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THE RELATIONSHIP BETWEEN A. I. SIRES AND THE INDEX VALUE OF THEIR DAMS

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Robert W. Everett
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THE RELATIONSHIP BETWEEN A. I. SIRES AND
THE INDEX VALUE OF THEIR DAMS

By

ROBERT W. EVERETT

AN ABSTRACT

Submitted to the College of Agriculture
Michigan State University
in partial fulfillment of the requirements
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MASTER OF SCIENCE

Department of Dairy

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Approved _ _Clinton E. Meadows_ _ _ _

ABSTRACT

THE RELATIONSHIP BETWEEN A. I. SIRES AND
THE INDEX VALUE OF THEIR DAMS

by Robert W. Everett

To study the value of selection indexes in a Young Sire Program, 126 artificially proven sires which met the qualifications of having at least 25 artificial daughters, 5 natural daughters, and pedigree information on the dam of the bull and her relatives were used. The dam's side of the pedigree was completely analyzed by compiling all the available production records on (1) the bull's dam, (2) the dam's dam, (3) the dam's daughters, (4) the dam's maternal sisters, and (5) the dam's paternal sisters. All records were converted to a 305-day, 2X, mature equivalent basis and were deviated from the 305-day, 2X, mature equivalent herd average.

The 126 cows (dams of the bulls) had 704 lactations which averaged 1,420 pounds of milk above herd average for all records and 1,847 pounds above herd average for first records. There were 79 dams with 385 lactations which averaged 1,432 pounds of milk above herd average for first records and 1,117 pounds of milk above herd average for all records. The 258 daughters had 1,043 lactations which

had an average deviation of 684 pounds of milk for all records and 1,176 pounds of milk for first records. The 171 maternal sisters had 758 lactations with an average deviation of 531 pounds of milk for all records and 947 pounds above herd average with first records. There were 5,910 paternal sisters which averaged 186 pounds of milk above the herd average.

The A. I. Proofs ranged in numbers of daughters from 25 to 1,326 and from 5 to 120 daughters for the Daughter-Dam Comparison and the Natural Proof. To correct for unequal numbers, the A. I. Proofs were regressed with the factor N/(N + 12) and the two non-A. I. Proofs were regressed by the factor N/(N + 16).

The dams of the bulls were indexed using first records and the average of all records by McGilliard's (1962) selection index. The index using first records correlated with the A. I. Proof + .148 and the index using all records with the A. I. Proof + .149. The dam's index correlated approximately one half as much as the correlation between the A. I. Proof and either non-A. I. Proof.

If the sire's side of the pedigree would yield as much information as the dam's side, a complete pedigree with information on the dam and a sire which has an A. I.

Proof may yield as much information on a young sire as a Natural Proof could yield.

The advantages of a young sire program are: (1) high selection intensity, (2) lower initial cost per sire, (3) an earlier A. I. Proof on the sire, and (4) a longer A. I. service life.

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INTRODUCTION

Genetic improvement in milk production in dairy cattle can be achieved by culling the poor cattle and saving offspring of the superior individuals. The genetic superiority of an individual can be estimated by its pedigree, its own performance, and its progeny. To evaluate the genetic potential of the sex-limited trait in the non-producing male involves consideration of the pedigree and progeny. Individuality and ancestry furnish the only basis of selection for a young bull calf. Type is little correlated with production, and this leaves the study of the ancestry as the main basis of selection.

The present trend in Artificial Breeding units (A. I.) in proving bulls is the "Young Sire Program." The procedure is to select the best young bulls to test and to do the final selection after the tests are available. From a large number of young bulls, it is proposed to sort out the bulls of highest potential merit by the use of a selection index which weights the records of the ancestors to estimate best the genetic potential of the bull. The final selection of the bull for extensive use would be on the A. I. proof.

The young sire would be the son of a selected and superior proved A. I. sire whose proof would be an accurate indication of his genetic ability. The dam, however, may have few records, and her production alone may not yield the best estimate of her genetic ability. Thus, the accuracy of the selection of young sires seems to depend on how accurately the dam's genetic ability can be predicted.

