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# Genetic Improvement of Dairy Cattle[1]

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Dairymen are constantly concerned with improvement of their herds. Dairy cattle improvement is expressed most frequently as increased milk production and less often in terms of changes in body conformation or "type." Improvement in milk production can be considered as being environmental or genetic. Both environmental and genetic factors contribute to variation in milk production. There are environmental and genetic limitations of production. More importantly, management of environment and genetic factors can result in improved performance, i.e., greater milk production.

## GENETIC PRINCIPLES OF REPEATABILITY

Understanding the concept and knowing the repeatability of economically important traits help considerably in deciding which cows to cull. Repeatability also is important in sire proofs. All repeatability estimates represent some type of correlation. The trait one is considering, and the times and places it was measured, influence the estimate. The correlation between 305-day mature equivalent (M.E.) milk records of first-calf heifers, and their records as second-calf heifers, is about 0.5.

So milk records are said to have a repeatability of 0.5. Conception rate from year-to-year with the same cow has a repeatability of about zero, indicating that there is little or no relationship (correlation) between the number of services it takes for a cow to become pregnant each time.

These estimates are useful in making culling and management decisions, since they help us make the best possible guess at how well the cow will do next year if we know how well she did this year. For milk yield, 50% of the apparent superiority (or inferiority) of the cow for this year will appear next year on the average. If a cow gave 1000 pounds more than her herdmates this year, the best prediction of her yield next year will be 500 pounds more. Naturally, what she actually does is another story; she could be much better or much worse than our guess. The same process is used for below average cows; only one-half of their apparent inferiority will appear the following year on the average. Repeatability is included in the calculation of estimated relative producing ability (ERPA) in DHI.

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Only a fraction of the cow's performance is permanent (repeatable). Superior cows may do even better next year, but on the average they do worse; inferior cows on the average do better. Estimates for important traits are given in Table 1.

## GENETIC PRINCIPLE OF HERITABILITY

Heritability is a measure of the degree to which a trait such as milk yield is genetically determined. Although not all of the genetic contribution is included, essentially all which is available to a breeder who is trying to select within a breed is included. Obviously heritability is an important factor among the several factors determining how much genetic improvement can be made in any characteristic.

One of the disadvantages with the dairy cow, in attempts to make genetic progress, is that most of the economically important traits can be measured only in the female. Another disadvantage is that heritabilities are low or close to zero in several cases. A zero heritability would mean that no genetic change could be expected from usual selection techniques.

A practical idea of the meaning of heritability can be obtained easily. Let us say that a genetically average group of males is mated to a large group of high producing first calf heifers. These heifers average 1000 pounds of milk (305-day, M.E.) more than their contemporaries. Assume also that no extraordinary changes in environment have occurred by the time that daughters from these matings freshen and complete their first record. How much milk will the daughters produce compared to their herdmates? Answer: about 100 to 150 pounds more. Reason: milk yield has a heritability of about 20 to 30%, and since the sires used were genetically average, and sires and dams contribute about equally to the genotype of their offspring, only 10 to 15% of the superiority of the dams will be seen in the offspring.

A good practical definition of heritability is, therefore, the fraction of the merit (or lack of merit) observed in the parents which can be seen in the offspring, with merit being defined as a deviation from the population average. Heritabilities of many traits of the dairy cow can be seen in Table 2.

Note that several reproductive traits have very low heritabilities. Milk yield would be said to be moderately heritable; fat and protein percentages are highly heritable.

One possibility exists for genetic improvement of important traits with zero or very low heritability. This revolves around what geneticists call nonadditive genetic variance (heritability involves additive genetic variance). If there is appreciable nonadditive genetic variance, it can be taken advantage of by crossbreeding. Heterosis (hybrid vigor) is a reflection of this type of genetic variability. Unfortunately, although there is some heterosis in reproductive performance, longevity, livability and milk yield, it is not a large amount. Further, crossbreeding has several disadvantages for dairy cattle, although this discussion cannot be covered here. Few people are ready to advise taking advantage of nonadditive genetic variance in dairy cattle at the present time, and few cattleman are attempting to do so. Reproductive efficiency can be improved considerably by improving management practices while selection is being practiced for more highly heritable traits.

