table 6. Characterization of 323,374 cows with between **60** and **71** months of herdlife opportunity length including predicted and actual opportunity totals for Relative Net Income (RNI) and Days of Productive Life (DPL) for different herdlife opportunity lengths.

Variable	Mean	SD	Minimum	Maximum
Opportunity length (months)	65.6	3.4	60	71
Year of first freshening	88.3	1.2	82	90
Predicted RNI84 ($)	1245	1425	-1433	7631
Weight for RNI84[1]	.85	.14	.72	1.00
Predicted DPL84[2] (days)	959	591	15	1858
Weight for DPL84	.68	.29	.41	1.00
Predicted RNI72	1028	1226	-1423	6711
Weight for RNI72	.91	.08	.84	1.00
Predicted DPL72	867	504	15	1679
Weight for DPL72	.72	.25	.49	1.00
RNI60[3]	666	937	-1489	5525
DPL60	685	361	15	1540
RNI48	361	655	-1247	4642
DPL48	537	246	15	1184

[1] Weight given to the records in calculating the herd-year means for RNI and DPL and deviating the herd-year means from the overall herd means. RNI and DPL totals predicted for cows still alive were weighted by square root of R^2 values given in Tables 3 and 4, respectively. Totals for cows classified as dead were given a weight of 1 and are included in this table.

[2] Predicted DPL totals were required to be equal to or greater than the actual 60 month total for DPL.

[3] Totals for 60 months or less are actual totals because all cows had a minimum of 60 month herdlife opportunity.

Table 7. Characterization of 329,640 cows with between **48** and **59** months of herdlife opportunity length including the distribution of predicted and actual totals of Relative Net Income (RNI) and Days of Productive Life (DPL) for different herdlife opportunity lengths.

Variable	Mean	SD	Minimum	Maximum
Opportunity length (months)	53.7	3.35	48	59
Year of first freshening	89.3	1.13	83	91
Predicted RNI84 ($)	1317	1231	-2439	8048
Weight for RNI84[1]	.69	.18	.59	1.00
Predicted DPL84[2] (days)	996	494	15	1695
Weight for DPL84	.52	.28	.36	1.00
Predicted RNI72	1124	1095	-2119	7195
Weight for RNI72	.75	.14	.67	1.00
Predicted DPL72	911	437	15	1551
Weight for DPL72	.56	.26	.41	1.00
Predicted RNI60	808	885	-1645	5938
Weight for RNI60	.85	.09	.80	1.00
Predicted DPL60	768	344	15	1337
Weight forDPL60	.62	.22	.50	1.00
RNI48[3]	361	640	-1333	4491
DPL48	517	231	15	1176

[1] Weight given to the records in calculating the herd-year means for RNI and DPL and deviating the herd-year means from the overall herd means. RNI and DPL totals predicted for cows still alive were weighted by square root of R^2 values given in Tables 3 and 4, respectively. Totals for cows classified as dead were given a weight of 1 and are included in this table.

[2] Predicted DPL totals were required to be equal to or greater than the actual 48 month total for DPL.

[3] Totals for 48 months are actual totals because all cows had a minimum of 48 month herdlife opportunity.

Table 8. Characterization of 406,791 cows with between **33** and **47** months of herdlife opportunity length including the distribution of predicted and actual totals of Relative Net Income (RNI) and Days of Productive Life (DPL) for different herdlife opportunity lengths.

Variable	Mean	SD	Minimum	Maximum
Opportunity length (months)	40.3	4.32	33	47
Year of first freshening	90.4	1.1	84	92
Predicted RNI84 ($)	1314	973	-1719	6250
Weight for RNI84[1]	.47	.09	.46	1.00
Predicted DPL84[2] (days)	911	373	15	1546
Weight for DPL84	.30	.11	.28	1.00
Predicted RNI72	1135	879	-1629	5602
Weight for RNI72	.52	.08	.51	1.00
Predicted DPL72	840	336	15	1442
Weight for DPL72	.33	.11	.31	1.00
Predicted RNI60	847	729	-1480	4569
Weight for RNI60	.60	.06	.59	1.00
Predicted DPL60	724	278	15	1263
Weight for DPL60	.40	.10	.38	1.00
RNI1[3]	-126	289	-1147	1610
DIM1	247	78	15	305

[1] Weight given to the records in calculating the herd-year means for RNI and DPL and deviating the herd-year means from the overall herd means. RNI and DPL totals predicted for cows still alive were weighted by square root of R^2 values given in Tables 3 and 4, respectively. Totals for cows classified as dead were given a weight of 1 and are included in this table.

[2] Predicted DPL totals were required to be equal to or greater than the actual days in milk for first lactation.

[3] RNI1 and DIM1 are first lactation totals for RNI and days in milk, respectively.

shorter herdlife opportunity, suggesting that positive phenotypic trends for RNI and DPL contribute to observed results.

Application of Opportunity Cost

Distribution of completed 84, 72, 60 and 48 month opportunity length totals are given in Tables 9-12. After edits, a total of 1.6 million cows with at least 84 months of herdlife opportunity remained. Cows with less than 84 months of herdlife opportunity were allowed to contribute to the analysis and are included in Tables 10-12.

The mean and standard deviation of totals for RNI increased with increasing herdlife opportunity. Increased mean RNI totals are expected with increasing opportunity length because the fixed costs of rearing are spread over more DPL. DPL, DIM, actual milk and fat, and OC also increased with increasing opportunity length. Because average RNI increased at a faster rate than average total DPL, average OCPD increased with increasing opportunity length. The standard deviation of OCPD remained fairly constant across opportunity lengths.

Use of OCPD to calculate RNIOC resulted in a profit measure that had a negative mean and a smaller standard deviation than RNI in all opportunity groups. Average RNIOC became more negative as opportunity length increased from 48 to 84 months. This indicated that average OCPD, estimated

Table 9. Distribution of 84 month opportunity totals from 1,606,419 cows with greater than or equal to **84** months of herdlife opportunity.

Variable	Mean	SD	Minimum	Maximum
# Lactations[1]	2.8	1.4	1	6
DPL84[2]	932	589	15	2288
DIM84	755	449	15	1830
MIM84	24.6	14.1	.5	58.4
MLK84	44,077	30,035	150	169,840
FAT84	1062	1096	5	6772
RNI84	931	1344	-1990	9852
OCPD84	1.01	.47	-6.96	2.81
OC84	969	816	-2135	5442
RNIOC84	-37.8	729	-2864	5543
1st lactation ME Milk	18,413	3719	2975	42,757
1st lactation ME Fat	666	132	110	1892

[1] Number of lactations includes only those records initiated before 84 months of age.

[2] DPL = days of productive life, DIM = days in milk, MIM = months in milk up to 84 months of age, MLK = total milk produced (pounds), RNI = relative net income ($), OCPD = opportunity cost per day ($/day), OC = total opportunity cost ($), RNIOC = RNI adjusted for OC ($), ME = first lactation 305d mature equivalent yield (pounds).

Table 10. Distribution of 72 month opportunity totals from 1,922,224 cows with greater than or equal to **72** months of herdlife opportunity.

Variable	Mean	SD	Minimum	Maximum
# Lactations[1]	2.5	1.2	1	5
DPL72[2]	846	490	15	1938
DIM72	694	378	15	1525
MLK72	40,324	25,223	150	146,110
FAT72	1,466	920	5	5699
RNI72	795	1146	-1817	7359
OCPD72	.95	.47	-3.28	2.80
OC72	824	674	-1903	4494
RNIOC72	-29.6	659	-2716	4821
1st lactation ME Milk	18,605	3778	2975	42,757
1st lactation ME Fat	673	134	110	2081

[1] Number of lactations includes only those records initiated before 72 months of age.

[2] DPL = days of productive life, DIM = days in milk, MIM = months in milk up to 72 months of age, MLK = total milk produced (pounds), RNI = relative net income ($), OCPD = opportunity cost per day ($/day), OC = total opportunity cost ($), RNIOC = RNI adjusted for OC ($), ME = first lactation 305d mature equivalent yield (pounds).

Table 11. Distribution of 60 month opportunity totals from 2,245,588 cows with greater than or equal to **60** months of herdlife opportunity.

Variable	Mean	SD	Minimum	Maximum
# Lactations[1]	2.2	.9	1	4
DPL60[2]	720	369	15	1565
DIM60	603	290	15	1220
MIM60	18.7	8.4	.5	38.3
MLK60	34,565	19,193	150	116,150
FAT60	1,257	700	5	4635
RNI60	575	893	-1586	6130
OCPD60	.80	.48	-3.23	2.59
OC60	596	501	-1905	3456
RNIOC60	-20.4	562	-2552	4101
1st lactation ME Milk	18,785	3836	297	45,731
1st lactation ME Fat	680	137	11	2081

[1] Number of lactations includes only those records initiated before 60 months of age.

[2] DPL = days of productive life, DIM = days in milk, MIM = months in milk up to 60 months of age, MLK = total milk produced (pounds), RNI = relative net income ($), OCPD = opportunity cost per day ($/day), OC = total opportunity cost ($), RNIOC = RNI adjusted for OC ($), ME = first lactation 305d mature equivalent yield (pounds).

Table 12. Distribution of 48 month opportunity totals from 2,575,210 cows with greater than or equal to **48** months of herdlife opportunity.

Variable	Mean	SD	Minimum	Maximum
No. Lactations[1]	1.7	.5	1	3
DPL48[2]	540	237	15	1210
DIM48	472	190	15	915
MIM48	13.9	5.3	.5	28.4
MLK48	26,298	12,470	150	89,490
FAT48	957	455	5	3386
RNI48	259	606	-1556	4642
OCPD48	.46	.51	-3.55	2.39
OC48	263	323	-1764	2374
RNIOC48	-4.1	441	-1656	3403
1st lactation ME Milk	18,969	3900	2975	47,981
1st lactation ME Fat	686	140	110	2081

[1] Number of lactations includes only those records initiated before 48 months of age.

[2] DPL = days of productive life, DIM = days in milk, MIM = months in milk up to 48 months of age, MLK = total milk produced (pounds), RNI = relative net income ($), OCPD = opportunity cost per day ($/day), OC = total opportunity cost ($), RNIOC = RNI adjusted for OC ($), ME = first lactation 305d mature equivalent yield (pounds).

with cows born more recently and with shorter opportunity lengths, increased faster than the average profit per day produced by those cows with longer opportunity lengths.

If phenotypic trends exist for RNI, the later lactation returns of a cow should be adjusted to reflect that the average replacement would be more profitable than herdmates from the herd-year of first freshening. The importance of correctly estimating the adjustment for OC becomes more important as opportunity length increases and more records are included.

Phenotypic trends by year of first calving and year of birth for first lactation ME milk and fat production, and different opportunity lengths for DPL, DIM, RNI, OCPD and RNIOC are given in Table 13. Ranges in year of birth and year of first freshening for cows with at least 48 months herdlife opportunity were 1978-88 and 1981-91, respectively; ranges of cows with 84 month herdlife opportunity were 7 years for each variable. Year of birth trends may be more important in describing changes in the population over time, but for this study year of first freshening trends have more impact on results with OC.

Trends were estimated with PROC GLM of SAS. Estimated trends for increases in production are consistent with those estimated by USDA AIPL (unpublished) and similar for year of first freshening and year of birth. Estimates for AFF were

Table 13. Phenotypic trends by year of birth and by year of first calving for first lactation mature equivalent (ME) milk and fat production, age of first freshening (AFF), and different opportunity length totals for relative net income (RNI), days of productive life (DPL), days in milk (DIM), opportunity cost (OC) of post-poned replacement per day of productive life, and RNI adjusted for OCPD (RNIOC) when opportunity cost is specific for each herd-year of freshening or when the same opportunity cost is applied to all lactations.

	Phenotypic Trend[1]			
Variable	Year of first calving		Year of birth	
	Specific OC	Same OC	Specific OC	Same OC
First lactation ME Milk (lbs)	307		318	
First lactation ME Fat (lbs)	11.2		11.6	
AFF (days)	-.7		-4.0	
DPL48 (days)	-4.4		-2.9	
DIM48 (days)	-4.3		-3.2	
RNI48 ($)	28.3		33.0	
OCPD48 ($)	.036	.040		
RNIOC48 ($)	10.9	8.1	12.9	10.1
DPL60	-8.4		-6.7	
DIM60	-7.6		-6.2	
RNI60	29.2		35.5	
OCPD60	.034	.030		
RNIOC60	10.7	13.1	13.2	15.5
DPL72	-11.8		-10.3	

DIM72	-10.4		-8.9	
RNI72	26.7		34.4	
OCPD72	.030	.024		
RNIOC72	11.3	16.3	14.2	19.2
DPL84	-14.8		-13.3	
DIM84	-12.5		-11.0	
RNI84	21.6		31.1	
OCPD84	.028	.020		
RNIOC84	9.4	17.2	13.0	20.7

[1] 2,575,210 cows with greater than or equal to 48 months herdlife opportunity used in estimation of trends for first lactation production, AFF and 48 month opportunity totals. For 60, 72 and 84 month opportunity totals, 2,245,588, 1,922,224 and 1,606,419 cows were used, respectively.

quite different for year of first freshening and year of birth, but both estimates indicated that AFF decreased over time. Differences reflect that placing edits on maximum age at first calving (36 months), year of first freshening (>=81), but not on year of birth may have selected cows with late AFF in early years of the data.

Estimated trends for phenotypic DPL and DIM were negative for all opportunity lengths. These estimates appear to be in conflict with results in Tables 5-8 that predicted cows with more recent birth years would have increased DPL. Estimates by VanRaden and Wiggans (71) show that, although genetic trend for MIM84 is positive, increased culling standards and shrinking cow numbers cause phenotypic trend for herdlife to be negative. Therefore, cows born in later years of the data have increased ability to survive, but actually have shorter DPL.

Phenotypic trends in RNI and OCPD were positive and largest for the shorter opportunity lengths. Average OCPD was higher when specific to each herd-year of first freshening than when the first lactation OCPD was used throughout the life of the cow for 60, 72 and 84 month opportunity lengths. Trend for 48 month OCPD was higher when first lactation OC was used throughout the life of the cow, which may indicate problems in estimating an OC for later lactations for these cows. Estimation of OC for second or third lactations of cows with 48 months herdlife would be based on cows with 36 month opportunity length. These predictions are less accurate than with longer opportunity lengths, and herd-year means are regressed more towards the overall herd mean. Because cows with a maximum of 48 months of opportunity length are from more recent birth years, OC from the herd-year of first freshening would be expected to be much higher than the overall herd OC.

