ABSTRACT

Several economic concepts that influence definition of economic merit are discussed. A profit equation including fixed and variable costs, an aggregate genotype including important lifetime traits, and a selection index are used in a hierarchical approach to economic definition of total performance, breeding goals, and breeding values.

A composite profit equation includes milk sold, calf value, ending inventory value, initial inventory value, feed cost, facilities cost, labor cost, veterinary cost, insemination cost, and individual cow care costs. Variation in the numerous studies with profit equations is mainly in method of estimation and completeness of items.

Progress has been less in quantifying economic breeding goals and criteria for selection than in defining total performance. Economic importance of traits is discussed.

Comprehensive selection goals reflect profit per day of herd life. An index includes milk and constituent yields, cell count, beginning and ending weight, calving interval, age at first calving, conformation, and calving difficulty score. Milk yield will continue to be the major trait for selection. Other traits will need to be added to the selection criteria to improve genetic gains for total economic merit based on their availability and on specific economic and environmental conditions.

GENERAL CONCEPTS OF ECONOMIC DEFINITION

The possibility of basing economic definition on translating an underlying production function into economic terms would be most desirable. However, lack of an adequate biological function has led to the accounting approach in most studies. In this approach, inputs and outputs are translated into monetary terms. The form of the function of income (In) and expense (E) to be used for economic definition, however, is less certain. Harris (18) suggested three functions of In and E as measures of economic efficiency: In−E, In/E, E/In. The function In−E (profit) provides a net economic effect of input and output items and appears to be the function of choice for dairy cattle. Preferably, estimates of In and E should be as complete as possible and In−E should be expressed per day or per year of herd life. This function [(In−E)/day of herd life] has the advantages of being understood more easily by dairymen and of being easier to work with from a statistical viewpoint. However, it has the disadvantage of not reflecting the limitation of availability of labor, credit, and other resources.

A second economic concept that needs to be considered in assessing breeding decisions (31, 33, 35) is: from whose standpoint is profit to be maximized? National or aggregate viewpoint is that when supply and demand are in equilibrium, increases in production income are worth relatively less than decreases in expenses as there is no market for the additional output at the current price. Thus, when production per unit is increased, there is a tendency to drive producers from the market. This effect often is mediated by government purchases and price changes. Individual producer viewpoint is that in contrast to the aggregate viewpoint, increases in production are relatively more valuable to...
the established individual producer as he can market his increased production without affecting the price received. These ideas are discussed more fully by Moav (35). Most dairy geneticists tend to think in terms of the established producer, but the aggregate and consumer viewpoints should be considered.

A third economic concept is the timing of In and E items. Economic returns ($) received currently are worth more than those received in the future. Thus, the concept of discounting income and expense to a constant time appears to be gaining in animal breeding circles. The formula used by Gilmore (17):

\[
\text{Present value of future net income} = \sum_{t=1}^{s} \frac{(1+r)^{-t}R(t) + (1+r)^{-s}M(s)-M(0)}{1}
\]

where,

- \( R(t) \) = earnings received at the end of year \( t \)
- \( r \) = discount rate
- \( s \) = age in years of the asset when replaced
- \( M(s) \) = salvage value of the asset
- \( M(0) \) = cost of asset which is purchased at day zero

Early users of discounting suggested high interest rates (7 to 15%) to reflect the risk and the current cost of money. More recently, however, Smith (50) has made a case that interest rates are high because of inflation; thus, the rate should reflect that inflation will increase net returns in the future. He suggested using an inflation-free interest rate of 2 to 6%. The interest rate, however, should reflect the degree of uncertainty or risk in the expected outcome of the decision. The role of the discount rate in genetic comparisons not involving large capital outlays at their initiation is minimal.

In general, a hierarchical approach to economic definition will be used in this manuscript. The function \((\text{In} - E) / \text{day}\) will be the economic definition of total performance; the aggregate genotype equation \((H)\) will represent the economic definition of the breeding goal; and the selection index \((I)\) will be the economic definition of breeding value (19). With this approach, inputs and outputs are weighted by their prices to calculate total performance, a's of the \(H\) equation can be calculated as the partial regression of the profit equation on traits in \((H)\) (36), and b's in \(I\) are the partial regression coefficients of \(H\) on the traits in \(I\) (19).

While there is advantage in using the regression procedure just described, several alternative methods need to be considered. The method that has been used most frequently is to trace the economic impact of a unit change in the trait and its resulting impact on all inputs and outputs. This can be done by an accounting method (51) or by simulation (44). Another method that may have some advantages is linear programming (13). This method, however, has not been given great consideration.