The purpose of this study is to evaluate the accuracy and usefulness of available selection indexes in selecting dams of young sires.

REVIEW OF LITERATURE

<u>Sire evaluation</u>

Professor Nils Hansson, in 1913, suggested that a rating of sires for fat percentage could be obtained by placing the daughters half-way between the sire and dam. No method of rating sires on milk quantity was proposed. The first sire index published as a commercial advertisement was the Mount Hope Index by Dr. Hubert D. Goodale in 1927. This index had the feature of doubling the difference between daughters and dams to predict the bulls genetic ability for milk, fat, and fat test (Prentice, 1935).

Rice (1933) suggested the following three standards be met by sire indexes: (1) the index must be simple and easily understood by the average dairyman, (2) it must employ both the dams' and daughters' records, and (3) it must be a definite numerical statement of the bull's potential.

In the United States there are many and varying methods used to evaluate a bull's genetic ability. These usually vary with location and involve different adjustment factors for seasons, years, and number of progeny. O'Connor (1962) has outlined the methods used in Europe

which range from the daughter-dam comparison used in France to the progeny testing stations used in Denmark.

The basic types of proofs are: (1) the sire's daughter level or the average 305-day production of the sire's daughters, (2) the daughters' production minus their contemporary stablemates' average production, and (3) a comparison of daughters with their dams. There are many modifications of the ones listed above being used in the United States and Europe.

Edwards (1932) evaluated five methods of expressing a progeny test: (1) the daughter-dam comparison, (2) the Equal Parent Index, (3) the Mount Hope Index, (4) a regression index, and (5) the average production of the daughters of a bull. The index which most closely approached the ideal was the average production of the daughters of a bull without reference to the dams' records. The minimum number of daughters necessary for an accurate index was six.

Gaunt and Legates (1958) studied five measures of a sire's transmitting ability using 6,949 daughter-dam pairs in 2,420 herds. The five measures were: (1) the daughter average, (2) the daughter-dam difference, (3) the equal-parent index, (4) the daughter-contemporary herd difference, and (5) the daughter-contemporary herd index.

Contemporary DHIA herd averages were used in (4) the daughter-contemporary herd difference and (5) the daughter-contemporary herd index. Correlations between each of the five measures and the average of a specific number of future artificially sired daughters were computed. The daughter average appeared to be about as reliable as the equal parent index or the daughter-herd index in predicting future production of daughters. As the herd average included the daughters in question, using a contemporary herd average which excludes the daughter in question in the two daughter-herd measures should improve their accuracy as a measure of a sire's breeding value.

O'Bleness et al. (1960) compared the New York method with 17 other methods of ranking A. I. sires. The New York procedure is the most difficult computationally. Correlations were estimated between sire estimates for each procedure and the New York method which was used as the control. The 17 procedures were put into five groups. Group 1 included deviations of the daughters' averages from various contemporary averages; Group 2 was deviations of averages of first records from contemporaries; Group 3 was the percentage of average records exceeding contemporaries; Group 4 was percentage of first records exceeding contemporaries; and Group 5 was actual averages and actual averages adjusted for stablemates. When all sires regardless of the number of daughters were included, Group 1 correlations with the New York method were about .77; Group 2, .69; Group 3, .69; and Group 4, .47. Unless the number of daughters is large, none of the procedures ranks the sires the same as the New York method. If adjustment is made for the number of daughters, the correlations all increase, but correlations for Group 1 are still the largest.

Touchberry et al. (1960) studied first lactation milk and butterfat records of 5,454 daughters of 305 Red Danish Milkrace sires tested at Danish testing stations and the first test year milk and fat records of 3,270 daughters of 110 of these same sires tested in farmer herds. Heritabilities of milk and fat at the test stations were higher than in the farmer herds. The genetic correlations between station tests and field tests were .68 for milk and .75 for fat. Independent field tests had genetic correlations of .94 for milk and .92 for butterfat. It was shown that the field test was superior for milk and fat if the number of daughters per sire was seven or more and fifteen or more, respectively. Selection on the testing station data was superior if there were less than seven daughters per sire for milk and less than fifteen for fat. For twenty daughters per sire, the field test was 1.14 and 1.02 times as effective as the station tests for milk and butterfat, respectively.