The actual differences among the cows with different maximum opportunity length are much larger than those shown in Tables 9-12, since all cows in Table 9 (the largest group) are also included in Table 12. Averages for first lactation ME milk, year of first calving and different opportunity length values are given separately for cows of the different maximum opportunity lengths in Table 14. Several of the trends shown in Table 13 are reflected in the differences between maximum opportunity length groups. As maximum opportunity length decreases, year of first freshening, first lactation ME milk and profitability all increased. Cows between 48 and 59 months total opportunity averaged 1809 lbs higher for ME milk, $157 higher for RNI48, $53 higher OC48, and first calved an average of 5.2 years later than cows with at least 84 months opportunity.

Averages for total OC and RNIOC when OC is estimated specific to each herd-year of freshening and when OC from

Table 14. Averages of first lactation mature equivalent milk (MEMLK1), year of first freshening (YFF), relative net income (RNI), total opportunity cost of post-poned replacement estimated specific to each herd-year of freshening (OC), total opportunity cost when first lactation OC is applied to all lactations (OC*), and RNI adjusted for OC and for OC* for groups of cows with different ranges of maximum opportunity length.

	Range of Maximum Opportunity Length			
Variable	48-59	60-71	72-83	>=84
MEMLK1	20,222	19,854	19,578	18,413
YFF	89.3	88.3	87.3	84.1
RNI48	361	361	323	204
OC48	289	319	315	236
OC48*	318	334	310	229
RNIOC48	72	42	8	-31
RNIOC48*	43	26	14	-24
RNI60	--	666	667	539
OC60	--	640	642	577
OC60*	--	608	630	564
RNIOC60	--	26	25	-39
RNIOC60*	--	57	37	-26
RNI72	--	--	872	780
OC72	--	--	855	818
OC72*	--	--	807	798
RNIOC72	--	--	17	-38
RNIOC72*	--	--	64	-18
RNI84	--	--	--	931
OC84	--	--	--	969
OC84*	--	--	--	934
RNIOC84	--	--	--	-38
RNIOC84*	--	--	--	-3

year of first freshening is applied to all lactations are given in Table 14 for the groups of cows with different maximum opportunity length. Comparing the total OC for 60, 72 and 84 months between methods, it is evident that applying a separate OC to each lactation increased total OC for all cows. Total OC was higher for cows with shorter maximum opportunity lengths. Estimating OC specific to the herd-year of each freshening increased the differences between the opportunity length groups for total OC.

As previously mentioned, total opportunity cost for cows with between 48-59 months opportunity may be underestimated. Use of a function to smooth estimates of OCPD across years for such cows may be a possible solution.

Conclusions

Relative net income totals for 84, 72 and 60 month herdlife opportunity totals can be predicted with information available from cows alive at earlier ages with moderate accuracy. Predictions of RNI reflected phenotypic trends of increased RNI over time. Predictions of DPL for the same opportunity lengths were less accurate and predictions are over-estimated because of a negative environmental trend for DPL over time.

Phenotypic trends for increased RNI result in increased OC and OCPD over time. Application of OC from herd-year of first freshening to all lactations over-values the estimated RNI from later lactations of cows with longer herdlife opportunity. Use of predicted RNI and DPL totals for cows with shorter opportunity lengths allows for estimation of OC for each herd-year of freshening, and increases average OC and OCPD.

Due to trends in RNI, OC specific to each herd-year of freshening seems justified for longer opportunity lengths. Such a procedure more accurately expresses a cow's value within a herd when genetic merit of her potential replacement improves across her lifetime. Assignment of correct economic weights to component traits of RNIOC depends on proper estimates of net income.

Appendix

The net percentage of total product value produced is based on the value of the milk produced, the percentage of milk produced that is actually sold and the feed cost for each pound of milk produced (net margin feed cost). The value of $12/cwt for 3.5% milk was taken from Smith (59), but the fat differential was lowered to $.08 to reflect recent changes in milk component pricing. A 3% discarded milk loss (97% milk sold) was also taken from Smith (59).

The first step in calculating the net margin for feed cost is to split the total feed cost into two parts: that used for production and that used for maintenance and gain. This division was made using the values of an example ration from the Nutrient Requirements of Dairy Cattle (44). The ration was balanced to meet the both the energy and protein requirements for the production and maintenance and gain of a 1543 lb cow producing 77 lbs of 3.5% fat corrected milk/day.

The $3.33/day total cost of the ration was divided into the cost for production and for maintenance and gain based on both the energy (Mcal) and protein (gram) requirements. The percentage of the total cost due to milk production was estimated to be 85.5 based on the energy requirements but only 68.2 based on protein requirements. The average of the two values (76.85%) was used to calculate a $2.56 cost/day for production and a $.77 cost a day for maintenance and gain.

The marginal feed cost is given by dividing the cost of production by total pounds of milk and is equal to $0.0335/lb in this example. The net margin percent profit after feed cost is 1 - (0.0335/.12) or 72%, where .12 is the value of 1 lb of 3.5% milk. Including the 3% discarded milk loss and a $.08 fat differential, total returns after variable feed costs are estimated as ($0.092 * (lbs of milk) + (.80 * lbs of fat)) * .97 * .72.

Chapter 3

Multiple Trait Prediction of Transmitting Abilities for Herdlife and Estimation of Economic Weights Using Relative Net Income Adjusted for Opportunity Cost

Abstract

Genetic and phenotypic (co)variances among linear type traits, final score, months in milk to 84 months (MIM84), 84 month herdlife opportunity relative net income (RNI84), relative net income adjusted for opportunity cost of postponed replacement (RNIOC84) and first lactation milk and fat yields were estimated with a multiple trait sire model. Data were classification records and 84 month herdlife opportunity production information for 433,116 cows in the herds participating in the Holstein Association classification program. Production information from all cows in classified herds indicated that classified cows are not a random sample of cows in those herds.

Heritability of RNIOC84 (.17) was higher than RNI84 (.12), but the genetic correlation between the traits was high (.97). RNIOC84 also had high genetic correlations with first lactation milk yield (.80), fat yield (.60) and dairy form (.48). Heritability of MIM84 was .06. The genetic correlation between MIM84 and RNI84 (.84) was higher than between MIM84 and RNIOC84 (.70). MIM84 predicted from 36 months had low heritability (.02), but fairly high genetic correlations with MIM84 (.74) and RNIOC84 (.70). Genetic correlations of MIM84 to the yield and linear type traits were less than .31 in absolute value.

Evaluation of net merit using economic weights developed with RNIOC84 for traits available relatively early in life was more accurate than indirect prediction of MIM84. Approximate reliability of a first crop AI sire evaluation for net merit is .65 compared to .42 for MIM84. Although MIM84 is an important component of net merit, production traits dominate net merit evaluations.

Introduction

A goal of selection efforts in many livestock species is to increase genetic merit for lifetime net merit. Selection may be done either directly or indirectly with correlated traits. Direct selection for net merit in dairy cattle has been shown to be the more efficient method (42,61). However, indirect selection is usually the method favored because evaluation can be done with traits measured earlier in life and a variety of indexes can easily be formed for different economic conditions.

Production and herdlife are the two traits generally regarded as being most important to overall net merit (3,17,29,49,66), but only production is evaluated nationally. National evaluations of herdlife have not been performed, because it has low heritability, is measured late in life and may not be accurately described with linear models (74). Lack of an accurate method to evaluate herdlife may be the major impediment to evaluation of lifetime net merit.

Multiple trait BLUP analyses are useful for evaluation of lifetime traits such as herdlife because accuracy and timeliness of evaluations can be improved by considering the genetic and phenotypic relationships among the lifetime measure and traits with higher heritabilities that can be measured earlier in life (57).

Multiple trait evaluation for large populations are currently feasible only through the use of transformation algorithms such as the canonical transformation (40). A multiple trait evaluation can be performed with separate single trait evaluations with this method (40). However, the canonical transformation requires identical incidence matrices for all traits, which does not allow the evaluation of a lifetime trait for younger animals (10).

As an approximation to multiple trait evaluations, Boldman et al. (10) developed weights to predict sire transmitting abilities for herdlife from multiple trait PTA's for linear type traits. Data containing grade cows with both herdlife and the linear type scores were used to estimate the matrix $\mathbf{G}_{t+1}$, the genetic (co)variances among the t linear traits and herdlife. Sire effects for those sires without herdlife information are predicted as:

$$
\begin{aligned}
\hat{s}_n &= Cov(s_n,s)' \, [Var(s)]^{-1}\hat{s} \\
&= (g_{tn} \otimes A)' \, (G^{-1}A^{-1})\hat{s} \qquad [1] \\
&= [(g_{tn}G^{-1})] \otimes I_q \, \hat{s} \\
&= (w_t \otimes I_q) \, \hat{s}
\end{aligned}
$$

where

$\hat{s}_n$	is the qx1 vector of predicted sire effects for herdlife
g_{tn}	is the tx1 vector of sire covariances between herdlife and the t linear traits
A	is the numerator relationship matrix among sires
G^{-1}	is the inverse of the txt matrix of additive genetic (co)variances among the t linear traits
$\hat{s}$	is the tqx1 vector of predicted sire effects for each of the t linear traits
I_q	is the identity matrix of size q = the number of sires
w_t	is a tx1 vector of weights for predicting the herdlife sire effect from the set of effects of the same sire on each of the t linear traits

which is equivalent to the solution from the multiple trait MME for sires with no herdlife data.

The vector of weights works for all sires without herdlife information, regardless of the amount of information from progeny or **A**, since this has been accounted for already in the MME when calculating $\hat{\mathbf{s}}$. The reliability of indirect prediction was approximated with the matrix

$$\hat{C} = \left[\begin{bmatrix} (R^{-1} I_t \, x \, p) & 0 \\ 0 & 0 \end{bmatrix} + G_{t+1}^{-1} \right] \qquad [2]$$

where:

$\hat{\mathbf{c}}$ is a (t+1)x(t+1) matrix with approximate effective progeny numbers for each trait on the diagonal

$\mathbf{I}_t$ **is an identity matrix of size t**

p is the effective progeny number for the sire

The approximate reliability of indirect prediction is solved for as

$$\hat{r}^2_{s\hat{s}} = 1 - \hat{c}_{(t+1),(t+1)} / \hat{g}_{(t+1),(t+1)}$$

where:

$\hat{c}_{(t+1),(t+1)}$ is the diagonal element of $\hat{\mathbf{c}}$ pertaining to herdlife

$\hat{g}_{(t+1),(t+1)}$ is the estimated sire variance for herdlife.

The maximum accuracy of indirect prediction is approximated as $(\mathbf{w}_t' * \mathbf{w}_t) / \hat{g}_{(t+1),(t+1)}$. One drawback of this method of indirect prediction is that ancestral and early daughter information for the trait of analysis (herdlife) is not included in the prediction of sire effects.

Van Raden and Klaaskate (74) have proposed total months in milk to 84 months of age (MIM84) as a measure of herdlife. Cows are credited with a maximum of 10 months of milk for each lactation up to 84 months of age. The resulting trait is more normally distributed than previous definitions of herdlife, and, therefore, more accurately evaluated with a linear model. MIM84 records are projected for live cows younger than 7 years of age to utilize cows with more recent birth years (74).

The heritability of MIM84 was estimated to be .085 for completed records, with projected records being more bimodally distributed, less heritable and less variable (74). Expansion factors were developed to equalize genetic variance of projected records with that of completed records with the same method as used for yield traits (74). Once expanded, projected records are given less weight in evaluations than completed records.

Use of completed and projected MIM84 records in a multiple trait evaluation would result in unequal incidence matrices for bulls with daughters less than 84 months old and thereby preclude the use of canonical transformation. Alternatively, the method of Boldman et al. (10) could be expanded to include projected 36 month MIM84 records with the linear type traits for indirect prediction of MIM84.

Inclusion of herdlife into a net merit index requires calculation of the proper economic weight. There are several methods to calculate the weights given to traits in selecting for overall profit including simulation (66), dynamic programming (49) and use of profit data (31,18,46). Profit is not measured directly but can be estimated with functions of DHIA variables. One such function is relative net income (RNI) (46,5,62).

Failure to adjust profit from field data for the opportunity cost of postponed replacement (OC) has been shown to over-estimate the weight given to herdlife in calculation of the net merit index (66). Also important to studies of profitability is that sufficient herdlife opportunity be given for expression of lifetime differences (43).

Chapter 1 characterized the profit function RNI adjusted for OC with an 84 month opportunity length (RNIOC84). If RNIOC84 is used as the trait of analysis instead of herdlife in the method of Boldman et al. (10), the resulting weights for indirect prediction are the economic weights for each of the traits in the selection index for profit in the population studied.

Research by Short and Lawlor (58) indicates that estimates of genetic correlations between type traits and herdlife are different for registered and grade populations. Genetic correlations between herdlife and body traits were strongly negative in grade cattle, while the genetic relationship of the udder traits and herdlife was not as strong (58). Boldman et al. (10) found similar relationships in grade cattle as Short and Lawlor (58), except that the genetic correlations between udder depth, fore udder attachment and herdlife were much higher.

The objectives of this research were to 1) estimate the variances and covariances among RNIOC84, MIM84, MIM84 projected from 36 months (PMIM84), the type traits, and milk and fat yield in a population of grade and registered Holsteins 2) to investigate the use of type traits and PMIM84 in a multiple trait index to predict MIM84, and 3) to derive economic weights to evaluate net merit using the type traits, milk and fat yields and either MIM84 or PMIM84.

Materials and Methods

Data for this study came from two sources. The original data set from the Holstein-Friesian Association of America (HFAA) contained age adjusted scores (score nearest 30 months) and PTA's for final score and the 14 linear traits. Data included the 1.5 million registered and grade cows scored on the linear scale from 1983 to 1990. The second data set, provided by the Animal Improvement Programs Laboratory (AIPL) of the USDA, contained DHI production information from the 18,433 herds represented in the HFAA data set. All records for the 4.6 million registered and grade cows, which first calved in these herds between January 1981 and July of 1992, were included.