The purpose of this manuscript is: a) to review the work that has been reported on economic definition of total performance, breeding goals, and breeding values; b) to propose composite income and expense equations; c) to discuss comprehensive selection goals; and d) to suggest possible traits for inclusion in selection indexes.

**ECONOMIC DEFINITION OF TOTAL PERFORMANCE AND ITS USES**

Two of the earliest attempts at determining comprehensive net returns from dairy cattle involved evaluation of various crossbred groups (28, 54). The importance of heterosis in non-yield traits of economic importance is the probable reason that the more comprehensive economic evaluation first was attempted to evaluate crossbred groups. Fitness traits such as disease resistance, reproduction, and livability, which are important economically, exhibit relatively large nonadditive genetic effects and exhibit less additive variation. Thus, the economic ranking of various crossbred groups is determined less fully by milk yield than would be within the purebreds.

Gill and Allaire (16) compared the efficiency of selection on age at calving, milk/day, profit/day during first lactation, and various indexes of these traits for improvement in \(H\) where \(H = \text{profit/day of life}\). For a constant selection pressure, selection on profit/day, and indexes including age at calving and milk/day; age at calving, milk/day, and profit/day; and milk/day and profit/day all produced equal or greater response than direct
selection on profit/day of life. These results were dependent upon the relatively high heritability of age at first calving and its positive genetic correlation with profit during first lactation and life. In further analysis heritability of age at first freshening probably was biased upward from confounding service sire and time in which heifers were bred (1). Initial weight, herd life, milk, and profit traits were increased, and age at first calving was decreased by nearly identical amounts when selection was on any of the most efficient selection criteria or indexes.

Lin and Allaire (25) constructed selection indexes including milk yield, fat percentage, days in lactation, number of breedings, and age at calving for first lactation to improve total profit to 72 mo or lifetime (H). Regression indexes also were calculated from the phenotypic covariances with lifetime profit (rather than genetic covariances). For all indexes, age at calving, number of services, and days in lactation had negative weights; milk yield and fat test had positive weights. Selection indexes were more efficient than regression indexes in producing genetic improvement in profit to 72 mo and lifetime. However, profit to 41 mo was superior to any of the indexes for increasing phenotypic profit to 72 mo and lifetime.

Gilmore (17) calculated several measures of discounted economic merit for 190 cows in the Cherry Hospital Holstein Herd: annualized net income (included all income and expenses), annualized health costs, and annualized milk income minus feed costs minus health costs. He then determined how well milk and fat yield in first lactation, and Holstein-Friesian Association classification traits predicted annualized net income and its component parts.

Milk and fat fat in first lactation, and dairy character (DC) were significant predictors of annualized net income and annualized milk income minus feed costs minus health costs, while body capacity (BC) and Final Score (SC) had a smaller effect on the latter. The R^2's for the two traits were .27 and .40. Classification traits were more useful in predicting annualized health costs, mastitis costs, and reproduction costs. However, the R^2's for the three traits were only .09, .20, and .10 and some of the regression coefficients had a sign opposite from expected. Milk and DC were significant predictors of lifetime milk yield (R^2 = .13) and milk, DC, SC, mammary system (MS), and general appearance (GA) were significant predictors of herd life (R^2 = .07). Higher general appearance scores were associated with a decrease in herd life.

Andrus and McGilliard (4) used a multiple regression approach to determine the importance of milk yield, mastitis, milk fat test, live freshenings, herd life, body weight, and milking time in predicting profit per year of herd life. A rather complete model was used to estimate profit. Milk yield, mastitis, milk fat test, and live freshenings were significant contributors to profit. Their standard partial regression coefficients were .64, -.38, .31, and .22. Herd life, body weight, and milking time had nonsignificant coefficients of .1, .09, and .03. The totally linear regression model used in this case may not reflect fully the biological effect of the traits, but it does provide the best attempt to date of determining economic weights.

Burnside et al. (6) estimated the relationship of returns over variable costs through 36 mo of production to sire's breeding value and pedigree estimate of breeding value of the cow. They find a strong curvilinear relationship, with cows of intermediate breeding values having the highest returns over variable costs. Further investigation demonstrated that, in part, the curvilinear relationship was from lowered reproductive performance.
general, they used market prices to form the relative economic weights. They avoided the problem of the multiplicative relationship of economic weights for milk and fat percentage by giving fat percentage zero weight and placing a value on milk and fat yield. However, these weights seem to give fat yield double credit.