In New York, bulls are sampled and subsequently are selected on the basis of their progeny tests. Heidhues et al. (1960) studied the validity of this procedure of sampling bulls which depends upon the assumption that the daughters of a sire are a representative sample of all possible daughters. The actual proof was computed according to the method developed by Henderson. The data included 53 Holstein sires with at least 300 daughters each. The correlations were only slightly lower than the expected correlation from a sample of all possible daughters.

Berry (1952) proposed a plan in which each record would be expressed as a percentage of the breed class average. The system of breed class average (BCA) is presently used for age correction in Canada. The actual breed averages have been computed by ten-day intervals according to age from data over a five-year period. Official lactations are reported and are expressed as a percentage of the BCA for milk and for butterfat for 305 days. The daughters of a sire would be compared with their dams on the basis of percentage above or below breed average used in the equal parent, regression, or expectancy indexes.

Barr (1962) expressed his data on a BCA basis in his analysis of the selection of young sires.

Wilcox (1960) obtained the coefficients of variation of 9.64, 11.48, and 13.26 for the daughter average, the difference between daughter and herd average, and the contemporary comparison, respectively, as methods of testing sires. It was concluded that the method of the daughter average was easily the first choice among the three methods studied. It had the lowest coefficient of variation, is easiest to compute and makes use of all the data whereas some individual records may not be used in the other methods. The difference between daughter and herd average was second and the contemporary comparison third. The contemporary comparison method was criticized in that it may not make use of all single records.

From the regression of future daughters on present daughters, it was concluded by Wilcox (1960) that the first twenty daughters give a reliable estimate of the production of the future daughters under conditions of random mating and random distribution of daughters in tested herds.

Sendelbach *et al.* (1957) studied the number of A. I. daughters necessary to predict a sire's A. I. performance and the repeatability of natural service daughter averages in A. I. Fifty-one sires with 100 or more A. I. daughters were used. The first 50 daughters as well as the fifty-first through the one hundredth were regressed on the first 5, 10, 15, through 50 A. I. daughters. Both methods, the first fifty and the second fifty daughters, yielded similar results which indicated that 20 to 30 A. I. daughters are sufficient to estimate future A. I. daughters with reasonable accuracy. The first 50 A. I. daughters were regressed on the first 5, 10, 15, through 50 natural daughters. The results showed that the ability to predict the performance of A. I. daughters from natural service records is low, approximately one half that achieved in artificial service. The regression coefficient of future daughters on the first 25 daughters was .61 which equals $N/(N + 16)$, if no environmental correlations are present.

Specht (1957) measured the regression coefficient of A. I. future daughters on _N_ tested A. I. daughters to be $N/(N + 11.9)$ for milk and $N/(N + 16.4)$ for fat. Specht also cited Legates _et al_. (1956) as obtaining values of $N/(N + 16)$ for milk and $N/(N + 13.8)$ for fat. Robertson and Rendel (1950) were cited as using the regression of $N/(N + 15)$ when heritability equals .25. Carter was cited as finding a regression of $N/(1.1N + 14.9)$ with one record per cow from New Zealand. Henderson was cited as using the factor $N/(N + 12)$.

Lush (1935) demonstrated that the superiority of the progeny test over the individual's phenotype for a given trait is greatest where heritability is low and under conditions where the offspring do not resemble each other for reasons of having been under common environmental conditions. If the trait is highly heritable or the progeny resemble each other very much, then many more than four daughters will be needed to equal the individual's own phenotype and under certain conditions it is impossible to equal the individuals own phenotype. The progeny test is needed in a sex-limited trait, as in milk production in dairy cattle. For traits which the sire cannot express, there is nothing but a pedigree estimate of the sire against which to compare the accuracy of a progeny test. A progeny test surpasses the best pedigree estimate when there are three or more progeny except where the offspring resemble each other very closely. In actual practice the pedigree becomes available first and progeny testing comes last. Care should be taken not to let early selection on the pedigree exhaust selection on the progeny test.