A complete description of the data including edits on cows and herds is given in Chapter 2. After edits, 2,982,001 cows with at least 33 months of herdlife opportunity remained in the production data set. Estimated profit was calculated with the RNI function. RNI estimates profit by accounting for the total net values of the milk, fat, and calves produced and the total rearing, feed, labor, fixed and variable costs (Chapter 2).

The opportunity cost of postponed replacement (OC) for each herd-year was calculated using a weighted average of projected and actual RNI and days of productive life (DPL) totals of heifers freshening for the first time in that herd-year. RNI adjusted for OC (RNIOC) was then calculated as:

$$RNIOC_{hi..} = RNI_{hi..} - \sum_{j=1}^{n} [(DIM_j + DDRY_j) * OCPD_{hk})]$$

where DIM is the total days in milk for the j^th^ lactation, DDRY is the total days dry preceding the j^th^ lactation for the i^th^ cow in the h^th^ herd, and OCPD is the OC per day for the k^th^ year within herd h.

Months in milk (MIM) was calculated with the method of VanRaden and Klaaskate (74). MIM totals were calculated for 36 and 84 months of age by summing the months in milk (with a maximum of 10.2 months per lactation) up to the target dates. Projection factors were calculated for cows alive at 36 months using the same variables and method as VanRaden and Klaaskate (74).

Production and type data files were merged to obtain 568,667 cows with both classification scores and 84 month opportunity length. An additional 9,908 (1.7%) cows were removed from the data because of non-matching sire codes from the two data sources. Additional edits required sires to have at least 30 daughters in 15 herds. Daughters of sires born prior to 1960 were also removed from the data, leaving 433,116 daughters of 995 sires in 52,787 herd-years of first freshening.

REML estimates of the genetic and residual variances and covariances among the traits were estimated with a multiple trait sire model as described by Van Raden et al. (70). Fixed effects of herd-year of first freshening were absorbed. An additional 113 sires were added to provide relationship ties among sires.

Traits included in the analysis were RNIOC84, MIM84, first lactation 305d-2X-ME milk and fat yields, age adjusted scores nearest 30 months for the 14 linear type traits and final score, and PMIM84. To reduce computing costs, submatrices of the original 22 X 22 matrix were used to form all of the different combinations of traits for indirect prediction. Accuracy of prediction for different combinations of traits was approximated using the $\hat{\mathbf{C}}$ matrix as described by Boldman et al. (10).

Results and Discussion

Means of first lactation ME milk and fat yields, DPL84, MIM84, RNI84 and RNIOC84 for the 1,606,419 cows with 84 month herdlife opportunity in classified herds are in Table 15. Also in Table 15 are the means for the cows in these herds that had classification scores. Comparison of these means may give an indication of whether cows that are classified are a random sample of the population or a selected group.

Because the classified cows are also included in the first group, differences in the means are 1-(558,759/1,606,419), or roughly two-thirds that of the differences between classified and unclassified cows in the same herds. Adjusting for this factor, classified cows in this data set had an average of 1283 pounds higher first lactation ME milk, 45 pounds higher first lactation ME fat, 247 days longer productive lives, 6 months longer MIM84, generated an estimated $557 more total income and $236 more income above OC over 84 month herdlife opportunity length

Table 15. Means of first lactation mature-equivalent (ME) milk and fat production, type scores and 84 month herdlife opportunity totals for 1,606,419 cows in classified herds, the 558,759 cows in those herds with classification scores, and the subset of 433,116 classified cows used in estimation of (co)variances.

Variable	Group		
	All	Classified	Used for estimation
DPL84[1]	932	1093	1103
MIM84	24.6	28.5	28.7
RNI84 ($)	931	1294	1345
RNIOC84 ($)	-37.8	116	142
1st lactation ME milk (lbs)	18,413	19,250	19,406
1st lactation ME fat (lbs)	666	695	701
Stature		30.3	30.6
Strength		28.7	28.9
Body depth		30.7	30.9
Dairy form		29.6	29.8
Rump angle		25.2	25.2
Thurl width		27.2	27.3
Rear leg set		27.4	27.3
Foot angle		23.9	24.0
Fore attachment		24.2	24.3
Rear udder hgt		25.8	26.0
Read udder width		25.4	25.6
Udder cleft		26.6	26.7
Udder depth		23.2	23.2
Teat placement		24.2	24.4
Final score		80.6	80.8

[1] See Table 7 for abbreviations.

than their herdmates that did not have classification scores. The standard deviations of the two groups (Table 16) indicated that the classified cows was less variable for length of productive life, MIM84, first lactation ME yields but more variable for total profit, both adjusted and unadjusted for OC. These differences indicate that cows classified by the HFAA are not a random sample of the population.

Requiring sire to have a minimum of 30 daughters in 15 herds and to be born after 1960 reduced the data set of cows with 84 month opportunity and classification scores by 22%. Means and standard deviations of the cows used for estimation of (co)variances are also given in Tables 15 and 16. Because cows used in estimation are a subset of all classified cows, differences in the means of the two groups are only 22% of the difference between cows included in the estimation of (co)variances and those that were not.

Cows that were included in the estimation of (co)variances averaged 694 pounds higher for first lactation ME milk, 27 pounds higher for first lactation ME fat, had 44 more days of productive life, .9 more MIM84, generated $227 more total profit and $116 more profit adjusted for OC. Cows used in estimation were an average of .9 points higher for the majority of the linear traits and final score. There were no differences between the two groups for mean

Table 16. Standard deviations of first lactation mature-equivalent (ME) milk and fat production and 84 month herdlife opportunity totals for 1,606,419 cows in classified herds, the 558,759 cows in those herds with classification scores, and the subset of 433,116 classified cows used in estimation of (co)variances.

Variable	Group		
	All	Classified	Used for estimation
DPL84[1]	589	552	554
MIM84	14.1	13.0	13.0
RNI84 ($)	1344	1352	1365
RNIOC84 ($)	729	766	774
1st lactation ME milk (lbs)	3719	3482	3465
1st lactation ME fat (lbs)	132	127	126
Stature		8.2	8.2
Strength		7.4	7.4
Body depth		7.5	7.5
Dairy form		7.5	7.5
Rump angle		5.3	5.3
Thurl width		7.0	7.0
Rear leg set		6.9	6.9
Foot angle		6.6	6.6
Fore attachment		7.0	7.1
Rear udder height		7.3	7.3
Read udder width		7.4	7.4
Udder cleft		5.8	5.8
Udder depth		4.9	4.9
Teat placement		6.2	6.2
Final score		3.8	3.8

[1] See Table 7 for abbreviations.

udder depth or rump angle, or for the standard deviations of the type traits.

These results suggest that the sires removed by edits before estimation of (co)variances were not a random sample of the population. The combination of requiring cows to be classified and be sired by a well sampled AI bull results in a selected group of cows. Estimates of the (co)variances among traits may be affected by this selection.

Regression coefficients for the variables used in prediction of MIM84 from cows alive at 36 months of age from this study and from Van Raden and Klaaskate (74) are in Table 17. Coefficients are similar, except for the coefficient for age at first calving which was larger in this study. The within-herd squared correlation coefficient (R^2) of .04 from this study was lower than that of .05 of VanRaden and Klaaskate (74). The average of completed and projected MIM84 at 36 months (PMIM84) in Table 14 was 3 months longer than that of VanRaden and Klaaskate (74), but the standard deviation was 1.9 months smaller.

The sire model REML estimates of the heritabilities of all traits and the genetic and phenotypic correlations to RNIOC84 and MIM84 are in Table 18. Heritability estimates for the linear traits and ME milk were similar to those estimated by Short and Lawlor (58) for the combined

Table 17. Regression coefficients and within herd-year of first calving squared correlation (R^2) of prediction of months in milk at 84 months (MIM84) from variables available for cows alive at 36 months of age.

	Regression coefficient for					
Source	MIM36[1]	FRESH	AFF	DRY	STATUS	R^2
VanRaden and Klaaskate (74)	1.246	-.329	0.069	0.024	-.615	.05
This study[2]	1.519	-.360	0.011	0.256	-.996	.04

[1] MIM36 = total months in milk at 36 months of age, FRESH = months fresh in current lactation, AFF = age at first calving (days), DRY = months dry in current lactation, STATUS = lactation status (dry = 1 and milking = 0).

[2] All effects significant at the $\alpha = .0001$ level.

Table 18. Heritabilities, genetic and phenotypic correlations among relative net income adjusted for opportunity cost (RNIOC84), days of productive life (DPL84), months in milk (MIM84), first lactation mature equivalent milk (MEMLK1) and fat (MEFAT1), and age adjusted linear type and final scores estimated from 433,116 daughters of 781 sires with multi-trait restricted (residual) maximum likelihood (REML).

		RNIOC84		MIM84	
Variable	h^2	Gen.	Phen.	Gen.	Phen.
RNIOC84	.17	--	--	.70	.72
MIM84	.06	.70	.72	--	--
RNI84	.12	.97	.92	.84	.89
DPL84	.06	.74	.69	.99	.97
PMIM84	.02	.70	.26	.74	.45
MEMLK1	.34	.80	.51	.29	.20
MEFAT1	.32	.60	.42	.28	.17
Stature	.34	-.05	.04	.04	.04
Strength	.23	-.16	.01	-.12	.02
Body depth	.28	-.10	.05	-.12	.03
Dairy form	.24	.48	.20	.27	.10
Rump angle	.30	.07	.01	.04	-.01
Thurl Width	.22	-.04	.03	.00	.03
Legs side view	.16	.05	-.00	-.01	-.02
Foot angle	.10	-.07	.03	.08	.05
Fore udder att.	.20	-.14	.02	.30	.10
Rear udder hgt.	.18	.10	.12	.31	.12
Read udder width	.16	.11	.14	.29	.12
Udder cleft	.15	-.06	.06	.16	.10
Udder depth	.26	-.20	-.07	.31	.05
Teat placement	.22	-.12	.04	.14	.08
Final score	.25	.04	.17	.32	.18

population of registered and grade Holsteins.

The estimated heritability of .06 for MIM84 in this study (Table 18) was similar to the estimate for true herd life of Short and Lawlor (58), but lower than that reported by Van Raden and Klaaskate (74) for MIM84 (.085). The heritability of PMIM84 of .02 (SE=.007) was slightly lower than the estimate of .03 reported by Van Raden and Klaaskate (74). MIM84 was highly correlated to DPL84, both genetically (.99) and phenotypically (.97).

Genetic and phenotypic correlations between the linear type traits and MIM84 were similar to those reported for true herdlife (58). The udder traits, dairy form and milk yield had the highest genetic correlations with MIM84, although the correlations for dairy form and milk yield were lower than those reported for true herdlife (58).

Adjusting net income for OC resulted in a higher heritability estimate (.17) than unadjusted net income (.12), but the phenotypic (.92) and genetic (.97) correlations of RNI84 and RNIOC84 indicate that the two traits are very closely related. Both the genetic and phenotypic correlations of RNI84 and MIM84 were higher than those of RNIOC84 and MIM84, which is consistent with Van Arendonk (66). DPL84 (.74) and PMIM84 (.70) had similar genetic correlations to RNIOC84.

The traits with the highest genetic correlation to

RNIOC84 were first lactation milk (.80) and fat yields (.60). The lower correlation to fat yield was probably due to the higher value of carrier relative to fat in calculating RNI (Chapter 2). Dairy form (.48) and udder depth (-.20) had the highest absolute genetic correlations to RNIOC84 among the linear type traits, reflecting the relationship of these traits with milk yield.

Approximate reliabilities of indirect prediction of net merit and MIM84 from different combinations of traits in relation to the effective number of progeny are presented in Figures 1 and 2, respectively. Values for the maximum reliability of prediction (infinite progeny group size) and the value for an effective progeny number of 80 are given in Table 19. An effective progeny number of 80 was used to represent the accuracy of the first crop evaluation of a well sampled AI bull.

The maximum accuracy of prediction of MIM84 from the linear type traits of .45 was lower than that of .56 reported by Boldman et al. (10) for prediction of true herdlife in grade cows. The higher heritability of MIM84 and lower correlation of MIM84 to the linear traits makes indirect prediction of herdlife less valuable in this population.

Addition of PMIM84 to the linear type traits increased the maximum reliability of indirect prediction to 72%, but

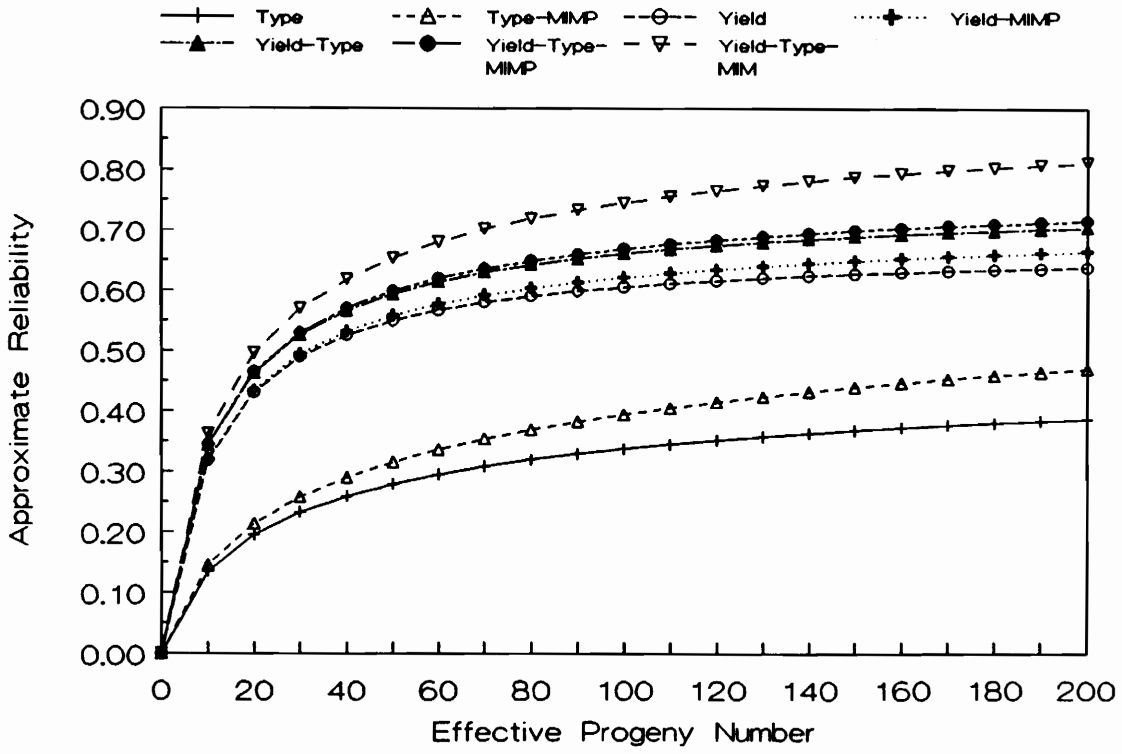

Figure 1. Plot of approximate reliablities for net merit evaluated using the linear type traits and final score (Type), months in milk predicted from 36 months of age (MIMP), first lactation mature equivalent milk and fat yields (Yield), months in milk to 84 months of age (MIM84) and combinations of these traits.