Wilton and VanVleck (55) approached the interdependence from the point of developing a quadratic index to reflect the price of milk adjusted for fat percentage. Again, market values were used because information on net values was lacking. Although index calculations may yield correct answers, they are considerably more difficult. Since the value of milk can be written linearly in the form of the value of milk with 0% fat and the differential $x$ fat yield, the added work and complexity of the quadratic index do not seem justified. The methodology may be useful where economic values may not be written independently.

Recently this topic has received additional attention by workers at Iowa State. They have sought answers to three questions:

a) What are the net values of an increase in fat, protein, and carrier under different pricing systems?

b) What effects do net values of protein, fat, and carrier have on selection index weights under different pricing systems?

c) What are the net values of fat, protein, and carrier in different products (how should milk be priced)?

Return over feed costs (Table 1) ignored correlations between traits (these are accounted for in forming the index) and was based on the estimated energy needed for producing each component and on total feed cost being 50% of the milk price (11, 12). Gross returns were calculated from a milk price of $22/100 kg and a fat differential of $.25. These data indicate that most dairy producers realize a negative net return from an increase in protein yield and suggest a change from the current inequitable pricing system.

Selection indexes were formed (11) for the normal US pricing system had several Dutch pricing systems that weight fat and protein yield about equally and give either no credit for volume or a negative weight to volume (approximately 84% of their milk is used for manufacturing products in which the water content represents an added cost). The efficiency of various indexes compared to an index including milk yield, fat percentage and yield, and protein percentage and yield were computed for each selection goal. Under the US system, selecting on milk was 97% efficient while selecting for fat yield was 89% efficient. Under the Dutch system, with no credit for the carrier, selecting on milk was 82% efficient while selecting on fat yield was 94% efficient. With a negative price on the carrier, selection on milk dropped to 74% efficiency while selecting on fat yield had an efficiency of 92%.

As for the future, perhaps a more important question is, "What should the pricing system be to reflect the net value of the components and the mix of products produced from milk?"

Hillers et al. (22) considered four types of products: fluid milk, hard cheese, butter nonfat dry milk (NFDM), and cottage cheese. Fixed and variable costs were obtained from various sources to determine the net value of the protein and fat to the manufacturer. Net values per .1% fat and protein (Table 2) were calculated.
culated. In a milk shed where the percentages of producer milk utilized for fluid, hard cheese, butter-NFDM, and cottage cheese were 40, 25, 25, and 10%, respectively, protein would have an average value of $.70 per 1% and fat would have an average value of $1.23/1%. Norman (37) obtained a differential of 9.4¢/. 1% protein based on the value of skim milk. Although these prices reflect the current value to the milk processor, they are not the differential prices received by most dairymen. Thus, the question of what prices should be used in the selection process still remains to be resolved.

Mastritis

Putting an economic weight on mastitis frequency or resistance is extremely difficult. Exposure, pathogen type, types of prevention programs, and many other factors have a significant effect on the weight for a given dairyman.

Janzen (23) and Dobbins (8) have spelled out specific costs from mastitis. Although their reference was related more to control regimens, listing their costs may be useful. These costs were: losses in milk, losses in milk composition, discarded milk, drug costs, veterinary fees, added labor, and cow replacement costs. Production loss from mastitis was the major cost; replacement cost of cows culled for mastitis ranked second. Discarded milk, drug and veterinary costs, and extra labor all together amounted to less than the replacement cost.

Two investigators included the cost of mastitis in a profit function (4, 17). Andrus and McGilliard (4) obtained a regression of profit per year on number of cases of mastitis per year of $13.16. The standard partial regression for number of cases of mastitis was about .5 the value of milk. In Gilmore's study (17), annualized mastitis cost was $31.40 per year (compared to an $8.00/45.4 kg milk price). This figure is per cow and includes discarded milk, drug costs, veterinary fees, and added labor. Thus, from these two studies, we have a rough idea of the relative cost of mastitis on a case and on a cow-year basis.

When one considers forming an index to include mastitis incidence or resistance, a major question that must be answered is what measure of the trait should be used: number of cases, cell counts, or bacteriological test results? Because of all the problems involved, neither selection indexes that include measures of mastitis nor an H equation that reflects changes in profit due to mastitis has been developed.