Barr (1962) has shown that very complete pedigree information on a young sire gives as much information as records on eight daughters of the bull. Lush and

McGilliard (1955) estimated that usually four or more offspring are needed to be of more value than the individual's own phenotype. Lush (1931) has shown that when there are as many as 4 to 6 offspring in a progeny test, the test will be about as accurate as an estimate based on a very complete pedigree. A pedigree would be more reliable than a progeny test if a bull's daughters in one herd are given very poor care compared to other bull's daughters which had very good environmental conditions. When environmental conditions for all cows are made as uniform as possible, the progeny test can approach perfection.

Lush and McGilliard (1955) have shown the amount of bias which is caused by the selection of N daughters with the largest records as compared to using all the daughters in a proof. Selection of a sire's mates will generally have been more intense than the selection of the daughters, but it introduces less bias. To use only the highest record of a cow is to say that her genetic ability is expressed most adequately in an environment which gives a superior phenotypic expression. The amount of bias for many combinations of selected records are given. Using the best record is especially unfair for comparing individual cows since all cows have not had an equal chance to be exposed to a superior environment.

Lush and McGilliard (1955) indicated that to correct for herd to herd differences which are estimated to be 80 to 90 percent environmental and 10 to 20 percent genetic, usually records are expressed as deviations from the herd average. Robertson et al. (1961) using data from England and Wales found that the mean contemporary comparison declined with increasing mean level of production. This decline was such as to imply that 20 percent of the differences in production between herds were genetic in origin.

Robertson and Rendel (1954) showed that A. I. bulls selected from elite herds are not genetically superior to a random sample of non-A. I. bulls in average herds, indicating that the management level is superior in the elite herds. Pirchner (1959) showed the heritability of herd differences to be .11.

Lush et al. (1941) discussed the major sources of error and the magnitude of the error in estimating breeding values. Bias due to differences in selection intensity and the use of lifetime averages was also discussed.

Carter (1961) studied the sampling of young sires in high herds and a random sample of all herds. Thirty-three Holstein sires with 100 or more tested daughters were selected. The daughters' records were expressed as deviations from their contemporaries and were divided into 5 equal groups from high to low, according to production. A regular daughter study was made independently. The records of 19,652 A. I. cows from 33 sires with a minimum of 20 daughters per group per sire were used. The sires were ranked according to the butterfat production of their daughters using the New York method with adjustments for herds, years, season of calving, and number of daughters. These data indicated that young sires can be sampled in elite herds and still be ranked with a reasonable degree of accuracy. High or low herds are less desirable than the average level herds for sampling young bulls.

From the progeny tests of sons from superior and inferior parents, Varo (1959) found that the "relative evaluation method" (based on deviations from herd averages) is a more accurate guide to the breeding value of a sire for milk yield than the actual average yield of his daughters. This accuracy would be expected to increase in the future if artificial breeding reduces the existing genetic differences between herds. It was found that the accuracy of the progeny test based on a given number of daughters was greater in herds of higher production. However, it was also found that the ranking of different bulls was similar at different production levels. The average fat content of the milk in the herd had no influence on the accuracy of progeny testing for milk yield.

Fifty-seven Friesian, 8 English Ayrshire, and 11 Scottish Ayrshire A. I. bulls with at least 100 "effective daughters" were analyzed by Robertson _et al_. (1961). The herd-years were divided into 3 equal groups on the basis of the average heifer yield of both daughters and contemporaries (high, medium, and low producing herd-years). Three independent contemporary comparisons were calculated for each bull. The variance between and within sires increased with the mean level of production, but almost exactly in parallel with each other such that the heritability, and, consequently, the accuracy of the progeny test for milk yield was effectively the same at all production levels.

