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# *Invited Review:* Selection on Net Merit to Improve Lifetime Profit

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## ABSTRACT

Genetic selection has made dairy cows more profitable producers of milk. Genetic evaluations began with 2 traits measured on a few cows but now include many traits measured on millions of cows. Selection indexes from USDA included yield traits beginning in 1971, productive life and somatic cell score beginning in 1994, conformation traits in 2000, and cow fertility and calving ease in 2003. This latest revision of net merit should result in 2% more progress, worth $5 million/yr nationally, with improved cow health and fitness, but slightly less progress for yield. Fertility and longevity evaluations have similar reliability because cows can have several fertility records, each with lower heritability, compared with one longevity record with higher heritability. Lifetime profit can be estimated more accurately if less heritable traits are evaluated and included instead of ignored. Milk volume has a positive value for fluid use, but a negative value for cheese production. Thus, multiple selection indexes are needed for different markets and production systems. Breeding programs should estimate future rather than current costs and prices. Many other nations have derived selection indexes similar to US net merit.
(**Key words:** selection index, net merit, genetic progress)

**Abbreviation key: CM$** = cheese merit, **DCE** = daughter calving ease, **DPR** = daughter pregnancy rate, **FM$** = fluid merit, **NM$** = net merit, **PL** = productive life, **SCE** = service sire calving ease.

## INTRODUCTION

Dairy cattle improve because breeders choose the best bulls and best cows to be parents of the next generation. Definitions of what is best and methods of selection have become more scientific over time. Breeders have to plan ahead because genetic choices today will improve profit only in future generations. A review of past selection may be of use in determining new selection goals.

This report presents a history of net merit and other animal breeding terms, a discussion of the traits included and the economic values assigned, an international comparison of selection indexes, and some future directions in selection of dairy cattle.

## HISTORY

For thousands of years, breeders have tried to decide which animal traits are most important. A few ancient breeders profited from selection simply by assuming that animal health traits were inherited. For example, Jacob "grew exceedingly rich" by breeding from stronger rather than feebler animals (Genesis, ~1500BC). Selection changed domestic animals, but not always in the right direction. For example, some breeders consumed or killed their healthiest animals and kept less fit animals in their breeding populations (Malachi, ~475BC).

### Goals

During the last century, genetic principles became known and genetic progress became a goal of most breeders. For selection to be profitable, the market should offer rewards for animals with superior traits. Lush (1960) discussed the potential to improve a trait such as protein percentage before it had a price in the market: "One would like to select today in accordance with the economic values which will prevail 10 to 20 yr from now. To do that with complete success would require prophetic ability of a high order; still it must be done as best we can. The breeder's main task in this respect is to decide which price and other economic variations are only temporary and which are longtime trends."

Specialized breeds selected for different traits can make more profit than a single breed selected for many traits. For example, dairy breeds serve a different purpose than beef breeds even though all cows can produce both milk and beef. Miller (1977) compared dairy selection in North America to dual-purpose selection in Europe and concluded: "In the future, particularly if international selection goals become more uniform, research

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will be needed to determine what can be gained by introducing semen of bulls from other countries into US improvement programs." Dairy selection programs are now global, but different breeders might still benefit from selecting different breeds or different animals within breeds depending on local prices, environments, and purposes.

Breeders can measure incomes and expenses and select for profit or just look at their cows and select the most stylish. Swett and Graves (1930) concluded that "the whole system of dairy cattle judging has been built on the superficial observations of breeders and cattle fanciers and upon a great many theories and suppositions which have been passed down through several generations of breeders and instructors until they have become rather generally accepted as facts, even though there is little if any tangible evidence to support many of them. The show ring as now conducted is more of a sporting than an educational event, and as such, it undoubtedly creates false impressions as to the relative importance of beauty and performance." Cow shows and judging contests still have these same problems, but linear conformation traits now allow breeders to select for particular traits that do affect profit.