Milk, Flow Rates, and Milking Times

Increasing peak flow rate has been considered a method of reducing milking cost and improving the milking process. At least in some countries, increasing peak flow has been thought to be important enough to warrant obtaining information on the daughters of AI bulls (46). Some investigators feel, however, that optimum milking speed is intermediate. Faster milking may be associated with a looser sphincter muscle and may result in a higher susceptibility to mastitis. The concern of higher susceptibility was based primarily on the work of Dodd and Neave (9), who reported that faster milking cows were more susceptible to mastitis. Results in our lab, however, suggest that the relationship between flow rate and mastitis may not be a major problem (34).

Blake et al (5) found that milking speed has little effect on milking labor in modern milking facilities. When these economic results are combined with the positive genetic correlation of flow rate and milk yield, there appears to be little reason for sire selection on milking speed. Similarly, Andrus and McGilliard (4) estimated the regression of profit on milking time was near zero. Markos and Touchberry (30) pointed out, however, that milking speed may be useful in helping to predict the genetic value of a cow for milk production.

Growth Rate or Size

Little or no consideration has been given to selection on growth rate for beef production in the US. In Europe, however, growth rate has been considered in the selection of bulls for AI. The reasons for these differences have been discussed by Soller and Bar-Anan (51) and Dommerholt (10). Several conditions in the US continue to render the value of increased growth of calves near zero for the dairyman: a) dairy beef still is discriminated against in the market (51), and b) where feeder or younger calves are sold, virtually no difference is paid for animals of superior growth rate (10, 18). If we can accept that there is little or no economic gain to dairymen from increased growth rate in
beef production, then the question of size relates only to the female.

The role of cow size in determining net income is in rearing costs, cow maintenance costs (feed), and salvage value. In the US, the difference between salvage value and initial value at first freshening is negative and often great. Larger cows tend to produce slightly more milk; however, it is unclear whether it is enough more to offset the difference in salvage and initial values. Miller et al. (32) looked at the relationships of weight taken at each stage of lactation to lactation milk, feed intake, and feed efficiency. Initially, higher weight was associated with high yield ($r = .15$), feed intake ($-.25$ to $.45$), and lower feed efficiency ($-.02$ to $-.24$). Relationships with weight at the end of lactation were distinctly different: milk ($-.17$ to $-.30$), feed intake ($-.27$ to $.15$), and feed efficiency ($-.14$ to $-.53$).

Dickerson (7), from estimates in the Beltsville herd, calculated indexes to improve feed efficiency in first lactation. The index including fat-corrected milk and weight change was 33% more efficient than selection solely for milk and also more efficient than selection solely for feed efficiency.

Andrus and McGilliard (4) estimated the partial regression of profit on body weight at freshening to be $.04/kg. However, the regression was not significant. This positive economic weight is in contrast to previous discussion. Similarly, Gill and Allaire (15) found a small positive relationship between weight at first freshening and profit per day of life. Gilmore (17) did not consider weight as a selection variable; however, body capacity score may serve as a rough estimate of body size. Body capacity was not a significant predictor of annualized net income but was a negative predictor of annualized milk minus feed and health costs. The only measure of size that had a positive relationship to profit was weight immediately following calving. This measure may be more an indicator of maturity and condition than of skeletal size.

**Type**

The only direct value of type (conformation) is its effect on cattle sold for breeding purposes. For most commercial dairymen, the direct value is small, because they will merchandise few animals. However, there is a general feeling of a substantial reduction of health costs and increased longevity associated with improved type.

Gilmore (17) found that DC was the only type trait that was a significant predictor of annualized net income. Although DC, BC, and SC were significant predictors of annualized milk minus feed and health costs, lower scores for the last two type traits were associated with higher income. These results cast doubt on the indirect positive value of type suggested previously.

**Reproductive Efficiency**

Reproduction is composed of a multitude of traits and an even larger number of measurements of those traits, just a few of which are: age at sexual maturity, age at first calving, calving interval, days open, and services per conception. In addition, the female and male components of reproductive efficiency must be considered.