Van Vleck _et al_. (1961) analyzed deviations of records from different contemporary averages according to the following model:

$$Y_{ijk} = u + h_i + s_j + e_{ijk}$$

where u is the 5-year breed-season average, h_i is the effect due to the ith herd-year-season, s_j is the effect due to the jth sire, and e_{ijk} is the random element associated with the ijkth record. The components were assumed to be independent and to have zero means. The four types of deviations were: (1) regressed adjusted stablemate averages, (2) adjusted stablemate averages, (3) stablemate averages (all records made in the herd, excluding the cow), and (4) herd averages (includes the record of the cow). The properties of the best model included: (1) unbiasedness and (2) an estimator with a small variance. The first three procedures give unbiased rankings of the sire effects. The fourth is biased by a factor which depends on the number of stablemates. If the bias were constant, the ranking would not change. The smallest variance of a deviation is given by the fourth method, but this method is the only one that gives a biased estimate of the rank. In the unbiased ranking procedures, the smallest variance is given by the deviations from regressed adjusted stablemate averages. This method was considered the best of the four.

TABLE 1

The Comparison of A. I. and Non-A. I. Sires[a]

Breed	No. of A.I. Bulls	No. of A.I. Daus.	No. of Nat. Daus.	Superiority of A. I.
Friesian	14	332	403	+26 ± 13
Shorthorn	31	803	975	-5 ± 6
Guernsey	11	288	351	-14 ± 10
All	56	1,423	1,729	+1 ± 5

[a]Robertson and Rendel, 1954.

Robertson and Rendel (1954) analyzed the performance of heifers sired by A. I. and natural service. A large percentage of the A. I. bulls were pedigree bulls, and those that were not generally had a pedigree sire. The A. I. animals produced almost exactly as much as the non-A. I. animals in the same herd. In fat percentage the A. I. animals were superior in all breeds. The A. I. bulls were not genetically superior to the non-A. I. bulls in milk yield.

Tucker et al. (1960) used 6,888 records in North Carolina and found first lactation contemporary comparisons showed A. I. progeny to average 366 pounds of milk and 15.7 pounds of fat more than naturally sired progeny.

Wadell et al. (1960) found that first lactation records of A. I. daughters averaged 199 pounds of milk and 2.5 pounds of fat below the herd average. The second records of A. I. daughters averaged 50 pounds of milk and 4.5 pounds of fat above the herd average.

Specht (1957) utilized information from 34,073 Holstein cows and found evidence to suggest that bulls used by the A. I. studs have not substantially increased the milk producing ability of the population.

In herds of less than 100 cows, progeny testing was less efficient than selection of young sires based on the production of their dams (Specht, 1957). Progeny testing had a slight advantage in herds of 100 to 200 cows. Progeny testing in A. I. populations of 2,000 to 10,000 cows gave evidence of making possible 1.5 to 2.3 percent annual genetic gain of the average annual yield. A progeny testing scheme with young sires was estimated at 1.7 to 1.8 percent annual genetic gain of the annual yield. It was concluded that the most reliable method of improving the genetic merit of the dairy population was the selection of young sires and the saving of the best of these young sires. Seath (1940) showed the indicated hereditary improvement resulting from culling cows to have a range of 25 to 38 pounds of milk and .28 to 1.55 pounds of fat per year. In contrast to the predicted annual genetic gain from progeny testing sires, culling cows would yield an annual genetic gain of approximately .2 percent of the average annual yield.

Selection indexes

Wright (1940) outlined the principles underlining progress in livestock breeding. In the simple case, with many factors making the same additive contribution, there would not be any dominance and no environmental variability. Under these conditions, selection of the best animals should give the most rapid progress. The average

contribution of the gametes is indicated directly by the character of the individuals and any attention to pedigree or progeny tends to weaken the estimate of transmitting ability. Mating of unrelated animals maintains variability on which further progress depends. Much more progress is possible if the variability is due to multiple minor factors than if it is due to a few major ones. If there is a great deal of uncontrollable nongenetic variability, the character of an individual gives little information of its actual transmitting ability. The pedigree should be used as a preliminary test followed by a progeny test. The progeny should be from an unselected group to eliminate bias.