## SELECTION AND EXPECTED RESPONSE

Traits which are heritable presumably can be changed by selection, but the degree of heritability is only one of three factors which determine the progress which can be made. The other two are the culling level (intensity of selection) and the variability of the trait. These are logical since the more severely we can cull, the more progress we can make. Also, the more variable a trait is, the higher the population average will be for the selected individuals for any given culling percentage.

It turns out that the amount of progress which can be made in one generation (about five years in United States dairy cattle) is the product of intensity of selection, heritability for that trait, and the observed variability. Note that if any of the three components is zero, selection progress will be zero also.

Good estimates are available for how much progress can be made from selection for most of the economically important characteristics of dairy cattle. Of course, there are several traits which are important, so there is a need to look further than anticipated results from selection for a single trait.

### Correlated Response

Knowing what the genetic relationships are among the important traits, plus a few other things, permits us to predict what will happen to a trait such as fat percentage if we ignore it completely and select for milk yield, or vice versa. In Table 3 are results of a large scale study of milk yield and composition. Though these results pertain to Holsteins, they are similar to results for other breeds. Yields in Table 3 refer to pounds on a 305-day M.E. basis.

Values marked by an asterisk in Table 3 are the changes expected in the trait being selected for; values off the diagonal are changes expected to happen in other traits. Heritabilities and variabilities used in these calculations agreed with those generally accepted by dairy cattle geneticists. Intensity of selection in the estimations was fairly conservative. If more severe culling were practiced, greater progress would be made.

If milk yield alone is selected for at a reasonable level of intensity, an increase is expected in genetic merit in the next generation of 607 pounds (about 120 pounds increase per cow per year). Since milk yield, fat yield and protein yield are genetically fairly closely related (that is, their genetic correlations are high and positive), an increase is expected in fat and protein yields, even though these were ignored in the selection program. Because of the negative genetic correlations between milk yield and fat percentage, and milk yield and protein percentage, these two percentages are expected to go down. Selecting for milk yield and ignoring the other four traits would be expected to result in an increase per generation of 607 pounds of milk, 23.2 pounds of fat and 13.7 pounds of protein, but decreases of 0.036% fat and 0.018% protein.

If one attempted to increase fat percentage genetically in his herd by selecting for it and ignoring other traits, he could increase fat percentage. According to the table, a reasonable increase per generation to be expected is 0.190%. Along with this, however, there would be an actual decrease in milk yield of 287 pounds, although fat yield would increase 24.1 pounds.

Present pricing systems for milk in the United States are based mostly on its weight and fat percentage, although additional factors such as protein percentage may be included also. So the dairyman needs to decide what combination of milk yield and fat percentage and other changes is most profitable for him. He also needs to produce milk that passes minimum legal standards; this is an important factor in herds which already are near the minimum. Beyond this, there are a number of other important traits which must be considered. Dairymen, of course, mentally put all of these factors together in their selection programs and, depending on their present herd status and present milk pricing, give each trait a certain amount of emphasis. In other words, they weight each characteristic they think is important. Geneticists do the same thing and attempt to establish numerical values for the weights; a numerical index, called a selection index, then can be formulated for each economic situation.

### Index Selection

Since there are an infinite number of economic situations, it is not feasible to attempt to present one for Florida dairymen, but rather to generalize on which traits should be considered and how much emphasis should be placed on each.

#### Milk Yield and Composition

Just about every index formulated for the United States gives yield more emphasis than any other trait, with enough emphasis placed on fat percentage to meet legal standards. Protein has become more important in pricing systems in recent years.

#### Reproductive Performance

Efficient reproduction is very important economically because a cow must first reproduce to produce (at least until artificial induction of lactation becomes practical). However, most measures of heritability are zero or close to zero, suggesting that little or no improvement can be made by selection. Further, there already is considerable selection pressure being exerted on improving reproductive performance without any conscious effort being made by the breeder. This occurs because sterile males and females leave no offspring, and those with low efficiency leave a lot fewer than those of higher reproductive performance. So within a given herd culling for reproductive failure would have little effect on the genetic merit for reproduction of the herd. Now that large numbers of records are being obtained on reproduction of daughters of AI sires, however, it may turn out that this information can be taken advantage of in selecting which proven AI sires to use in the herd. Even though heritability of most single measures of reproduction are close to zero, estimates of average genetic merit of a large group of daughters for reproductive efficiency are much more reliable.