Andrus and McGilliard (4) found a partial regression of profit/year on live freshenings/year of $70.00. The standard partial regression was approximately one-third that for milk. Gill and Allaire (16) calculated several estimates of the relative economic importance of age at first freshening. Their estimates of economic trade-off between milk/day and age at first calving ranged from 1 kg milk/day of first lactation having an equal effect on profit to $-57$ days to $1$ kg milk having an effect equal to $-102$ days. The standard deviations for the two traits were 2.31 kg and 84 days. Lin and Allaire (25) calculated regression and selection indexes and estimated the relative gains in profit until 72 mo and profit in lifetime. Age at first calving and number of services were included in the index. Weights on age at first freshening were relatively smaller, and weights on number of services relatively larger in the regression index than in the selection index. Removing age at calving from selection indexes reduced their efficiency by about 7%. However, removing number of services reduced efficiency of indexes by less than 1%. The small reduction in efficiency reflects the small amount of additive genetic variation in the number of services. Part of the effect of age at first calving may have been removed if age-adjusted milk rather than actual milk had been used in the indexes.
Another method of looking at the relative economic weight of reproductive efficiency and milk is to calculate the relative value of semen from bulls of different milk potentials and nonreturn rates (28, 44). One thing that has become clear from these studies is that the value of reproductive efficiency is curvilinear and may interact with other variables.

Longevity — Herd Life

The value of extending herd life has been considered of great economic importance by many dairymen. Rendel and Robertson (47) delineated the economic value of longevity: a) reduce replacement cost, b) increase proportion of higher producing age groups, c) reduce amount of feed necessary for nonproducing heifers (more cows/metric), and d) increase the culling possible. Although it is not possible to take full advantage of all four simultaneously, they are the major benefits from increasing longevity.

Pearson and Freeman (45) demonstrated that when cow depreciation costs (rearing — salvage) were large in relation to the milk to feed price ratio, culling of calves was more profitable than the more accurate culling of cows. When all calves are raised and herd size held constant, cow depreciation costs for the herd are constant.

Ability to survive is most important for the more profitable cow; i.e.,

\[
\text{Number of years before a cow should be culled for genetic reasons} = \frac{(\text{The amount by which the animal is superior to the culling point in first lactation})}{\text{(Rate of improvement in the heifers entering the herd)}}
\]

[2]

However, since the rate of genetic improvement is small compared to variation in the cow herd, virtually all cows in the top .5 of a group of heifers would be kept for nearly 10 yr if they would continue to be sound and reproduce regularly.

The reduction in cow depreciation cost and the increase in production have a curvilinear relationship to years of herd life. Thus, much of the gain has been made by the time the cow survives to third lactation. Where a large premium can be obtained for breeding stock, additional calves per cow become an increasingly more important income item, and longevity becomes more important.

Renkema and Stelwagen (48) made an economic evaluation of replacement rates in dairy herds in the Netherlands. Their main objective was to determine the value of improved health on longer herd life. They showed a substantial increase in profit from an average producing cow by increasing herd life beyond the average 4.3 lactations.

Andrus and McGilliard (4) estimated a non-significant regression of profit on herd life of $7.74 per year. The standard partial regression was about one-sixth that for milk. However, Gilmore (17) found that a linear and quadratic prediction of profit based on number of lactations had a higher correlation with annualized net income than any function of milk and type traits in first lactation. Although these two sets of results cannot be compared directly, they suggest different relative economic value for longevity.

Economic Indexes In Use By The Industry

Predicted Difference Dollars (PD$). Currently, this index, which weights breeding value for milk and fat yield by their market prices, is the index most used with dairy cattle (40).

\[
PD$ = (BA_{m} + PD_{m}) \times (Price - Differential \times Base Test \%) + (BA_{f} + PD_{f}) \times (Differential \times 100\%)
\]

[3]

where,

- \(BA_{m}\) = breed average milk yield
- \(PD_{m}\) = predicted difference milk
- \(BA_{f}\) = breed average fat yield
- \(PD_{f}\) = predicted difference fat yield

This index was a step forward, because it provided a method of making selections for milk and fat at the same time. Two additional factors could make the index more accurate: a) including the phenotypic and genotypic inter-relationships between the traits, and b) using market prices minus feed costs for the two traits. The latter would have the greater effect.
on relative selection pressure applied to the two traits.