Lush (1937) showed that later records of high or low cows were not as high or low as their first records.

TABLE 2

Repeatability of Averages of Lactations[a]

No. of Records	Repeatability
1	.40
2	.57
3	.63

[a]Lush, 1937.

The data indicated that the major source of confusion in breeding selections are temporary things which can cause a cow's record to be high in one lactation and low in the next lactation. If dominance and nicking play a part, the data indicate that part usually to be a small one.

Copeland (1931) studied 694 Jersey cows which had at least one tested daughter and one R.O.M. son. The highest record of each cow was converted to 365-day mature equivalent basis by 1.15 factor. The correlation between the dam's record and daughter's record was .404. A cow's record was nearly twice as reliable a measure of the production of her daughters as was the production of her sons. This may have been due to the fact that the daughters of

TABLE 3

Correlations Between Bulls' Daughters and Bulls' Relatives[a]

Relationship	Bull's Daughters
Sire	.558
Dam	.331
Paternal Grandsire	.250
Maternal Grandsire	.427
3+ Maternal Sisters	.466
2 Maternal Sisters	.378
1 Maternal Sister	.357

[a]Copeland, 1934.

the cow were in the same herd and the son's daughters were in several herds, and corrections were not made for environmental differences. In general, the daughters showed about 32 percent as much variation from the breed average as did the dams.

Dickey and Labarthe (1945) studied the transmitting ability of young dairy bulls. The only criteria for selecting young bulls were pedigree and individuality. Using pedigree information, the data were analyzed according to Rice's Regression Index by regressing the sire's proof and the dam's records toward the breed average by a factor of .5. A second method used was to average the sire's proof and the dam's records. The regression method was superior in predicting milk and butterfat production of the daughter of the sire. The two methods are about equal in predicting butterfat test.

Eldridge and Salisbury (1949) studied the relation of pedigree promise to the performance of proved sires. The variables used were the mates of the bull, the maternal half sisters of the bull, the dam of the bull, the paternal half sisters of the bull, the dams of the paternal half sisters, and the paternal half sisters of the bull's dam. Forty-four percent of the total variance among bulls was accounted for by the mates of the bulls or the dams of the bull's progeny. The data were analyzed in the form of actual production records, thus differences between herds would probably account for a large amount of 44 percent of the total variance among bulls.

Multiple correlation squared (R^2) was .491, thus the other variables accounted for about 5 percent of the variance. The records of the dams could have been removed from the equation without affecting the results. There are no data within this study to evaluate properly the records of the dam in selecting the bull. The maternal half sisters of the bull or the daughters of the dam of the bull were deleted without affecting the prediction value of the equation ($R^2 = .490$). There were only 1.85 maternal half sisters per bull compared to 20 paternal half sisters.

The study indicated that the female relatives are of importance in the following order:

1. Average production of the paternal half sisters.
2. Average production of the dams of the paternal sisters.
3. Average production of the paternal sisters of the bull's dam.
4. Average production of the bull's dam.
5. Average production of the maternal sisters of the bull.

The bull's dam and the maternal half sisters of the bull showed almost no phenotypic relationship to the bull's daughters.

In farm animals, records on the sire and/or the dam are useful when early selection is desirable or when additional accuracy beyond the individual's phenotype is required. Young (1961) calculated the theoretical correlations between an individual's genotype and its relatives' phenotypes. The superiority of the selection index system over selection on an individual's phenotype was shown to be greatest where there are a large number of records on each individual and where heritability is small. When heritability is large, the gain by combined selection is small.