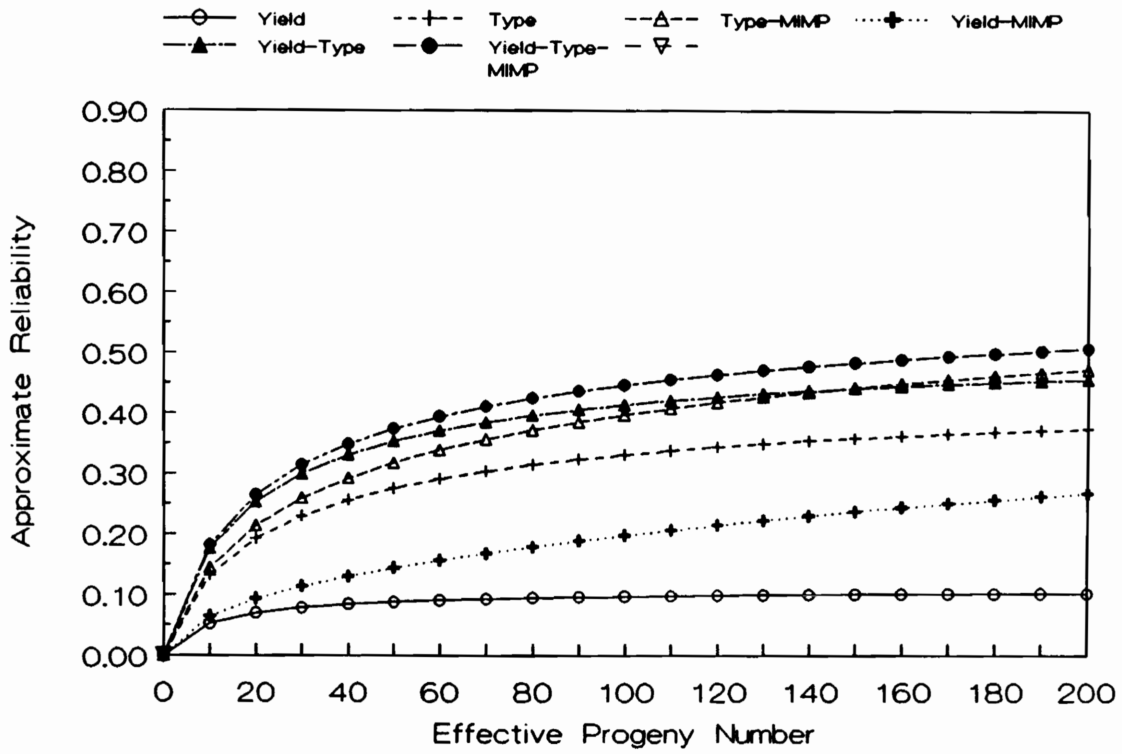

Figure 2. Plot of approximate reliablities for indirect prediction of months in milk to 84 months of age from first lactation mature equivalent milk and fat yields (Yield), the linear type traits and final score (Type), months in milk predicted from 36 months of age (MIMP) and combinations of these traits.

Table 19. Approximate reliabilities of indirect prediction of 84 month herdlife opportunity length totals for net merit and months in milk (MIM84) from combinations of first lactation mature equivalent milk and fat yields (Yield), the 14 linear type traits and final score (Type), MIM84 predicted from 36 months of age (PMIM84) variables and from MIM84 itself.

	Approximate Reliability			
	Net Merit		MIM84	
Variables	Maximum	80 EPN[1]	Maximum	80 EPN
Type	.48	.32	.45	.31
Yield	.67	.59	.10	.10
Yield-Type	.75	.64	.52	.40
Type-PMIM84	.70	.36	.72	.37
Yield-PMIM84	.75	.60	.58	.18
Yield-Type-PMIM84	.80	.65	.72	.42
Yield-MIM84	.89	.70	--	--
Yield-Type-MIM84	.91	.72	--	--

[1] Approximate reliability of indirect prediction for a sire with an effective progeny number of 80.

was less useful than first lactation mature equivalent milk and fat yields when effective progeny number is 80. Although the genetic correlation of PMIM84 to MIM84 was higher than that of the yield traits, the low heritability requires many progeny for accurate prediction. The combination of PMIM84 and both the yield and type traits (42%) gave only slightly higher reliability than that of the yield and type traits alone (40%) with an effective progeny number of 80.

Much higher reliabilities were observed for evaluation of net merit with economic weights calculated using RNIOC84. With an effective progeny number of 80, accuracy of evaluation using the yield traits alone (59%) was only slightly lower than that obtained when also including either PMIM84 (60%) or the type traits (64%) or both (65%). As progeny numbers increase, MIM84 becomes more important to accuracy.

Coefficients for prediction of MIM84 using the multiple trait transmitting abilities for the linear type traits, first lactation ME milk and fat yields and PMIM84 are in Table 20. Table 21 contains the economic weights for evaluation of net merit calculated using RNIOC84. Interpretation of coefficients and economic weights is difficult because of the correlations among traits and the differences in the genetic standard deviations.

Table 20. Coefficients for indirect prediction of months in milk to 84 months of age (**MIM84**) using multiple trait transmitting abilities for the linear type traits and final score alone (TYPE) and in combination with predicted and completed months in milk from 36 months of age (PMIM84) and first lactation mature equivalent milk and fat yields (YIELD).

Trait	TYPE	TYPE+ PMIM84	TYPE+ YIELD	TYPE+ YIELD+ PMIM84
PMIM84		3.219		3.648
1st lactation ME milk (lbs)			.0005	-.0001
1st lactation ME fat (lbs)			.0127	-.0074
Stature	-.215	.275	-.146	-.129
Strength	1.036	-.444	.414	.363
Body depth	-1.312	.030	-.852	-.456
Dairy form	.440	.055	-.032	.137
Rump angle	.212	-.062	.186	.047
Thurl Width	-.105	-.022	-.053	-.071
Legs side view	.020	-.060	.037	-.028
Foot angle	-.116	.025	-.148	-.042
Fore udder att.	.034	-.089	.019	.031
Rear udder hgt.	-.096	-.022	-.127	-.074
Read udder width	-.094	.084	-.119	-.011
Udder cleft	-.181	.364	-.097	.091
Udder depth	.060	-.227	.201	.366
Teat placement	-.282	.468	-.313	-.210
Final score	2.085	3.219	2.271	.185

Table 21. Economic weights for evaluation of **net merit** developed with 84 month opportunity length relative net income adjusted for opportunity cost of post-poned replacement using multiple trait transmitting abilities for first lactation mature equivalent milk and fat yields alone (YIELD) and in combination with the linear type traits and final score (TYPE), months in milk to 84 months of age (MIM84), and with predicted and completed MIM84 from 36 months of age (PMIM84).

Trait	YIELD	YIELD+ PMIM84	YIELD+ TYPE	YIELD+ MIM84
MIM84				50.429
PMIM84		151.253		
1st lactation ME milk (lbs)	.129	.108	.136	.111
1st lactation ME fat (lbs)	1.217	.453	1.477	.742
Stature			-4.888	
Strength			44.478	
Body depth			-63.302	
Dairy form			1.240	
Rump angle			5.936	
Thurl Width			2.090	
Legs side view			1.574	
Foot angle			-11.407	
Fore udder att.			-2.270	
Rear udder hgt.			7.142	
Read udder width			-22.422	
Udder cleft			-3.723	
Udder depth			9.675	
Teat placement			-16.570	
Final score			97.095	

Conclusions

Mean first lactation ME production and 84 month herdlife opportunity totals for MIM84, RNI84 and RNIOC84 of classified cows were much higher than that of their unclassified herdmates, indicating that classified cows are not a random sample of the herd. Requiring daughters to be sired by well sampled bulls with recent birth years may also select data. These sources of selection may affect the estimates of relationships among observed traits and the results based on those estimates. Having sire indentification codes from both DHI and HFAA may improve accuracy of estimates.

MIM84 evaluated at 36 months of age has a very low heritability. Indirect prediction of MIM84 with linear type traits using registered and grade cows was less accurate than previously reported for a population of only grade cows. Including production traits and MIM84 evaluated at 36 months of age improved approximate reliability of indirect prediction.

Adjusting for the opportunity cost of post-poned replacement lowers the value of herdlife relative to first lactation yield in 84 month herdlife opportunity length totals for net income and results in a more heritable measure of net income. Evaluation of net merit using economic weights developed with RNIOC84 can provide evaluations of AI sires using first lactation information. Accuracy of evaluations will be lower than evaluations for yield traits, but much higher than evaluations of MIM84. Although MIM84 is an important component of net merit, the production traits have higher heritability and are measured earlier in life. As a result, evaluations of net merit are dominated by the production traits until large progeny numbers with completed MIM84 are available.

Chapter 4

Prediction of 84 Month Totals for Milk Adjusted Months in Milk and Relative Net Income Adjusted for Opportunity Cost of Post-poned Replacement from Type Traits

Abstract

Data were production and classification results for 95,053 grade and 473,614 registered Holstein cows with 84 months of herdlife opportunity. Herdlife was measured by months in milk to 84 months, and was adjusted for rank of cow in herd-year of first freshening for mature-equivalent milk production using a categorical analysis with 20 levels. Net inncome was estimated by the function relative net income adjusted for the opportunity cost of postponed replacement.

Months in milk to 84 months increased at a decreasing rate with rank of cow in herd for first lactation mature-equivalent milk yield. Final score and linear type traits were age adjusted scores and PTA were used to predict 84 month herdlife opportunity totals for relative net income adjusted for opportunity cost and milk-adjusted herdlife within herd-year of first calving for both grade and registered cows.

Final score and the udder traits explained the greatest amount of variation for milk adjusted herdlife in both registered and grade cattle. Amount of variation explained for adjusted herdlife by type traits was higher in registered cows than grades, with final score explaining the greatest amount of variation in both registered (2.5%) and grade (.8%) cows.

Dairy form explained the most variation in net income of the type traits in both registered and grade cows. The other body traits explained virtually no within-herd variation for either milk adjusted herdlife or net income in registered or grade cows. Similar results were observed for prediction of milk adjusted herdlife with type trait PTA.

Although quadratic and cubic effects were statistically significant for most of the type traits, actual non-linearity of prediction within the range of the data for linear type scores and PTA was small. The exception to this was udder depth which was non-linear over the range of

phenotypes for both milk adjusted herdlife and net income.

Introduction

Much research has been devoted to studying the relationships among type traits and lifetime measures of herdlife and net income (10,11,15,18,28,51,54,58). Moderate correlations exist between several of the linear type traits and herdlife, although relationships may differ with registration status (58). Use of multiple trait procedures to evaluate herdlife with the linear type traits can be done with modest accuracy in grade cattle (10).

Prediction ability of the linear type traits may not be fully exploited with linear models. Foster et al. (28) used multiple regression techniques to study the relationships between yield, herdlife and type traits scored on a linear scale. Several of the type traits were found to have intermediate optimum scores for yield and herdlife, although herdlife opportunity was rather short for the cows studied (28).

Rogers et al. (51) found that the relationships between stayability and the linear type traits differed with registry status and became more important with the length of the herdlife measure. Sire estimated transmitting abilities for the linear type traits were more strongly related to differences in stayability in registered cows than grades and for stayability to 84 months than 54 months. The udder traits were most important regardless of registry status. Udder depth was the only trait with a significant non-linear relationship to 84 month survival, but only in registered cows (51).

de Haan et al. (18) found significant non-linear relationships between the linear trait scores and profit in 71,983 classified cows. Profit was measured by 60 month herdlife opportunity relative net income adjusted for opportunity cost (RNIOC60). Although many of the type traits had significant linear and quadratic relationships with RNIOC60 and 60-month herdlife, the amount of variation explained by the linear traits after product value was less than 2% (18). Burke and Funk (11) observed similar results for the amount of variation explained by linear type scores and PTA after fitting effects of herd and fat yield in a study of 84-month herdlife in 139,998 classified cows.

Because of voluntary culling for milk production, herdlife and production are often positively correlated (10,18,58,24). Some investigators have adjusted herdlife for milk production in an attempt to more directly measure ability to survive (10,58,24). Adjustments for milk production have used a regression approach (10,58,24), whereas a categorical analysis may allow for non-linear relationships (B.T. McDaniel, personal communication).

The objectives of this study were to investigate large populations of both registered and grade cows for non-linear relationships between the linear type traits and 84 month opportunity totals for RNIOC (RNIOC84) and months in milk to 84 months (MIM84) adjusted for milk production.

Materials and Methods

Data for this study consisted of the 568,667 cows with both 84 month herdlife opportunity and Holstein Fresian Association (HFAA) linear type scores as described in Chapter 3. Data were separated into 95,053 grade and 473,614 registered cows. Linear type traits were adjusted for age and season by the HFAA with unpublished factors routinely used for genetic evaluations. Linear type trait PTA's were also provided by the HFAA.

Months in milk to 84 months was calculated as described by VanRaden and Klaaskate (74). MIM84 was adjusted for milk production by using the rank of cow within herd-year of first calving for first lactation 305d mature-equivalent (ME) milk production (AMIM84). Adjustment factors were calculated using PROC GLM in SAS using rank of cow as a categorical trait with 20 levels with effects of herd-year of first calving absorbed. Ranks were assigned using PROC RANK of SAS. To ensure that cows did not have negative herdlife values, additive adjustment factors were set to be 0 or greater.