**PD$ Solids-Not-Fat (SNF) or PD$ Protein.**
With the increased interest in component pricing, the Animal Improvement Programs Lab at Beltsville started calculating PD protein and PD SNF and corresponding PD$ in 1977 (38). They used the value of nonfat dry milk to set the price for SNF and set the protein price so that it accounted for most of the value of the nonfat dry milk. The resulting formulas were:

\[
\text{PD$ protein} = \text{PD milk} \times [P - (D_f \times 3.5)] - (D_p \times 3.2)] + \text{PD fat} \times D_f \times 100 \\
\text{PD$ SNF} = \text{PD milk} \times [P - (D_f \times 3.5)] - (D_{SNF} \times 8.5)] + \text{PD fat} \times D_f \times 100 \\
\text{where,}
\]

- \( P \) = base milk price for 3.5% fat, and 3.2% protein or 8.5% SNF
- \( D_f \) = fat test differential for each 1% change in fat
- \( D_p \) = protein test differential for each 1% change in protein
- \( D_{SNF} \) = SNF test differential for each 1% change in SNF

Because only a small portion of the cows are tested for either protein or SNF, PD$ fat was calculated from this sample (PD$ fat = $0.0551 \times \text{PD milk} + $1.14 \times \text{PD fat}); PD$ protein and SNF were deviated from the PD$ fat in the sample; and the difference was added to the PD$ calculated for milk and fat of all daughters. This indirect procedure was necessary to correct for differences between the small number of daughters with protein and SNF data and all daughters with milk and fat.

**Production-Type Indexes.** The Holstein Association is calculating an index (TPI) that weights breeding value of milk (PD milk), breeding value of fat percentage (PD%), and breeding value of Final Score (PD type) divided by their standard deviations in a ratio of 3:1:1 (2). Similarly, the American Jersey Cattle Club has adopted an index (PTI) that weights PD$ and PDT approximately 3:1 (39). These ratios seem consistent with the goals of breeders of registered cattle selling some cattle for breeding purposes.

In none of the estimated breeding values calculated on an industry basis have the covariance between traits been considered. Covariances have been considered, however, in forming some of the indexes. This additional area of research may be fruitful in the future. The possibility of improving the accuracy of estimating breeding values in these industry indexes by considering simultaneously the covariances with traits not in the index should be considered (30).

**COMPOSITE INCOME AND EXPENSE EQUATIONS**
In the years since 1970, a number of investigators have developed profit functions for dairy cattle (3, 6, 14, 17, 24, 42, 43, 56, 57). The linear difference of income minus expense with some consideration of time has been used by most investigators. The major differences appear to be in the method of estimating the various inputs and outputs and in the completeness of the variables included. Using various aspects of these models, the following composite income and expense functions are proposed to estimate total performance over different times:

\[
\text{Income} = (\text{milk produced} - \text{milk discarded}) \times \text{price adjusted for composition} \\
+ \text{calf value} \times (\text{possibly adjusted for livability and estimated breeding value of dam (not sire)}) \\
+ \text{ending inventory value} \times (\text{dependent on weight of cows sold for beef or on profitability and expected remaining years for cows sold for dairy or still in the herd}) \\
\]

\[
\text{Expenses} =  \text{initial inventory value} \times (\text{dependent on weight, age at first freshening, and possibly on the value (based on pedigree) of the animal at birth}) \\
+ \text{feed costs (actual feed costs; or National }
\]
Research Council requirements for maintenance, growth, production and reproduction; or actual concentrate + forage (adjusted for concentrate intake and the weight of the cow)  
+ facilities cost\(^2\) \((\text{constant}) \times \text{days}\)  
+ labor cost\(^2\) \((\text{constant}) \times \text{days}\)  
+ deviations in labor for individual cow care  
\((\text{# of occurrences} \times \text{price})\)  
+ veterinary cost \((\text{# of occurrences} \times \text{price for a type of treatment})\)  
+ insemination cost \((\text{# of inseminations}, \text{adjusted for conception rate of the bull} \times \text{cost})\)

\[
\text{Net income/day of herd life} = \frac{\text{income} - \text{expense}}{\text{days of herd life}} \tag{8}
\]

When the function in \(8\) is used, facilities and labor costs become constant for all cows and do not affect comparisons between cows. Thus, with \(8\) labor and facilities cost could be omitted for comparison between cows. In contrast, when net income for a fixed period is considered, facility and labor costs either must be included for the period of herd life of the cow or totally omitted. Otherwise the cow is charged for a stall and labor that she did not use. Seldom will a dairyman leave an open stall for any extended time; this excess charge appears to be a problem in the approach suggested by Burnside et al. (6). Their approach seems to be overly in favor of the cows that lasted the whole time.

A comprehensive net income function has been developed. The accuracy of estimating certain parts of the function and the parts that can be deleted without seriously hampering its value remain to be determined.