### Desirable Body Type

Desirable type has appealed to dairymen for centuries, and major changes in appearance in dairy cattle have occurred over the years, accompanied by increases in milk yield. This fact does not itself mean that the two traits have (or ever have had) an appreciable, positive genetic correlation. Further, regardless of what has gone before, the breeder must concern himself with the present facts of life in his selection program.

The genetic relationship between type and production seems close to zero and may even be negative. There have been a number of changes in the breed association type classification programs and policies in recent years, and evaluation of all such changes cannot yet be made. A number of scoring systems also have been developed by others such as universities and AI studs. Yet the final value of desirable type must be in its relationship with production and longevity of the cow. Except for the breeder who derives an important fraction of his income from sale of breeding stock, dairymen should realize (according to research) that only 2 to 6% of their income is related to variability in body confirmation. USDA researchers estimated several years ago that giving equal emphasis to type and production would reduce the possible increase in milk yield by 29%. Though perhaps the final judgment on emphasis to be placed on desirable type cannot yet be made, it appears that if major attempts are made to improve type, they will be made at the sacrifice of possible genetic increases in milk yield.

### Longevity

Longevity may be defined as the ability to avoid death or culling, the former being mostly for disease or accident and the latter for reproductive failure, low milk yield, mastitis, etc. Few cows die simply from old age. Of the various possible reasons for loss, some have a genetic basis but few are highly heritable. In any event, high producing cows remain in the herd longer than low producers. Natural selection pressures also work in favor of the ability to resist death or culling. Selection for high milk yield, plus natural selection, seem to be exerting sufficient selection pressure for increased longevity such that the breeder need not give it major emphasis in his program.

### Body Size and Weight

Within each dairy breed, large cows give more milk, on the average, than small cows, but they also require more feed. Research suggests that the additional costs involved with larger cows about equal the additional income derived from them. In the case of two cows of equal production but different size, one actually would expect the smaller cow to be more profitable. Most measures of size (weight, height, etc.) show appreciable heritability and variability, so larger cows could doubtless be developed if desired.

However, most research now suggests that milk yield in dairy cows can be increased considerably without there being any increase in size. Selection for increased body size could be successful, but the correlated response in milk yield though probably positive would be close to zero. Though North Carolina researchers indicated that it might still be wise to check cows considerably above or below the breed average in body weight for productivity and longevity, they concluded that "undue emphasis on larger cows in the short run could lead to the development of less profitable animals."

### Other Traits

Many others are economically important and are heritable to some degree. Many qualitative (simply inherited) traits, ranging from lethals on one extreme to aesthetic traits on the other, can be important under some circumstances. Artificial insemination, particularly frozen semen, has caused concern because of possible widespread dissemination of undesirable genes. The genetics of the situation have been studied, however, and with present knowledge potential dangers apparently can be avoided.

Traits other than those mentioned also are important. Mastitis resistance, for example, is of extreme economic value and has measurable heritability. Further, a certain amount of direct pressure for resistance will be exerted from culling of mastitic animals, although clinical cases may remain in a dairy herd for years under proper treatment.

### Summary - Genetics

Present knowledge of genetics of dairy cattle suggests that major selection emphasis should be placed on milk yield, with enough selection pressure on fat percentage to maintain composition of milk at legal standards. Other components of milk may become important if pricing systems change to emphasize them. Care should be taken to include as few traits as practical in a selection program, since progress in milk yield may be sacrificed to a degree such that total profit per cow may decrease. This is especially true with traits of low heritability and only slight genetic relationship to milk yield (for example, body size and confirmation). Reproductive efficiency and resistance to mastitis may appear as economically important traits in future sire proving systems.