Lifetime profit was estimated using the profit function relative net income adjusted for opportunity cost of postponed replacement with 84 month herdlife opportunity (RNIOC84). Description of this profit function is given in Chapter 2.

Prediction equations for AMIM84 and RNIOC84 were developed using PROC GLM of SAS, with effects of herd-year of first calving absorbed. Models using linear, quadratic and cubic terms were tested, with all variables required to be significant at the .10 level. If all terms were not significant, the highest order term was deleted and a new model was tested. Because analyses were within herd-year of first freshening, intercepts for prediction equations were solved for by evaluating models at the mean value for the independent variable and subtracting the result from the mean of the dependent variable.

Results and Discussion

Analysis of adjustment of MIM84 for within herd-year of first calving rank for ME milk used the 1,606,419 cows with 84 month herdlife opportunity described in Chapter 2. Within herd R^2 using rank of cow in the categorical analysis was .12 and indicated a non-linear relationship between rank and MIM84. A plot of the least square means for MIM84 for each rank group is in Figure 3. Cows with rank of 6 or lower (bottom 30% of the cows) showed greatly reduced herdlife. MIM84 was increased slightly as rank increased above the 40th percentile of the herd.

Means and standard deviations for both grade and registered data sets are in Table 22. Registered cows had higher 84 month opportunity length totals for RNI, lower total opportunity cost (OC84) and 1 month more MIM84 than grade cows. Registered cows also had higher adjusted scores and PTA's for the linear traits and final score, especially for stature, strength, body depth, fore udder attachment, rear udder height and width. Although the phenotypic standard deviations of type traits were similar for registered and grade cows, variability in PTA was much higher in the registered population for all but one type trait. This may be the result of more accurate pedigree information or could be an indication of non-random mating

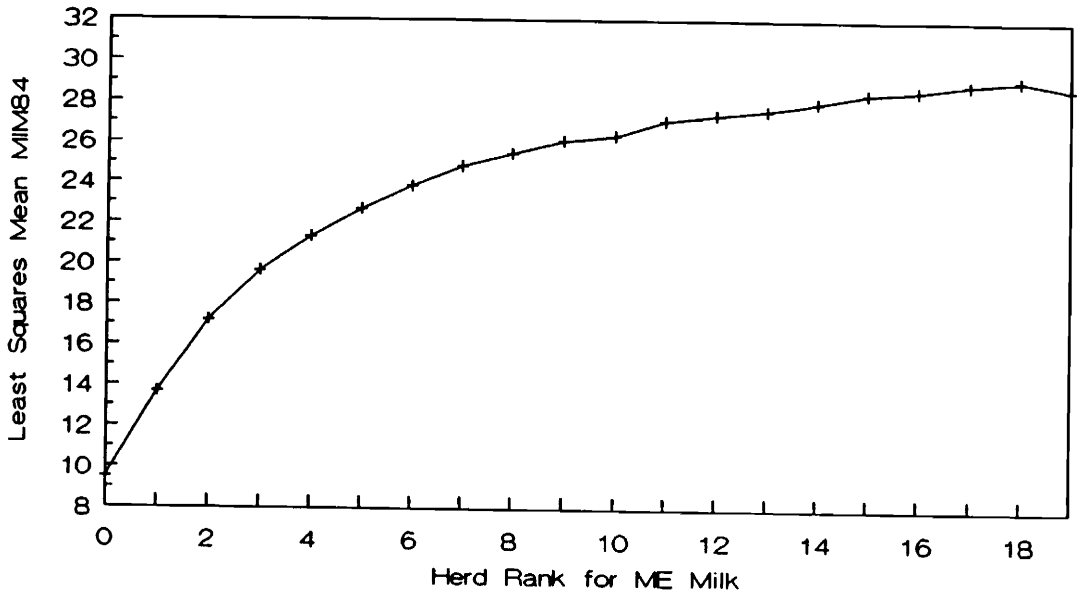

Figure 3. Plot of the least squares means for months in milk to 84 months of age (MIM84) for cows ranked into 20 levels for within herd-year of first freshening mature equivalent (ME) milk yield.

Table 22. Means and standard deviations (SD) of 84 month totals for relative net income (RNI84), total opportunity cost (OC84), RNI84 adjusted for OC84 (RNIOC84), months in milk (MIM84), MIM84 adjusted for milk production (AMIM84), 30 month age adjusted linear type scores and predicted transmitting abilities for the linear type traits for 95,053 grade cows and 473,614 registered Holstein cows.

	Grade		Registered	
Trait	Mean	SD	Mean	SD
RNI84	1255	1344	1295	1352
OC84	1180	835	1172	809
RNIOC84	75	738	122	771
MIM84	27.4	12.6	28.6	13.0
AMIM84	30.6	12.4	31.8	12.8
Stature	27.8	8.0	30.9	8.2
Strength	27.0	7.3	29.1	7.4
Body depth	29.0	7.4	31.1	7.4
Dairy form	28.9	7.7	29.7	7.4
Rump angle	25.3	5.8	25.2	5.2
Thurl width	26.2	7.0	27.5	7.0
Legs side view	27.9	7.4	27.2	6.8
Foot angle	22.9	6.9	24.1	6.5
Fore attachment	21.5	6.6	24.7	7.0
Rear udder hgt	23.6	7.4	26.2	7.3
Rear udder width	23.2	7.5	25.9	7.3
Udder cleft	25.6	6.0	26.8	5.8
Udder depth	21.7	5.2	23.5	4.8
Teat placement	22.7	6.5	24.5	6.1
Final score	78.5	3.8	81.1	3.7
PTA Stature	.28	1.39	.98	1.57
PTA Strength	.42	1.04	.80	1.14
PTA Body depth	.61	1.16	1.05	1.29
PTA Dairy form	.35	.98	.64	1.15

PTA Rump angle	.15	.89	-.03	.83
PTA Thurl width	.18	.92	.49	1.06
PTA Legs side v.	-.18	.70	-.21	.76
PTA Foot angle	-.01	.55	.21	.61
PTA Fore udder	-.62	.82	-.07	.94
PTA Udder hgt.	-.13	.80	.36	.92
PTA Udder width	-.08	.74	.36	.84
PTA Udder cleft	-.18	.61	.14	.68
PTA Udder depth	-.65	.70	-.33	.77
PTA Teat pl.	-.34	.80	.06	.89
PTA Type	-.02	.55	.46	.68

in registered cows.

Within herd-year multiple correlation coefficients (R^2) from prediction of milk adjusted MIM84 (AMIM84) for both grade and registered data sets are in Table 23, along with the number of terms (linear, quadratic and cubic) that were significant at the .10 level. None of the linear type traits explained more than 1% of the variation in AMIM84 in grade cows, although quadratic and cubic terms were statistically significant for almost all of the traits. Within-herd R^2's were much higher in the registered data set with a maximum of .025 for final score. The udder traits and final score were best predictors in both groups of cows.

Results from prediction of RNIOC84 from the linear trait scores are given in Table 24. Type traits correlated to milk production were more important in prediction of RNIOC84, although final score had the second highest R^2 in both groups of cows. Dairy form had the highest R^2 in both groups. Rank of the udder traits for predictive ability differed for AMIM84 and RNIOC84. Fore udder attachment was much less related to differences in RNIOC84 than in AMIM84 for both groups of cows, while rear udder height and width had stronger prediction ability for RNIOC84 than for AMIM84 in both groups of cows. Fewer cubic and quadratic terms were significant in prediction of RNIOC84 than of AMIM84.

Table 23. Within herd-year multiple correlation coefficient (R^2)[1] and number of significant terms[2] from prediction of milk-adjusted months in milk to 84 months of age (AMIM84) from age adjusted linear type scores for registered and grade cows.

	Grade		Registered	
Type Trait	Marginal R^2	# Terms	Marginal R^2	# Terms
Stature	.000	1	.001	3
Strength	.001	2	.001	3
Body depth	.002	3	.001	3
Dairy form	.001	2	.002	3
Rump angle	.001	2	.002	3
Thurl width	.000	2	.001	2
Legs side view	.002	2	.005	2
Foot angle	.001	3	.003	3
Fore attachment	.007	3	.016	3
Rear udder hgt	.003	3	.010	3
Rear udder width	.002	3	.007	3
Udder cleft	.004	2	.010	2
Udder depth	.008	2	.013	2
Teat placement	.003	3	.009	3
Final score	.008	3	.025	3

[1] R^2 for herd and year of first calving was .19 for the grade data set and .21 for the registered.

[2] Linear, quadratic and cubic terms for traits tested for significance at the .10 level.

Table 24. Within herd-year multiple correlation coefficient (R^2)[1] and number of significant terms[2] from prediction of 84 month opportunity relative net income adjusted for opportunity cost of post-poned replacement (RNIOC84) from age adjusted linear type scores for registered and grade cows.

	Grade		Registered	
Type Trait	Marginal R^2	# Terms	Marginal R^2	# Terms
Stature	.001	2	.002	3
Strength	.001	2	.001	3
Body depth	.002	2	.003	3
Dairy form	.032	2	.044	2
Rump angle	.000	2	.000	2
Thurl width	.001	2	.001	2
Legs side view	.002	2	.003	3
Foot angle	.001	2	.002	2
Fore attachment	.000	3	.001	3
Rear udder hgt	.008	3	.016	2
Rear udder width	.014	1	.021	3
Udder cleft	.002	1	.006	2
Udder depth	.010	2	.007	3
Teat placement	.001	3	.003	1
Final score	.020	2	.033	3

[1] R^2 for herd and year of first calving was .14 for the grade data set and .26 for the registered.

[2] Linear, quadratic and cubic terms for traits tested for significance at the .10 level.

Prediction of AMIM84 and RNIOC84 using type PTA's are shown in Tables 25 and 26, respectively. Predictive ability of the type trait PTA's was very similar to that observed for the phenotypic scores.

The prediction equations developed using the linear type scores for legs side view, foot angle, the udder traits and final score are presented graphically in Figures 4 through 12. Ranges shown for the dependent variables, RNIOC84 and AMIM84, are roughly 1.7 phenotypic standard deviations of those traits and are the same for all graphs. The equations were used to generate curves for linear type scores over the range of 3 phenotypic standard deviations on either side of the mean. Presenting the graphs in this manner confines prediction equations to that range of scores most important in creation of the equations and prevents distortion of results at extremes of the data.

As expected from the R^2 values, slopes of graphs for registered cows were steeper than those of grade cows. Predicted RNIOC84 was plotted only if that trait explained variation in RNIOC84. For the type traits plotted against changes in AMIM84 and RNIOC84, slopes of prediction lines of the two traits were similar. The relationship of udder depth (Figure 10) was an exception in that cows with extremely deep udders had higher RNIOC84, but tended to have

Table 25. Within herd-year multiple correlation coefficient (R^2)[1] and number of significant terms[2] from prediction of milk-adjusted months in milk to 84 months of age (AMIM84) from linear type PTA for registered and grade cows.

	Grade		Registered	
Type Trait	Marginal R^2	# Terms	Marginal R^2	# Terms
Stature	.000	2	.002	3
Strength	.001	3	.000	2
Body depth	.002	3	.000	2
Dairy form	.000	1	.001	2
Rump angle	.000	1	.001	3
Thurl width	.001	3	.001	3
Legs side view	.001	2	.001	3
Foot angle	.000	2	.003	3
Fore attachment	.006	2	.015	3
Rear udder hgt	.002	2	.008	1
Rear udder width	.001	2	.007	2
Udder cleft	.003	2	.009	2
Udder depth	.008	2	.014	3
Teat placement	.002	2	.008	3
Final score	.007	3	.022	3

[1] R^2 for herd and year of first calving was .19 for the grade data set and .21 for the registered.

[2] Linear, quadratic and cubic terms for traits tested for significance at the .10 level.

Table 26. Within herd-year multiple correlation coefficient (R^2)[1] and number of significant terms[2] from prediction of 84 month opportunity relative net income adjusted for opportunity cost of post-poned replacement (RNIOC84) from linear type PTA for registered and grade cows.

	Grade		Registered	
Type Trait	Marginal R^2	# Terms	Marginal R^2	# Terms
Stature	.000	2	.000	1
Strength	.000	1	.000	2
Body depth	.001	2	.000	3
Dairy form	.028	2	.041	3
Rump angle	.000	0	.000	3
Thurl width	.000	2	.000	3
Legs side view	.000	1	.000	3
Foot angle	.001	2	.002	3
Fore attachment	.001	3	.000	--
Rear udder hgt	.004	3	.009	3
Rear udder width	.007	3	.012	3
Udder cleft	.002	3	.008	2
Udder depth	.005	2	.002	2
Teat placement	.001	1	.004	1
Final score	.014	2	.025	3

[1] R^2 for herd and year of first calving was .14 for the grade data set and .26 for the registered.

[2] Linear, quadratic and cubic terms for traits tested for significance at the .10 level.

lower AMIM84. Udder depth also exhibited a great deal of non-linearity, although the range of scores was the smallest of any of the linear traits.

For many of the traits, both registered and grade cows with extremely low scores had noticeably lower AMIM84 and RNIOC84. Increasing score above the average had little effect in predicting AMIM84 for grade cows. Graphs of RNIOC84 tended to be more linear and more similar between registered and grade groups.

Equations using the type trait PTA's are presented for the same traits in Figures 13 through 21. Many of the same relationships for the phenotypic scores are observed. Relationships over the range of PTA's tended to be more linear, especially for udder depth (Figure 18). The lower standard deviations for grade cow PTA are reflected in the range of curves for those cows, and this tends to further reduce non-linearity in relationships presented.