**COMPREHENSIVE SELECTION GOALS**

The process of choosing a selection goal for dairy cattle should be to simplify a comprehensive expression. A function that reflects cow differences in the following traits is suggested: income from milk and milk constituent yields, income from calves, value at the end of herd life, feed costs, cost for mastitis, cost associated with reproduction, and cost of calf and cow losses. One major problem encountered in developing a comprehensive selection goal for dairy cattle is that many traits have a multiplicative relationship to one another or the traits are not related linearly to their economic effects.

The one approach that most nearly meets this requirement is \(H = \text{profit/day of life}\) (14). The function used by Gill and Allaire (16) included many of the traits suggested. This approach has two major advantages: a) the problem of deciding how to express the traits in \(H\) is minimized, and b) genetic covariances are calculated with only one item in \(H\). However, there are problems: a) it is difficult to provide different \(H\)'s for different segments of the industry. As the relative prices of inputs and outputs change, genetic parameters have to be reestimated with a new profit/day for each change; b) it is difficult to spot idiosyncrasies in the data set that may be causing incorrect weights for the population as a whole. Using \(H = \text{profit/day}\) is an excellent starting point for studying the problem; however, it would be less useful in developing selection criteria for use in practice.

A second approach might be a goal including a number of traits such as:

\[
H = a_1 \text{G milk/yr} + a_2 \text{G fat/yr} + a_3 \text{G protein/yr} + a_4 \text{G discarded milk/yr} + a_5 \text{G live freshenings/yr} + a_6 \text{G estimated feed consumption/yr} + a_7 \text{G average weight} + a_8 \text{G 1/yr of herd life (since 1st calving)}
\]

With this approach, each trait serves as an index in that it carries part of the weight of traits not in the goal. For example, milk/yr reflects the milk producing ability of the cow, reproductive efficiency (calving interval), and losses in milk production from subclinical mastitis. Traits not in \(H\) would be accounted for by calculating the \(a\)'s as regressions of a comprehensive estimate of profit on the various traits in \(H\). If the method of tracing the economic paths were used to compute economic weights, effects on correlated traits not in \(H\) would need to be included to arrive at \(a\)'s that would reflect a nearly comprehensive determination of net income.

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\(^2\) Different costs for milking and dry days may be necessary.
This approach has drawbacks because certain traits are omitted, and those included may not be accurate predictors of the indirect effects. However, this approach may be more useful in the more applied sense than $H = \text{profit/day}$. Once the genetic relationships and interrelationships are calculated, a's can be changed as necessary to represent alternative conditions.

In addition, this approach allows use of the system suggested by Henderson (21) and used by Tabler and Touchberry (52). In the system suggested by Henderson, breeding values (BV) are estimated separately for each trait in $H$ based on all traits in the index but as if all other traits in $H$ have an economic weight of zero. The economic weights then are applied directly to the BV's to calculate the final index. This method is used to calculate PD$, TPI$, and PTI except that the covariances between milk and fat are not considered in arriving at the estimated breeding value for the two traits. The greatest practical value of this system is that indexes reflecting differing economic conditions can be calculated with little work once the various breeding values are calculated.

POSSIBLE TRAITS FOR INCLUSION IN SELECTION INDEXES

Three major questions arise in devising indexes for dairy cattle. Should the index cover traits over a set time such as suggested by Young (57) and Lin and Allaire (26) or should it cover traits over variable time, i.e., all the data available? Should the same index be used for cow and sire evaluation? Should traits be corrected for environmental effects (as they are currently) even though some of those effects are also in the index?

One main advantage to fixed time is that indexes for a fixed period are much easier to calculate than indexes for variable time and estimation is simplified greatly. However, animals are not selected at a single stage of life. If the fixed time is relatively long, the animal is relatively old before it is evaluated; if the period is too short, sufficient information for accurate evaluation is not available. Thus, if the problems can be overcome, there is benefit to variable time, which allows for each cow to be reevaluated throughout her lifetime. Indexes for variable time probably would result in different traits in the index at different ages of the animal.

Although the question of including relatives was dismissed early in this presentation, it would enter into differences in indexes for cow and sire evaluation. In addition, the question of whether to include the same or different traits or at least different measures of traits needs to be examined analytically. If different traits are included in an index for different aged females, one easily might have several indexes on a bull.

Most of the advances in cow and sire evaluation have been improvements in removing environmental influences from the records. Thus, expanding $H$ and the selection index to be more realistic but removing adjustment for environmental factors could be a step backward. Use of production per day rather than standardized length of lactation is one example of this conflict.