## THE USDA SIRE PROVING SYSTEM

Proving of dairy sires on a national basis was initiated in the United States in 1933 by the United States Department of Agriculture (USDA); proofs were by dam-daughter comparison. The method was changed to daughter-herdmate comparison in 1962. After some modification in 1965, this method took into consideration for each sire the number of daughters; number of records per daughter; length of projected records; number of herds represented and the distribution pattern of the daughters across herds; number of herdmates per daughter; and the genetic differences between herdmates.

The modified contemporary comparison (MCC) was implemented in October 1974, and attempted to take into consideration items previously not included or not handled well. These additions or enhancements included genetic differences in herdmates, pedigree information, daughter distribution over herds, length of lactation, number of herdmates, and the number and average repeatability of herdmate sires. The MCC was used until January 1989.

Starting in 1948, work by C.R. Henderson at Cornell University applied linear model techniques to sire proving. Results of Henderson's research efforts have been described in a series of scientific articles through the years by Henderson, his students, and his colleagues. The methodology he developed is known as best linear unbiased prediction (BLUP). The techniques are well accepted and BLUP today is without doubt the preferred method of sire evaluation.

These methods have been used in the Northeast AI Sire Comparison Method (NEAISC), developed at Cornell, since 1970. The availability of increased computing power has made implementation of these techniques for simultaneous evaluation of sires and cows possible at the national level. The result is the current Animal Model evaluation system implemented by the USDA on a supercomputer. Genetic evaluations from this system were first made available to dairymen in July 1989.

### The Animal Model

The Animal Model does many things notably different from previous evaluation systems. These include simultaneous evaluation of all sires and cows. This means all information on all relatives is used to increase the accuracy of any one animal's evaluation. This also means that cow families are directly included in the evaluation of all sires and cows, effectively eliminating the basis for previous objections by some breeders. All female ancestors and descendants are used in the evaluation of both sires and cows, weighted by how closely they are related. Since all known relatives of both registered and grade cows are used, computing the evaluations for the Holstein breed requires simultaneous solution of about 50 million equations!

Other changes include correction for genetic merit of mates, use of a new genetic base (average of all cows born in 1985, called PTA90), new ways of using records on cows missing first records and cows changing herds, and definition of different management groups for registered and grade cows. Table 4 displays some differences between the new Animal Model evaluation and the old MCC.

There is some new terminology with the Animal Model emphasizing that new methods are truly different.

*Predicted Difference (PD) changes to Predicted Transmitting Ability* (PTA), or one-half the breeding value. This is the prediction of what the sire transmits to his offspring.

*Cow Index changes to Predicted Transmitting Ability* (PTA).

*Repeatability (RPT) changes to reliability*. Repeatability always has been a misnomer as used by the USDA in this context anyway. Since reliability includes contributions from additional relatives, reliability figures should be higher than the old repeatabilities. The biggest difference is for sires of cows with few daughters compared to those with many. A sire with no daughters would have a reliability of 37%.

*Percentile (%ILE) is sire's ranking based on the active AI bull population; for cows it will be based on cows with recent lactations. The rankings are based on an index (PTA PRO$, see below) including milk, fat, and protein evaluations. Previously they were based on an index including only milk and fat.*

As good as the new Animal Model system is, it cannot correct for preferential treatment of daughters of certain sires. No genetic evaluation system can. Random AI sampling of young sires and wide daughter distribution will continue to be important in establishing accurate first evaluations. This also is true for sires with relatively few daughters.

## Economic Evaluation of Sires and Their Semen

Predicted transmitting ability for dollar value (PTA PRO$) is based on milk, fat, and protein evaluations. Current national prices are used. For the July 1989 run these were $11.20 per hundredweight of milk containing 3.5% milk fat and 3.2% protein. Hence the equation for estimating PTA PRO$ is

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-PTA PRO$  =  $.0242(PTA milk)+
                   $1.54(PTA fat)+
                   $1.09(PTA protein)
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Note that the dollar value is computed from pounds fat and protein produced, not percentages. Percentile rankings are based on this index. In Florida, the milk price is higher than almost everywhere else in the United States, and the dollar values of superior sires should be proportionally higher. The ranking of bulls by evaluations would not change much, but the net value over their semen price would.