Many traits that affect dairy cattle profit can be included in selection indexes. For example, the national index of Sweden included 12 traits as early as 1975 (Philipsson et al., 1994; Philipsson and Lindhé, 2003). More traits provide more information about profit, but too many could confuse breeders and distract attention away from those with highest value. "A key priority in research and education should be to identify those traits that really affect cost of producing milk and concentrate selection on them" (McDaniel, 1976). Reasons to include or exclude particular traits were reviewed by Pearson (1986).

Trait values often are assigned by committee and consensus rather than by strict economic or mathematical models. Recently, Solkner and Fuerst (2002) compared index methods across countries and "found it very difficult, though, to find details on the rationale for choosing traits included in the index and methodology used for derivation of the index weights." Some difficulty may be caused by economic goals being debated informally in local languages and not translated into published scientific documents. According to Freeman (1984), "determining selection goals is one of the most difficult, if not the most difficult, task of animal breeders."

## Terms

Net merit defines a goal for selection and lets breeders measure progress toward the goal. "The idea of a yardstick or selection index for measuring the net merit of breeding animals is probably almost as old as the art of animal breeding itself" (Hazel, 1943). Lush (1948) further defined net merit as the sum of the effects of all genes for all traits important to the breeder: "Instead of genes, he sees individual plants or animals, each of which differs from the others in many respects. When deciding whether to select or reject a plant or animal for breeding, he adds together what he thinks are its advantages and disadvantages for his purposes. This is selection for a complex character, net merit, effected by many genes."

Reliability measures the agreement of estimated merit with true merit (Goodale, 1928). In Goodale's (1928) booklet on herd sire selection, a section titled "The reliability of the index figures" presented the basic idea of progeny testing: "The breeding worth of bulls in terms of milk production could be measured very accurately if every bull were mated to cows of the same quality, for then, whatever differences existed in production of the daughters would come from differences in the breeding worth of the bulls. The daughters' milk production would itself be the measure of the bull's value."

Transmitting ability is the average value of genes transmitted to progeny (Yapp, 1925) and was further explained in 1926 in USDA's first attempt at a national sire summary: "The pedigree of any individual is only an indication of what the transmitting ability of that individual, for milk and butterfat production, may be. Until such time as we have pedigrees in which the sires have a sufficient number of tested daughters from tested dams, so that their breeding performance can be analyzed, as has been done with these 23 sires, predictions can not be made with certainty as to the transmitting ability of any untried individual" (Graves, 1926). That first report included data from 198 daughter-dam pairs and 23 sires, whereas US genetic evaluations now include data from >20 million cows and >100,000 sires.

## USDA Economic Indexes

In 1971, USDA introduced its first economic index, called Predicted Difference Dollars, which estimated gross income per lactation using milk and fat yield (Norman and Dickinson, 1971). In 1977 and 1984, similar economic index formulas based on milk-fat-protein price and cheese yield price, respectively, were introduced (Norman et al., 1979; Norman, 1986).

In 1994, productive life (**PL**) and somatic cell score (**SCS**) were combined with yield traits into a net merit index (**NM$**) using economic values that were obtained as averages of independent literature estimates (VanRaden and Wiggans, 1995). The correlated response in feed intake was subtracted, focusing attention on net income per lactation instead of gross income as measured by the earlier milk pricing formulas. These continued to be published along with NM$ until being replaced in 1999 by cheese merit (**CM$**) and fluid merit (**FM$**) indexes that included PL and SCS. The only national indexes that included health traits before 1994 were in Scandinavia (Philipsson et al., 1994; Leitch, 1994).

In August 2000, NM$, CM$, and FM$ were revised to include linear conformation composites (Holstein Association USA, 2000) using a lifetime profit function (VanRaden, 2000) developed by scientists in multistate project S-284, "Genetic Enhancement of Health and Survival for Dairy Cattle". From 1994 to 2000, the type traits had affected NM$ only as early predictors of PL rather than by direct selection. Selection indexes of breed associations included final score for type as early as 1976 (VanRaden, 2002). Several of the breed association indexes were revised recently to include individual conformation and health traits. The USDA indexes and predictions of PL include udder composite, feet and leg composite, and body size composite instead of using all 17 type traits. The units of NM$, CM$, and FM$ changed in 2000 from per-lactation to lifetime profit, and the standard deviations of these indexes became 3 times greater because an average of 3 lactations was assumed.