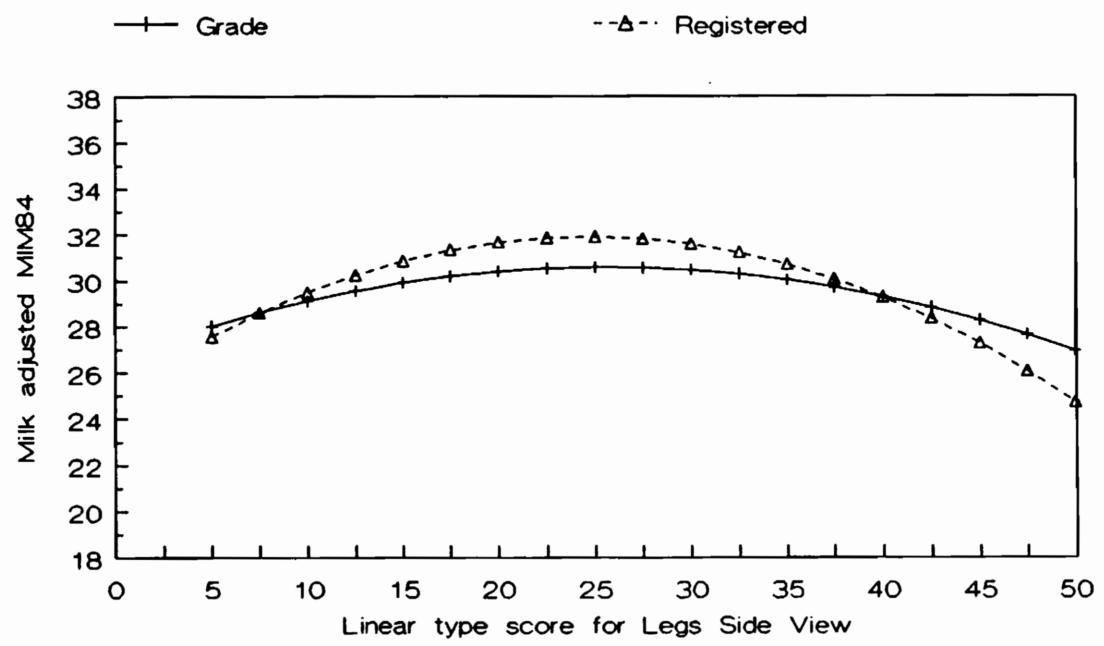

Figure 4. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) using linear type scores for rear legs, side view in registered (Reg) and grade cows.

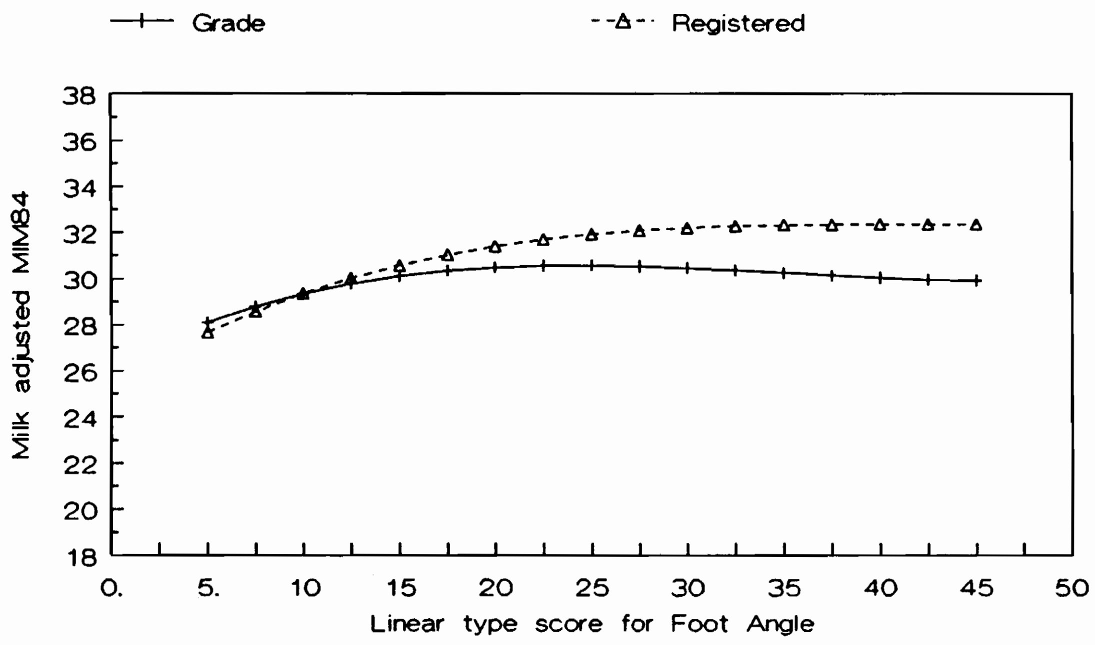

Figure 5. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) using linear type scores for foot angle in registered (Reg) and grade cows.

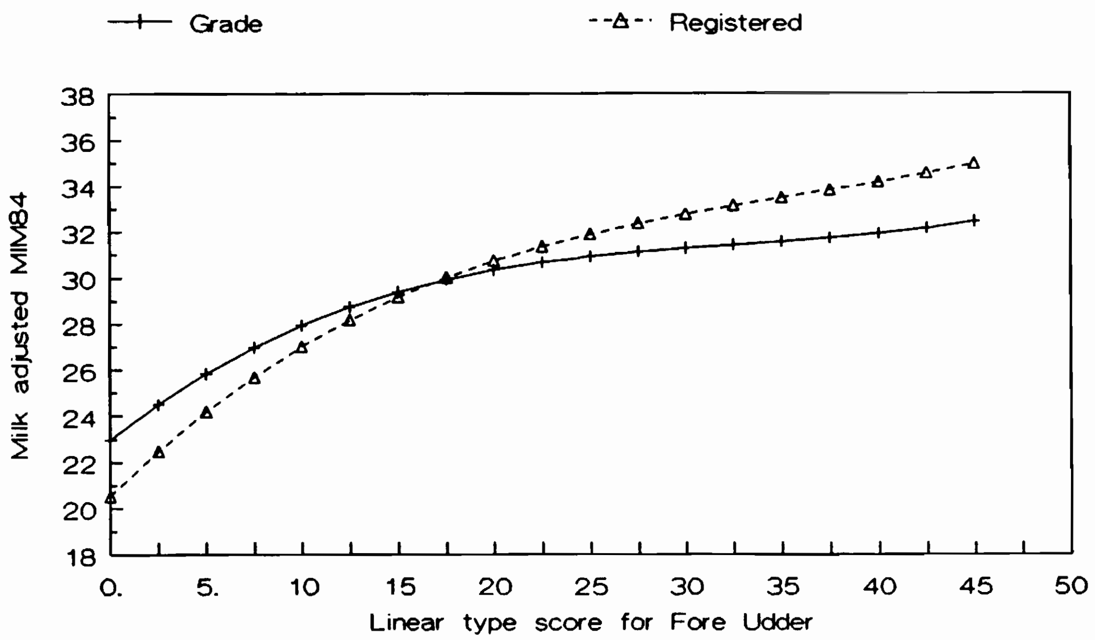

Figure 6. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) using linear type scores for fore udder attachment in registered (Reg) and grade cows.

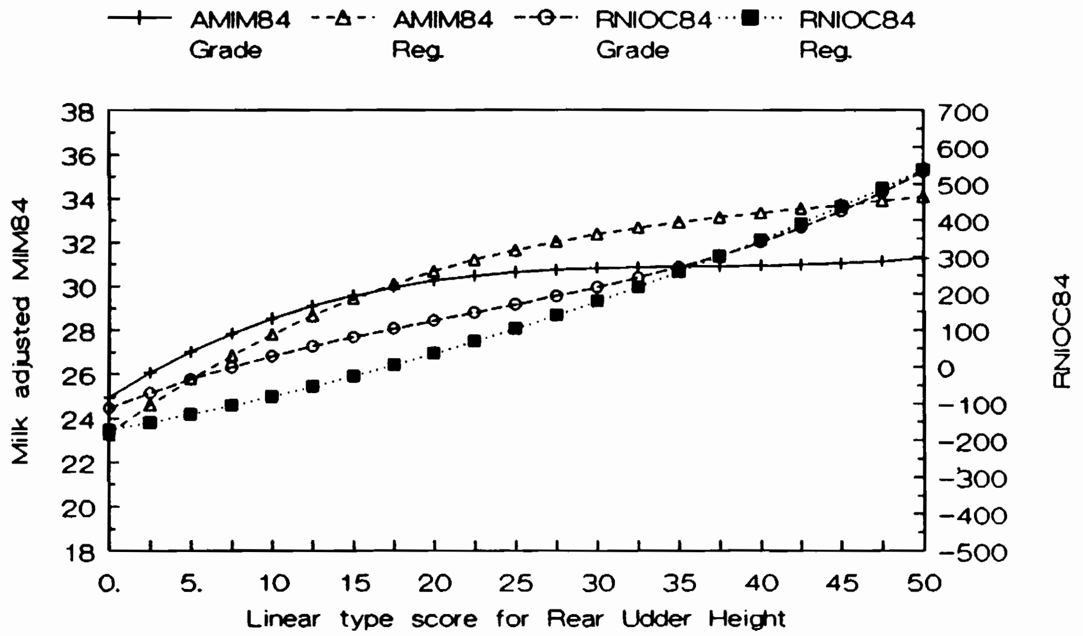

Figure 7. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement developed from linear type scores for rear udder height in registered (Reg) and grade cows.

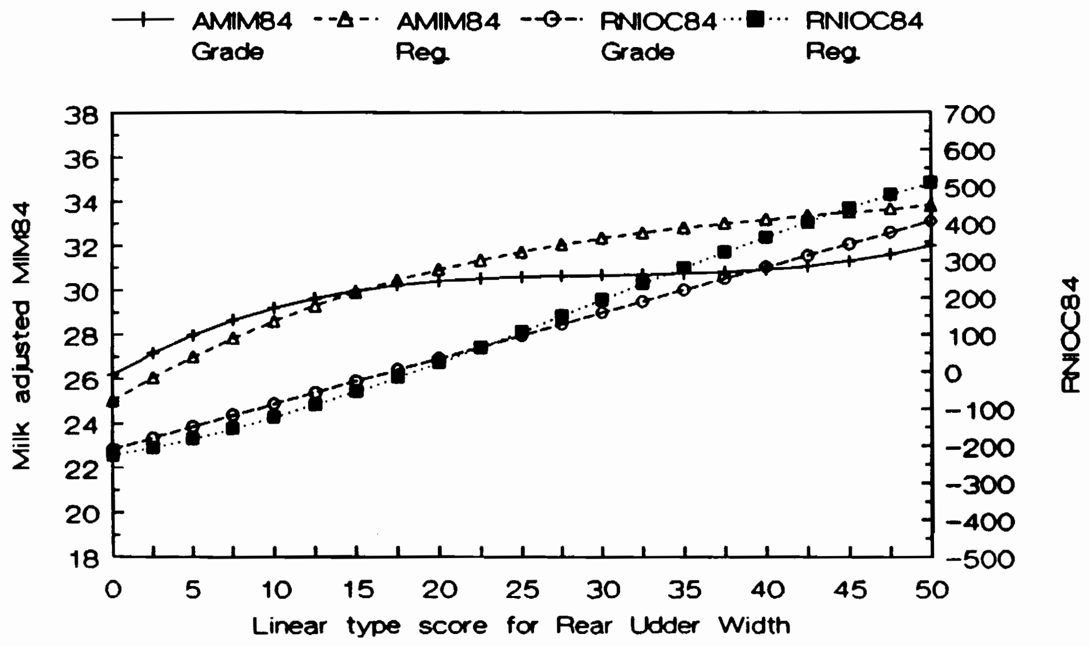

Figure 8. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement developed from linear type scores for rear udder width in registered (Reg) and grade cows.

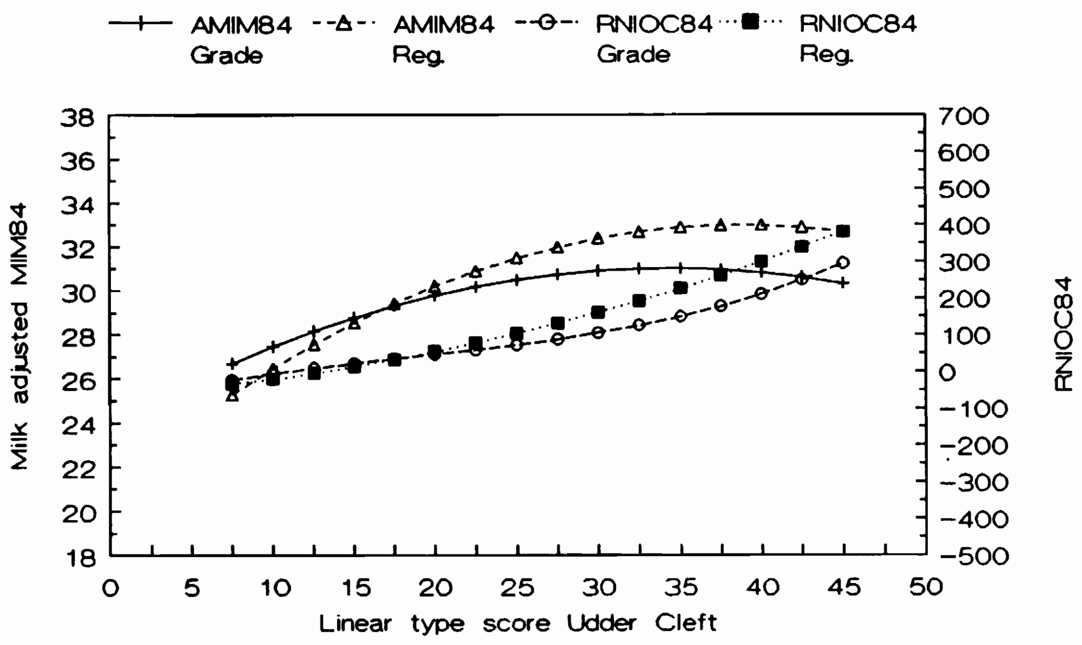

Figure 9. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement from linear type scores for udder cleft in registered (Reg) and grade cows.