Taking advantage of considerable previous research, Marsha Wilcox and coworkers developed techniques to aid dairymen in the selection of semen to purchase for herd use. The concept is that of net present value (discounted net income) of semen. Although the method is computationally elaborate, availability of microcomputers to dairymen will permit each to develop a system of evaluating semen based on a set of selection criteria tailored to individual needs. Information necessary for semen selection include sire proof for milk, fat, protein, type (PDT), interest rate, and such management parameters for the individual herd as conception rate, calving interval and female mortality rate. Outcome of this linear net merit index for semen is Present Value Dollars (PV$). These researchers then evaluated a number of possible economic and management situations to determine the effects on sire selection; considerable shifting of rank occurred with changes in criteria. For one sample selection program (all selection pressure on milk, none on desirable type), rank correlations of PV$ and PDM, and PV$ and PD$ + semen price, were .56 and .52. Such procedures should prove useful and profitable to dairymen who are able to characterize their own management parameters and to define their selection goals. Thus, the concepts of proving sires are not difficult. Efforts to obtain better estimates, thus increasing rates of genetic improvement, continue to make the exact calculations and formulas very complex.

## SELECTING SIRES FOR A SINGLE HERD

Most of the factors involved in sire selection have been covered in earlier sections, but one major question remains. Will the sire which has been proven to be superior in other herds also be superior in my herd? Older breeders will remember the term "nicking," which is not too often heard anymore. If a sire did well in one herd and poorly in a second, he was said to nick well in the first, poorly in the second. Today, researchers look at the importance of nicking by studying the importance of sire by farm interactions. Such interactions arise if there are real changes in the relative performance of sires (usually measured by the milk yield of their daughters) as they are used on various farms. Should there be an appreciable number of sires which rank high in some herds or farms, and low in others, and vice versa for other sires, this would show up as a sire-by-herd interaction.

The importance of this question is apparent; if there were such interactions, a dairymen would be unable to rely on USDA sire proofs, since he could not depend on sires with superior proofs to be superior in his herd. This was an area that obviously needed research, and during the past several years considerable research has been published on the subject.

A classic study by North Carolina scientists involved sire-by-region interactions. The two regions involved were North Central and Southeastern United States and the question essentially was, "Do AI sires used in these two areas rank about the same, or are there some who are outstanding in one region but poor in the other, and vice versa?" Much of the semen used by Florida dairymen is from sires bred, house and proven in the Eastern and North Central United States, so this question was of immediate concern. Results showed that this particular type of interaction was not an important factor, and indeed was almost nonexistent. The authors stated, "provided adequate unbiased progeny information is utilized, a bull may be safely selected and used for artificial insemination in one region, even though he was evaluated in the other region."

Studies on the importance of sire by herd interactions have been in very close agreement, with one being conducted by Florida researchers on records of Florida DHIA Guernsey, Holstein and Jersey first-calf heifers. Everyone recognizes that even the best bull may have a certain number of poor daughters. and that a dairyman who has only a few daughters of a particular sire may have been unlucky, by chance, and gotten one or more of them. The opposite can happen also with poor sires. The problem is to determine how important the interactions are overall, realizing that a certain amount of shifting in rankings of sires can occur by chance, particularly if a sire is represented in one or more herds by only a small number of daughters.

The research found that under Florida DHIA herd conditions, these interactions were of little or no practical or theoretical consequence for milk and fat yields. There was some evidence among Guernseys and Jerseys of an interaction for fat percentage; this has been suggested in other research studies also, but many of the scientists who have studied interactions have not looked at fat percentage.

In summary, it appears that sires proven superior for milk and fat yields in other herds can be used with confidence in Florida dairy herds, without concern for possible sire by herd interactions. The possibility exists for the presence of interactions with fat percentage.

## FINDING SUPERIOR FEMALES

Measurements for most of the economically important traits can be made directly on females. It frequently takes a long time to get the measurements of interest, however. Mature body size, for example, would have to wait until the cow is 6 to 8 years old. An estimate of milk yield must wait until the first lactation is completed (at about 3 years of age), unless one accepts an estimate of the lactation based on the first several months.