In August 2003, service sire calving ease (**SCE**), daughter calving ease (**DCE**), and daughter pregnancy rate (**DPR**) were included in NM$ calculations. Evaluations of SCE for US Holstein bulls had been available since 1978 (Berger, 1994), whereas evaluations of DCE (Van Tassell et al., 2003) and DPR (VanRaden et al., 2003) were introduced only recently. The fertility trait, DPR, is calculated from days open and measures ability of the daughter to cycle, express heat, conceive, and retain the pregnancy. Economic values for all traits in NM$ were reestimated, and breed-specific composites were used instead of using those defined by the Holstein Association USA (2000) for all breeds.

## METHODS

Prices of inputs and outputs change across time, and past trends may not predict future prices. Incomes and expenses associated with each trait in NM$ were reported by VanRaden and Seykora (2003). All of the details will not be repeated here, but some of the more controversial traits and assumptions deserve explanation.

### Values of Traits

Cow size is an example of a highly debated trait. Most breeders were taught from youth in judging contests that bigger heifers and cows were better. They observed that larger animals brought higher sales prices, but often forgot that more feed was required to grow larger replacements and to maintain heavier mature weights. Management practices that increase heifer growth rate probably do increase profit because well-grown heifers can calve and begin producing milk sooner. Bigger cows may give more milk, but larger cow size decreases profit if the selection index already has production traits included. The reason is that higher feed costs for large cows exceed their higher beef income, whereas any increase in yield is already accounted for by the yield PTA.

Some economic traits are not easy to measure directly, and correlated traits can be used as substitutes. But if reliable PTA are available for economic traits such as protein yield, little or no information is added by considering correlated indicator traits. Cow shows and judging contests may do more harm than good because they ignore incomes and expenses that can be measured and focus only on visual traits. Some breeders prefer to own cows with a pleasing appearance, but the goal of the NM$ index is to accurately predict the cow's profit on a commercial dairy.

Health and fitness traits received less attention in the past because accurate genetic evaluations were not available for less heritable traits. Selection for only yield and type traits is risky because some selection is needed to maintain health and fertility. Without selection pressure, fertility declined steadily because of unfavorable correlations with yield traits. This decline might have been reduced or avoided with index selection, which is ideal even when traits with lower reliability are included. The heritability of DPR is lower than that of PL, but the reliabilities of DPR and PL are similar (Norman et al., 2003) because cows can have multiple fertility records but just one longevity record, and fertility records arrive before reports of culling.

Longevity can be increased by selecting on PL evaluations or by selecting for the individual traits that contribute to PL (Rogers, 1994). Advantages of selecting for individual traits are that each trait is analyzed with its own heritability and the contributions of each trait to PL may change over time (Tsuruta et al., 2004). Thus, emphasis on particular contributing traits can be reassigned if conditions change. An advantage of selection on PL is that all reasons for culling are included.

Cow fertility is associated with several costs not accounted for by PL. These include increased labor and supplies for heat detection, inseminations, pregnancy exams, increased units of semen needed per pregnancy, and yield losses because ideal lactation length cannot be achieved. Cost estimates included heat detection labor and supplies of $20 per lactation, which increase by 0.5% per day open; pregnancy exams, which cost $10 and 0.012 more are required per additional day open; a semen price of $15 per unit and insemination labor of $5 per unit, both multiplied by a 0.025 unit increase per day open; and a reduced profit of $0.75 per day open from lactations longer or shorter than optimum. These per-lactation losses were converted to lifetime value by multiplying by 2.8 and converted from days open to DPR by multiplying by –4, which resulted in a DPR economic value of $17 per PTA unit. Further study of these assumptions is needed.

Calving ease is jointly affected by the service sire and by the dam. For many years, breeders were advised to avoid difficult births by mating heifers to favorable SCE bulls and cows to less favorable bulls rather than selecting for SCE (Rogers, 1994). However, selection and mating programs together can reduce difficulty by more than assortative mating alone (Dekkers, 1994). Selection for SCE in addition to DCE ensures that the selected group will include bulls that cause less difficulty when mated to heifers. Economic values for SCE and DCE were estimated from previous North American studies (Dekkers, 1994; Dematawewa and Berger, 1997), and these values were within the range of estimates obtained in Europe (Groen et al., 1997).