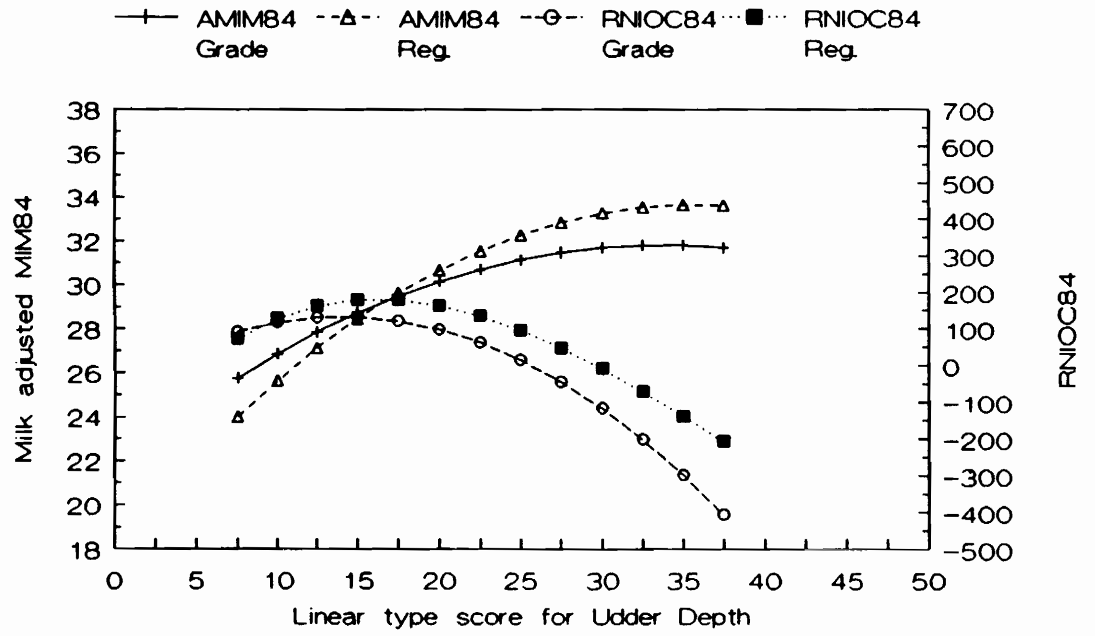

Figure 10. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement from linear type scores for udder depth in registered (Reg) and grade cows.

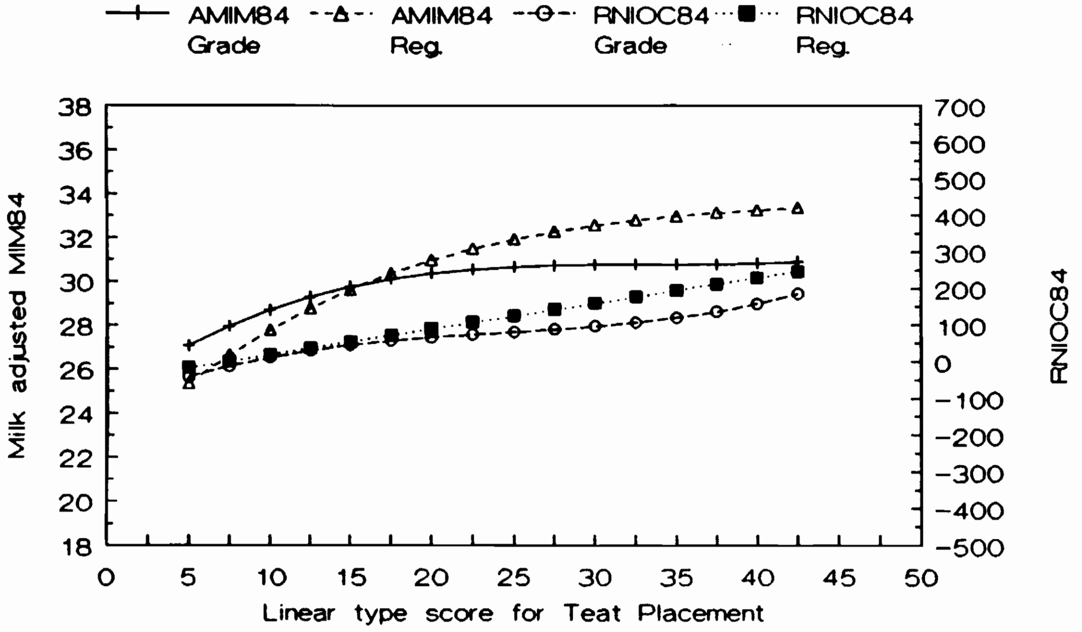

Figure 11. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement from linear type scores for teat placement in registered (Reg) and grade cows.

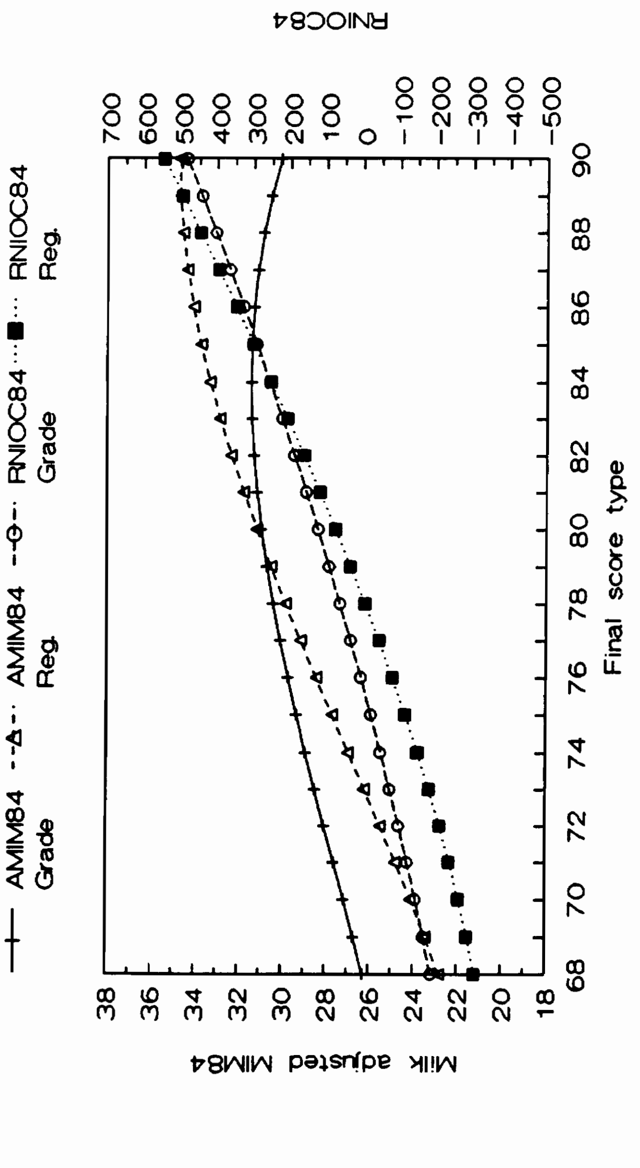

Figure 12. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement from final score type in registered (Reg) and grade cows.

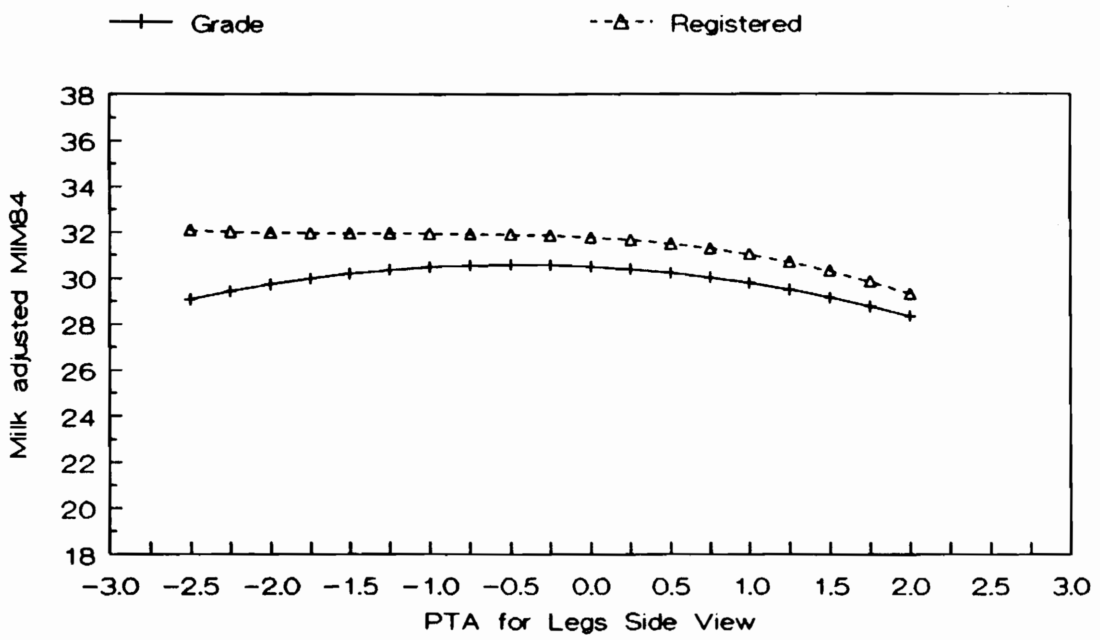

Figure 13. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) using PTA for rear legs, side view in registered (Reg) and grade cows.

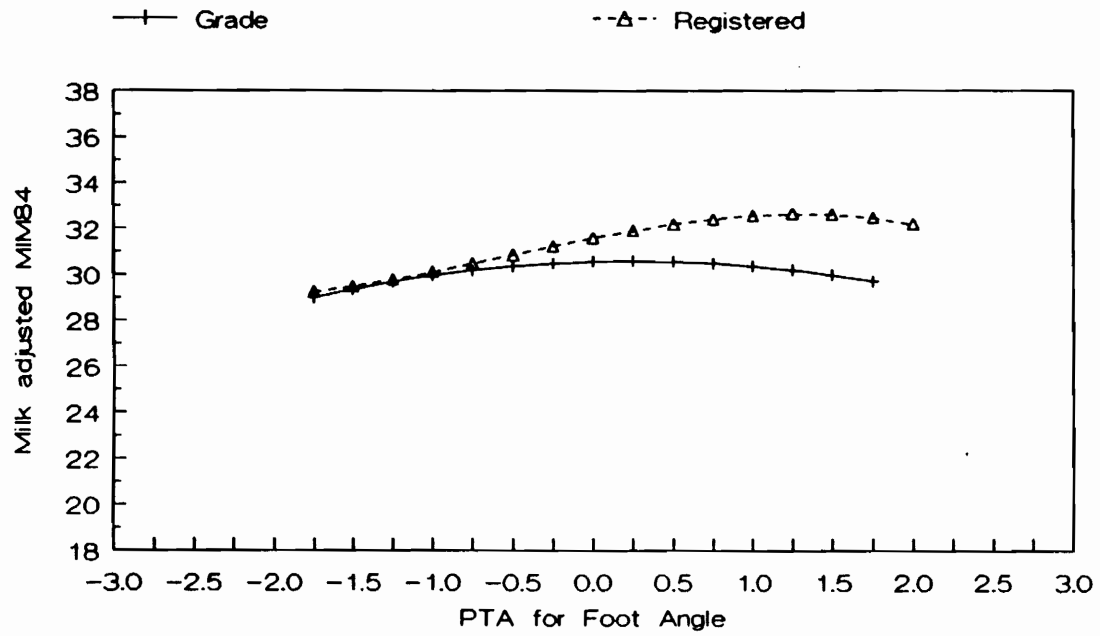

Figure 14. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) using PTA for foot angle in registered (Reg) and grade cows.

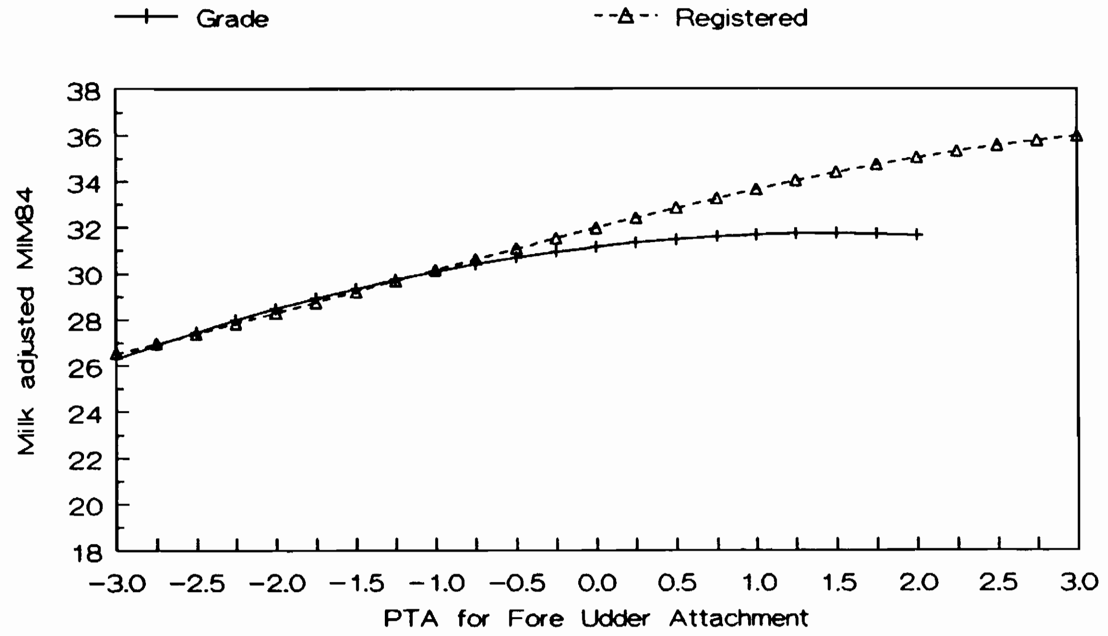

Figure 15. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) using PTA for fore udder attachment in registered (Reg) and grade cows.