These points are mentioned because genetic progress is influenced by the time at which measurements are made, and their reliability. Take milk yield as an example. An estimate of the milk producing ability of a cow comes with her first milk record. Certainly, however, one knows more about her when there are two records rather than one, and even more with three records. Generally, the more records available, the more reliable the estimate of her real ability; but it takes longer to get more records.

An estimate of the producing ability of a cow was called "Most Probable Producing Ability" years ago by Dr. J.L. Lush, well known animal geneticist. This measure (MPPA) takes into consideration the idea of repeatability, and shows how the number of records a cow has should influence the estimate of her producing ability. If a heifer produces more than her herdmates during her first lactation, we will certainly guess that she is a better than average animal. If the average of her first two records is above herdmates, one would be even more confident that she is truly above average, and her good performance did not just happen from some favorable accident which probably will not happen again.

The calculations are simple and can be applied to any trait of interest. Although the concept is rarely mentioned today, since availablity of computers makes more sophisticated procedures feasible, MPPA serves as the basis for modern methods. For example, state the milk record, or any other measurement, as a deviation from herdmates. If the cow has two measurements, state each as a deviation, and take the average. Use the repeatability value from Table 1, or from some other research source. MPPA then can be calculated as:

$$\text{MPPA} = (\text{average deviation}) \times [(nr)/(1 + nr - r)]$$

where n = the number of measurements and r = the repeatability. How much better two measurements or records are than one, as far as reliability, is determined by a similar equation.

$$\text{Gain in accuracy} = 1 - [(1 + nr - r)/ n]$$

with n and r as in MPPA. It seems logical, as shown by Table 5, that the more records one has on a cow, the more one can accept her records at face value. If she has six records averaging 2000 pounds better than her herdmates, the best guess of her MPPA is 1714 pounds better.

Which cow should be selected as a dam for a future herd sire, a cow with two records averaging 3000 pounds above herdmates, or one with four records averaging 2400 pounds above? The two estimates of MPPA are close, being 2000 pounds for the cow with two records and 1920 pounds for the older cow. One probably would look at other characteristics of the two animals, particularly fat percent but possibly others, before making a decision. The more sophisticated and useful application of this concept, of course, is that it is incorporated into calculations of ERPA.

## GENETIC CHANGE IN MILK YIELD

The theoretical upper limits of genetic change in milk yield have been known for quite some time. Knowing the various repeatabilities, heritabilities, generation intervals and selection pressures (intensities), one can calculate what would be expected to happen. This tells nothing about what is actually going on, of course, but it does tell what one can expect under the best conditions.

### Potential

If milk yield is given maximum emphasis in the selection program, with little or no pressure being exerted on other traits, and efficient use is made of an AI sire proving program, the maximum attainable genetic change in milk yield is slightly over 2.0% per year. Most of this, over 90%, theoretically would come directly or indirectly from sire selection. In a Holstein population averaging 15,000 pounds per cow, this would amount to 300 pounds per year. Though this estimate has appeared disappointingly small to some breeders, it is more than the actual total (genetic plus environmental) change which has been attained in the United States.

### Observed

It is only in recent years that it has been possible to obtain reliable estimates of the actual genetic change which has occurred in milk production. A major problem in the actual measurement of such progress is that environmental and genetic changes are confounded in such a manner over time as to make their separation extremely difficult. With the availability of high-speed large-capacity electronic computers, many of the problems can now be handled. Use of the animal model has improved the accuracy of the estimates.

As far as progress arising from selection of males and females, theoretical estimates have been right on target. About 90 to 92% of all genetic change in milk yield has occurred from sire selection; this represents the selection of males and females to produce herd sires and the selection of males to produce herd dams. The remaining 8 to 10% of genetic progress arises from selection of females to produce herd dams. The fact that we must raise nearly all female calves born alive in a population to maintain population size, and the difficulties of evaluating the true genetic merit of dams, precludes much selection pressure from selection of dams.

Average annual genetic change in milk yield of tested dairy cattle has been variable but seems to be about 0.7% of their average levels. This would amount to about 105 pounds per cow in a 15,000 pound herd, or 140 pounds in a 20,000 pound herd. In individual herds, one would expect to find genetic changes which were considerably higher or lower. If 2.0% annual genetic change is possible, as theory suggests, dairymen are progressing genetically only about one-third as fast as possible.