Milk volume can have a positive or negative value depending on fluid or manufacturing use (Weigel et al., 1997). Many milk drinkers prefer to buy low-fat milk, and US fluid processors have little incentive to maintain protein or solids content, except in California where minimums are higher. In some fluid markets, producers can lose money by selecting for protein because added feed costs exceed protein premiums. Cheese production requires protein and fat, but not water or lactose. These milk price differences may cause greater index reranking than many other trait values. Specialized breeds or lines of cows producing high- or low-component milk to match local markets may be more profitable than a randomly mating population trying to produce for all markets.

### Theory

Selection index theory uses heritabilities, phenotypic correlations, and genetic relationships among traits to maximize accuracy. For breeders, however, selection is simpler if multitrait PTA are supplied that already account for these parameters. Often, PTA are supplied only for measured traits, such as milk production, and not for important unmeasured traits, such as feed consumption. The value of measured traits then includes the direct value of the measured trait and also the genetic regression of the unmeasured traits on the measured traits (Rogers, 1994).

Economic relationships are often nonlinear, but linear selection indexes provide accurate rankings and are easier to explain and use (Goddard, 1983). Profit functions that seem nonlinear across the phenotypic range are more nearly linear across the narrower range of PTA, especially for traits with low heritability. A correlation of 0.999 was obtained when linear and nonlinear NM$ formulas were compared (VanRaden, 2000). The lifetime profit function is nonlinear because per-lactation incomes and expenses are multiplied by the number of lactations. The official, linear NM$ formula is the derivative of the nonlinear profit function evaluated at the mean for each trait. The NM$ measures expected profit for an average daughter, but may underestimate total future profit because genes contributed to grand-progeny and more remote descendants are ignored. Calculation of return on investment or discounting future profits to present value would be useful for an investment analysis but might have little affect on the relative values of traits or genetic rankings.

Genetic progress is proportional to accuracy, intensity, and genetic standard deviation, and is inversely proportional to generation interval. Real progress is also proportional to directional loss, or the loss from selecting in a less than optimal direction. Directional loss equals the correlation of the estimated economic function with the true economic function (Smith, 1983). Intelligent breeders may debate whether particular traits, such as body size, milk volume, or dairy form, should receive 2 or 3 times as much emphasis, or be ignored, or even selected in the opposite direction. Choosing the correct direction of selection is more essential for real progress than improving accuracy, intensity, or generation interval.

## RESULTS AND DISCUSSION

A history of the main changes in USDA indexes and the percentages of relative emphasis on each trait are provided in Table 1. The enhanced NM$ index implemented in 2003 was correlated by 0.98 with the previous NM$ formula from 2000 for recent progeny-tested bulls. The expected 2% increase in genetic progress is worth $5 million/yr nationally based on a $250 million value of current progress. However, some of the extra progress results from revised relative values for existing traits rather than just the addition of cow fertility and calving ease. Because NM$ now includes more traits that directly affect profit, accuracy of selection has increased.

Correlations of individual trait PTA with the 2000 and 2003 versions of the NM$ index are provided in Table 2. The revised 2003 index had higher correlations with DPR, PL, SCE, and DCE, but lower correlations with milk and protein. Table 2 also provides a compari-

**Table 1.** History of the main changes in traits and relative economic weights (%) in USDA selection indexes.

| | USDA economic indexes (and years introduced) | | | | | |
|---|---|---|---|---|---|---|
| Traits included | PD$[1] (1971) | MFP$[2] (1976) | CY$[3] (1984) | NM$[4] (1994) | NM$ (2000) | NM$ (2003) |
| Milk | 52 | 27 | –2 | 6 | 5 | 0 |
| Fat | 48 | 46 | 45 | 25 | 21 | 22 |
| Protein | — | 27 | 53 | 43 | 36 | 33 |
| Productive life | — | — | — | 20 | 14 | 11 |
| Somatic cell score | — | — | — | –6 | –9 | –9 |
| Udder composite | — | — | — | — | 7 | 7 |
| Feet/leg composite | — | — | — | — | 4 | 4 |
| Size composite | — | — | — | — | –4 | –3 |
| Daughter pregnancy rate | — | — | — | — | — | 7 |
| Service sire calving difficulty | — | — | — | — | — | –2 |
| Daughter calving difficulty | — | — | — | — | — | –2 |

[1]Predicted difference dollars.