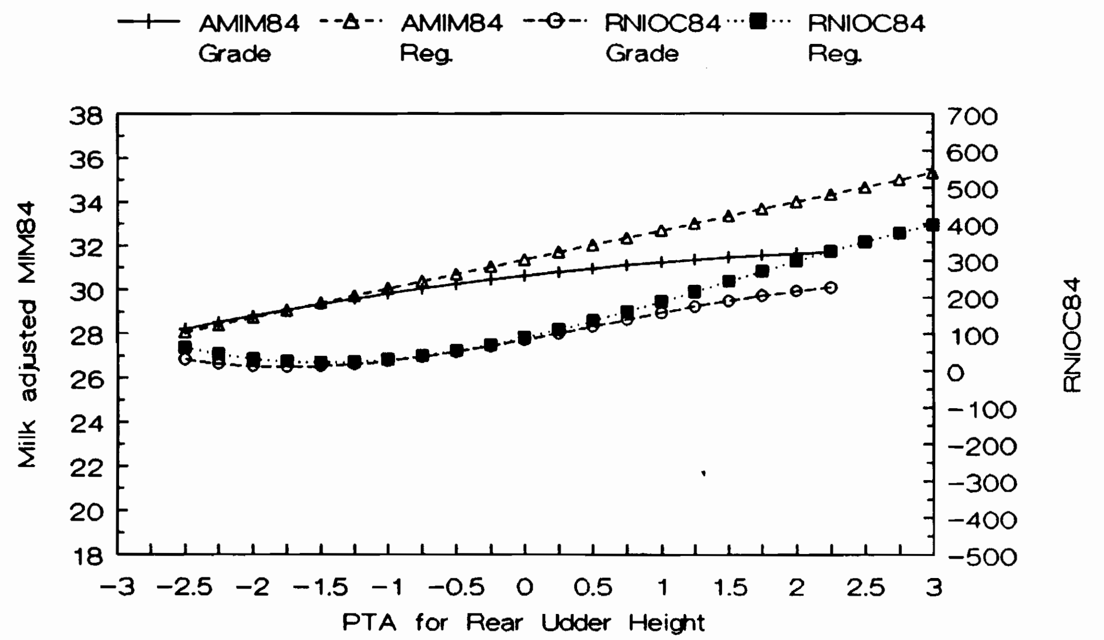

Figure 16. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement from PTA rear udder height in registered (Reg) and grade cows.

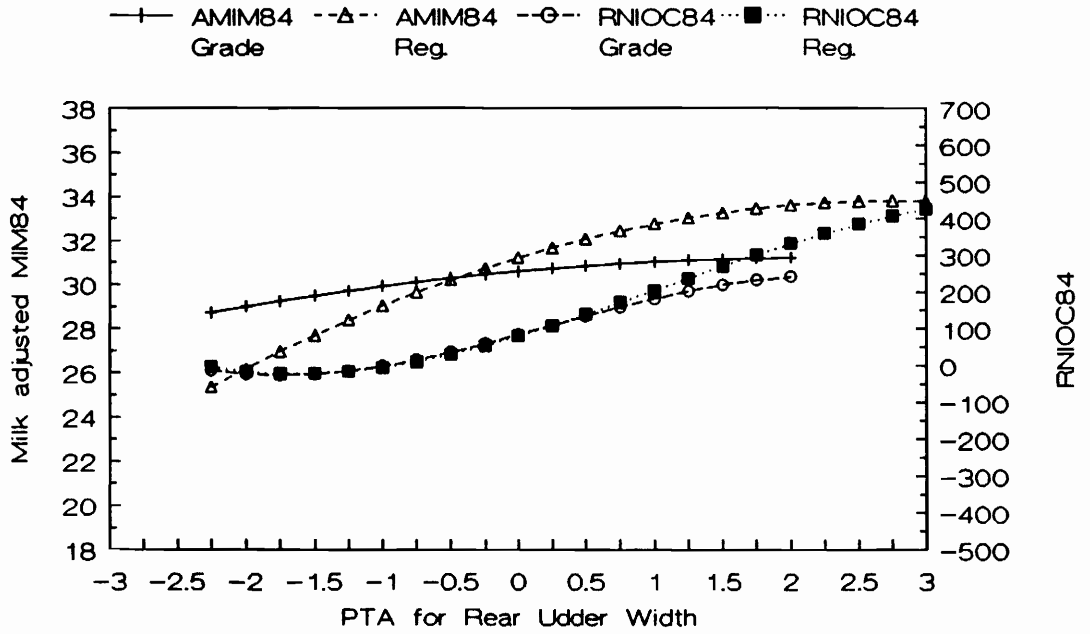

Figure 17. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement from PTA rear udder width in registered (Reg) and grade cows.

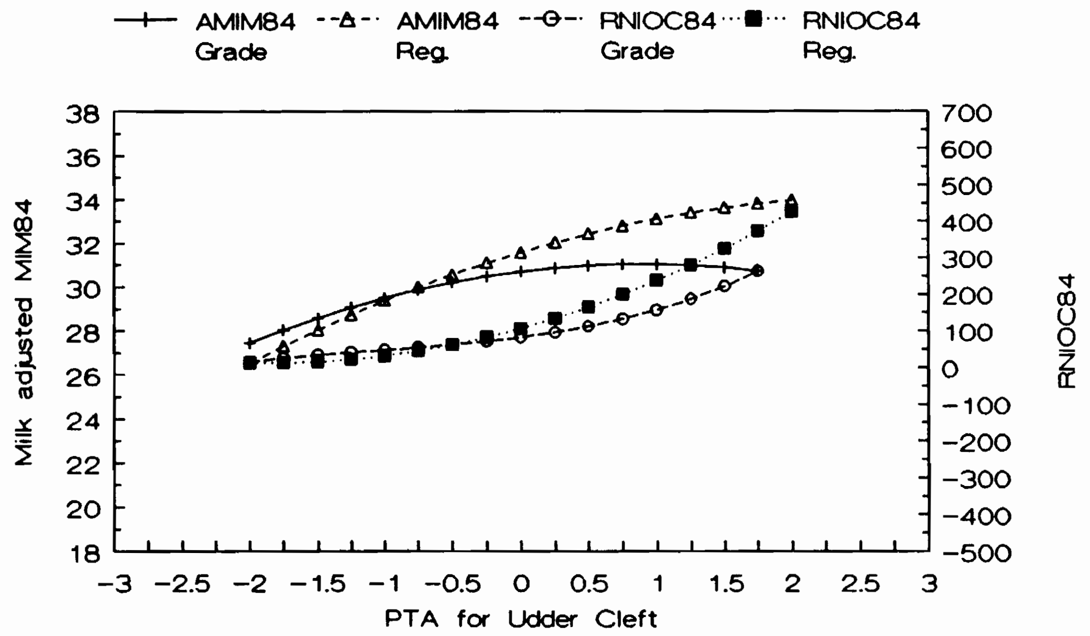

Figure 18. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement from PTA udder cleft in registered (Reg) and grade cows.

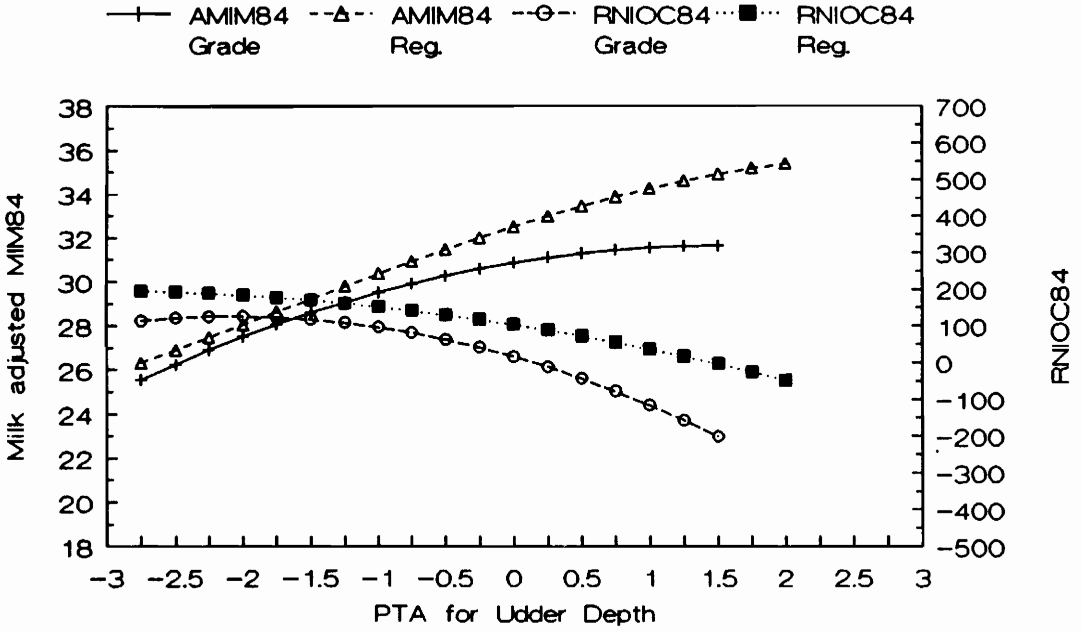

Figure 19. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement from PTA udder depth in registered (Reg) and grade cows.

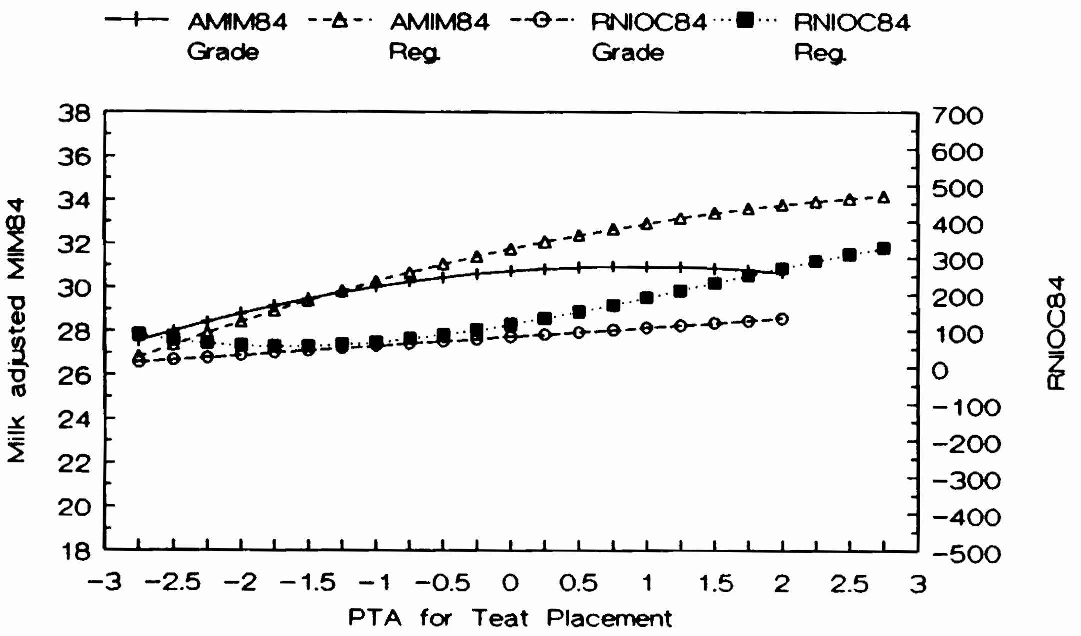

Figure 20. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement from PTA teat placement in registered (Reg) and grade cows.

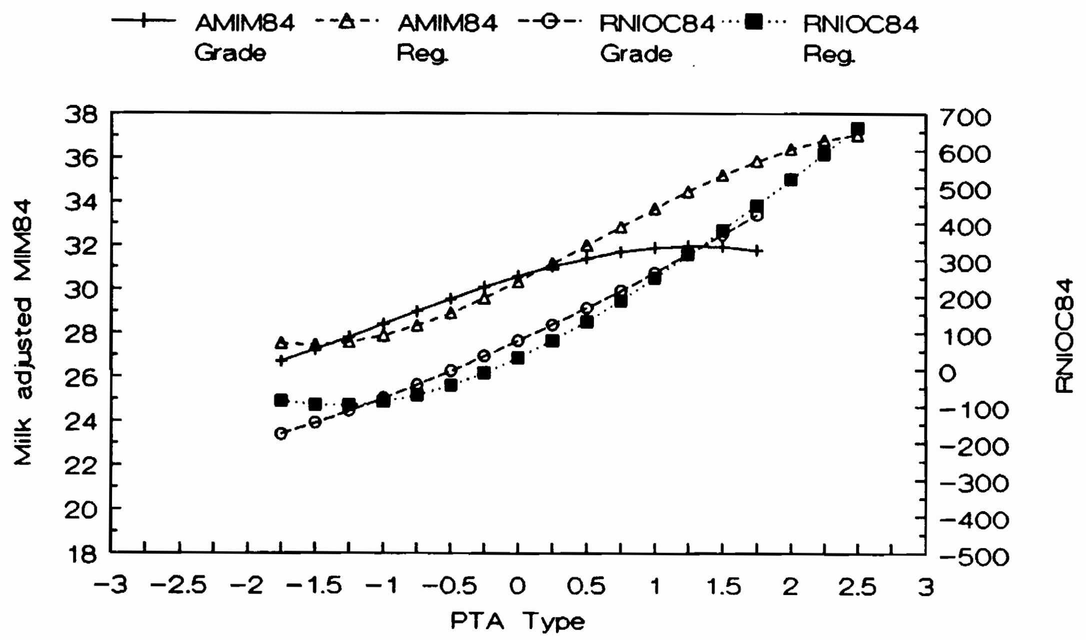

Figure 21. Prediction equations for milk adjusted months in milk to 84 months of age (MIM84) and relative net income adjusted for the opportunity cost of post-poned replacement from PTA type in registered (Reg) and grade cows.

Conclusions

The relationship between rank of cow in herd-year of first freshening for first lactation ME milk and herdlife is non-linear. Average herdlife increases greatly as herd rank for ME milk increases up to the 40th percentile, but herd rank for ME milk has little effect on herdlife for cows ranked average or above.

Linear type trait scores and PTA are much more important to within herd-year differences in milk adjusted herdlife in registered cows than in grade cows. Rank of the linear traits for amount of variation for AMIM84 explained is similar in registered and grade cows, with final score being most important followed by the udder traits.

Linear type traits related to production explain the most within-herd year variation in RNIOC84. Dairy form, final score and the udder traits related to udder capacity explain the most variation for RNIOC84 in both registered and grade cows. Differences in the body traits appear to have no effect on within-herd differences in milk adjusted herdlife or net income.

Slopes of prediction equations for RNIOC84 and AMIM84 were similar for all traits but udder depth, where shallow udders indicated lower net income but longer herdlife. Although quadratic and cubic effects were significant for many of the linear traits in prediction of within herd-year AMIM84 and RNIOC84, relationships are adequately described by a linear model within the range of the data.

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