Traits that might be included in an index can be broken into four categories: a) those that are reasonably continuous in expression over time (milk, fat, and protein yield, body weight, and conformation score); b) time variables (age at first freshening, calving interval, days open, days dry, length of herd life) affecting distribution of some of the fixed cost per cow; c) discrete variables at freshening (freshenings/yr, calving difficulty); and d) discrete variables throughout lactation (services/conception, cases of mastitis, reproductive exams or treatments, cases of foot care, and other health related traits). Traits in category a) can be estimated accurately by periodic visits to the farm; traits in category b) require information (possibly unsubstantiated) from the dairyman; traits in category c) require information from the dairyman but are limited to one stage of lactation; and traits in category d) require information from the dairyman throughout the lactation. Thus, there are some natural advantages to the accuracy and completeness of traits in category a).

Traits that may need to be included in the index are milk and milk constituent yields, cell count (as an environmental indicator and predictor of discarded milk), beginning and ending weight, calving interval, age at first calving, conformation, and calving difficulty.

SUMMARY

Several approaches for economic definition of total performance have been discussed, and many have been used. What remains to be done...
is to test the accuracy of these methods and to determine the relative magnitude of the various components. When this is done, it will be possible to assess the loss in accuracy of not including some items.

Estimated future profitability may provide an excellent method of determining which cows to cull. A method of this type for a simplified model has been suggested by Palmer (41). However, a measure that reflects the transmitting ability of cows should be used in selection of bull dams.

Expanding selection criteria to reflect economic realities is appropriate. However, the progress in accomplishing this on a population basis has been limited. The main emphasis of the work has been in determining the efficiency of various selection criteria. Although contributions have been valuable, a number of practical problems remain to be solved before benefits can be gained. One of the decisions in relation to the traits is whether to include traits that can be omitted voluntarily by the dairyman (selected data). If one is to include traits such as services per conception, how should the problems of incomplete reporting or, even worse, fraudulent reporting of data be handled? This problem may be avoided by obtaining data on traits that can be obtained by periodic visits to the farm.

Milk and constituent yields are the most important traits in dairy cattle improvement. Most other traits either have large economic effects but low heritabilities (for example, reproduction, mastitis, and longevity traits), or moderate heritabilities but small net economic values (for example, growth rate, body size, and milk flow rates), or are correlated strongly to milk yield traits (for example, feed efficiency). The relationships should not be misinterpreted to mean that there is no advantage to including other traits in our selection goal or selection criteria. It does indicate: a) that the measures of traits used must be chosen carefully, b) that expanded indexes should be used only if they increase efficiency of improving the profitability of dairy cattle, and c) that gains will be less dramatic than they have been for milk.

Any economic definition of dairy cow productivity depends on management, time, and market conditions. Thus, questions relative to the goal and index to be used for dairy cattle need to be reevaluated periodically. This need is particularly true when the relationship between breeding value and economic value is not linear. However, relative economic weights should not be changed without substantiating evidence.

CONCLUSIONS

1) Methods of economic definition in which prices are included as a final step are most useful as the biological relationships will tend to be more stable over time and geographic area than will price relationships. 2) Methods of calculating total performance are available. The accuracy of these estimation methods needs to be determined. Also, the loss from omitting different segments of the equations needs to be determined for different uses. 3) The possibility of using an estimate of future profitability as a culling guide deserves serious consideration. 4) Selection goals should reflect lifetime income and expenses, preferably per unit time. 5) Economic weights should be estimated as the partial regression of profit on the traits in the goal or alternatively by tracing all the economic paths. A multiherd data set should be used for estimating these parameters. 6) Best estimates of future stable price relationships should be employed in determining the economic weights. For example, protein should receive a net positive weight rather than the negative weight that current prices seem to justify. 7) Because not all animals will have all data, there will be a need to develop innovative ways to handle sire evaluation from daughters with different amounts of information. 8) Because of the time of expression of several of the important traits and the lack of large scale data collection, milk, milk constituents, and conformation will continue to be the mainstays of genetic improvement of dairy cattle. Additional effort should be made to weight traits to reflect lifetime profit. 9) Because of the cost of obtaining some additional traits and because of their limited value for herd management, expanded data collection systems should be developed primarily in the herds having the greatest impact on genetic improvement, i.e., AI progeny test herds and herds contributing young sires for progeny testing. This limited approach would appear to provide the greatest gain for the least cost.

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