[2]Milk-fat-protein dollars.

[3]Cheese yield dollars.

[4]Net merit dollars.

son of actual genetic progress in the last decade with expected progress in the next decade if breeders select on NM$. Genetic progress for NM$ should increase slightly because domestic and foreign sampling programs will test more bulls more accurately than in previous decades. Expected progress for each trait was calculated from the correlations with NM$ multiplied by the standard deviation of PTA multiplied by an expected NM$ gain of 3.4 standard deviations over the decade. The standard deviation of true transmitting ability for NM$ was estimated to be $191.

Actual genetic progress reported in Table 2 for breeding values equals twice the progress in transmitting abilities. An exception is that SCE trend is only for transmitting ability because calving ease trend is affected jointly by the sire trend plus twice the maternal grandsire trend. Much progress for yield traits was achieved during the 1990s, but actual trends for SCS, DPR, SCE, and size were not in the desired direction. Reasons are that SCS, PL, DPR, and DCE were not even evaluated in 1990, and that many breeders did not quickly adopt or emphasize the new traits when evaluations became available.

## International Selection Goals

Selection indexes for the 13 largest national Holstein populations evaluated by Interbull are compared in Table 3. For consistency, selection for SCS and calving traits is represented by positive values even if some national scales are defined with lower numbers desirable. Selection on yield traits is 50 to 70% of total emphasis in most countries. Most countries select either against milk volume or for concentration. Four countries select for larger cows and 3 select for smaller cows. Because some breeders prefer show cows and some prefer efficient cows, selection also differs within countries. Published indexes are useful for ranking and promoting top animals even though individual breeders may emphasize different traits and have their own goals.

National indexes are updated quite frequently and have become more similar over time. Already, 6 of the countries (United States, Germany, New Zealand, United Kingdom, Australia, and Denmark) revised their indexes since a similar survey 2 yr ago (VanRaden, 2002), and another country (Japan) is included. Holstein International (Wesseldijk, 2004) recently compared national indexes and trends across time. These

**Table 2.** Correlations of individual traits with indexes and expected trends and actual trends in breeding values.

| | Correlation of PTA with index | | | | Expected genetic trend/decade | |
|---|---|---|---|---|---|---|
| PTA trait | NM$ (2000) | NM$ (2003) | CM$ (2003) | FM$ (2003) | NM$ (2003) | Actual genetic trend 1990–2000 |
| Protein (kg) | 0.81 | 0.74 | 0.74 | 0.71 | 35 | 33 |
| Fat (kg) | 0.68 | 0.67 | 0.67 | 0.64 | 44 | 32 |
| Milk (kg) | 0.68 | 0.58 | 0.49 | 0.72 | 1082 | 1092 |
| Productive life (mo) | 0.51 | 0.58 | 0.56 | 0.58 | 4.8 | 1.5 |
| Somatic cell score | –0.35 | –0.38 | –0.37 | –0.39 | –0.44 | 0.04 |
| Udder composite | 0.19 | 0.22 | 0.21 | 0.22 | 1.4 | 1.5 |
| Feet/leg composite | 0.17 | 0.16 | 0.16 | 0.16 | 1.0 | 1.3 |
| Size composite | –0.10 | –0.10 | –0.10 | –0.09 | –0.6 | 0.8 |
| Daughter pregnancy rate (%) | 0.00 | 0.15 | 0.17 | 0.12 | 1.0 | –1.0 |
| Service sire calving difficulty (%) | –0.13 | –0.23 | –0.23 | –0.22 | –1.3 | 0.7 |
| Daughter calving difficulty (%) | –0.11 | –0.21 | –0.20 | –0.22 | –1.6 | –1.0 |

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