**Table 1.** Repeatability of economically important traits of the dairy cow.*

| Trait | Repeatability |
|---|---|
| Milk yield | 0.50 |
| Fat yield | 0.50 |
| Fat percentage | 0.75 |
| Protein yield | 0.40 |
| Protein percentage | 0.60 |
| Conception rate | 0.60 |
| Persistency | 0.60 |
| Overall type score | 0.50 |
| Dairy character score | 0.40 |
| *Refers to repeatability from year to year. | |

**Table 2.** Heritability of various traits of dairy cattle.

| Trait | Heritability | Trait | Heritability |
|---|---|---|---|
| Milk yield | 0.2-0.3 | Mature weight | 0.4-0.6 |
| Milk fat yield | 0.2-0.3 | Wither height | 0.4-0.6 |
| Protein yield | 0.2-0.3 | Heat tolerance* | 0.0-0.2 |
| Total solids yield | 0.2-0.3 | Conception rate | 0.0-0.1 |
| Milk fat percentage | 0.5-0.6 | Reprod. efficiency | 0.0-0.1 |
| Protein percentage | 0.5-0.6 | Calving interval | 0.0-0.2 |
| Persistency | 0.3-0.5 | Life span | 0.1-0.3 |
| Peak milk yield | 0.2-0.4 | Feed efficiency | 0.3-0.4 |
| Milking rate** | 0.3-0.6 | Mastitis resistance | 0.2-0.3 |
| Gestation length | 0.3-0.5 | Overall type score | 0.1-0.3 |
| Birth weight*** | 0.3-0.5 | Dairy character score | 0.1-0.3 |
| *Response to standard test. | | | |
| **Peak or average flow. | | | |
| ***Nonmaternal. | | | |

**Table 3.** Direct and correlated response from single trait selection (Holsteins).

| Trait | Milk yield (lbs) | Fat yield (lbs) | Fat percent | Protein yield (lbs) | Protein percentage |
|---|---|---|---|---|---|
| Milk yield | 607* | 23.3 | -.036 | 13.7 | -.018 |
| Fat yield | 443 | 34.7* | .058 | 14.1 | .010 |
| Fat percentage | -287 | 24.1 | .190* | 3.4 | .051 |
| Protein yield | 428 | 23.2 | .014 | 14.3* | .014 |
| Protein percent | -231 | 7.2 | .084 | 5.9 | .075* |
| *See explanation in text of Correlated Response. | | | | | |

**Table 4.** Comparison of present Animal Model and older sire proving system (MCC).

| Characteristics | Animal Model | MCC |
|---|---|---|
| Animal evaluated | All (simultaneously) | Recent only (sires, then cows) |
| Merit of mates considered | Yes | No |
| Dams contribute to sons | Yes | No (ancestor merit includes maternal grandsire) |
| Sons contribute to parents | Yes | No |
| Daughters contribute to dams | Yes | No |
| Lactations included | 1-5 | 1-15 |
| First lactation required | Yes (cow without first lactation records evaluated separately) | No (cows without first lactation receive less weight) |
| Later herd lactations included | Yes (in separate evaluations) | Yes |
| Reliability components | | |
| Parents for males | Yes | No |
| Daughters for females | Yes | No |
| Sons | Yes | No |
| Environmental group definition | Management group (registered grade 2 mo, flexible) | Contemporary group (5 mo centered) |
| Base definition | Birth year | Calving year |

**Table 5.** Most probable producing ability of a hypothetical cow.*

| Number of records | MPPA** (pounds) | Gain in accuracy*** (percent) |
|---|---|---|
| 1 | 1,000 | -- |
| 2 | 1,333 | 25 |
| 3 | 1,500 | 33 |
| 4 | 1,600 | 38 |
| 5 | 1,667 | 40 |
| 6 | 1,714 | 42 |

*Cow averaged 2,000 pounds (2x, 305-day, M.E.) more than her herdmates in 1, or 2, or 3 etc. records; all estimates based on a repeatability for milk yield of 0.5.

**Best estimate of a cow's producing ability compared with her herdmates.

***Improvement in reliability of estimate compared to estimate based on only one record.