Lush (1947) compared individual merit, family merit, and the optimum combination of some attention to individual merit plus some attention to the average merit of the family as a basis of selection. The correlation between breeding values of members of a family (r) and the correlation between phenotypes of members of a family (t) must be very unequal if combination selection is to make much more progress than would be made by mass selection alone. Where r is far larger than t, adding family selection properly to mass selection will increase the gain considerably. Where t is far larger than r, considering family merit also will increase considerably the effectiveness of selection, but the attention to family merit should be negative. When t is very small, family selection and combination selection are nearly equal, their advantage over mass selection increasing distinctly with larger family size. At intermediate levels of t combination selection is distinctly better than either of the others but less is gained by making N large. Under all conditions the combination method is at least equal to the other methods, but at some values of r and t its superiority is hardly enough to make the extra computations worth while. The combination is most superior when r is moderate and t is much smaller, but yet well above zero, and where t is distinctly larger than r. Making N large increases the effectiveness of family selection and of combination selection markedly only where t is extremely small and r is very large. Inbreeding will increase the effectiveness of family and combination selection markedly, mainly by increasing r. Finally, family selection is most superior to mass selection when family members resemble each other least or where t is small.

Hazel and Lush (1942) compared three methods of selection: (1) the Tandem Method, (2) the Total Score Method, and (3) Independent Culling Levels. The Total Score Method is the most efficient, while the Tandem

Method is the least efficient of the three. A total score based on N equally important, uncorrelated traits is $\sqrt{N}$ times as efficient as tandem selection for the same traits, one at a time. The progress made in any one trait by the Total Score Method is only $1/\sqrt{N}$ times as much as if selection were directed at that trait alone.

Hazel (1943), in his paper on selection indexes, shows the opportunity for making progress depends upon making the correlation between the index and the genotype of the animal (R_{IH}) as large as possible. (H represents the sum of an animal's several genotypes.) Accordingly I is defined as: $I = b_1X_1 + b_2X_2 + - - - - - - + b_nX_n$, where the X's represent the phenotypic performance of the several traits and the b's are the partial regression coefficients chosen as to make R_{IH} as large as possible. These regression coefficients are calculated from N simultaneous equations. The statistics needed for construction of an index are: economic value of the trait or traits, standard deviations of each trait, phenotypic correlations between the traits of relatives and genetic correlations between the traits of relatives. Wright's method of path coefficients is convenient for calculating the more complex correlations between H and the phenotypic performance of the traits. To measure the genetic correlation (r_{GiGj}) was to correlate one trait (2) in one animal (i) with the other trait (l) in a relative (j).

The formula $r_{GiGj} = \sqrt{\frac{bi2jl.bj2il}{bi2il.bj2jl}} = \sqrt{\frac{(covi2jl)(covj2il)}{(covi2il)(covj2jl)}}$ was adopted because it was unbiased. The amount of genetic progress expected when a given index is used in making selections is proportional to R_{IH}.

Tabler and Touchberry (1959) used 20,024 single daughter-dam pairs in 1,703 different herds in constructing a selection index for milk and fat. A selection index for milk alone would be expected to be most effective in improving milk and fat yield in dairy cattle due to the genetic correlation between milk and fat of .77.

Tabler and Touchberry (1955) used 2,810 daughter-dam pairs in 414 herds with production records and type classification in constructing a selection index based on milk, fat, fat percentage and type classification. The first single record was used and adjusted to mature equivalent. Selection on other traits reduced the increase in milk production, especially when type was included in the index, since .07 was the genetic correlation between milk and type.

An index for intra-herd selection for fat production was derived by Legates and Lush (1954), utilizing the fat yields as deviations from the herd average of the cow, her dam, daughters, maternal sisters, and paternal sisters.

Statistics to construct the index were computed from 23,330 lactation fat yields of 12,405 Jersey cows on H.I.R. test. The intra-herd statistics needed to construct the index were: repeatability, .412; correlation between maternal half sisters, .073; correlation between paternal half sisters, .12; and heritability, .201. Herd differences accounted for 39 percent of the total variance. Within herds, the year-to-year variation in things which affected all cows alike accounted for 8 percent of the variance. A cow's records were weighted according to the number of records to get her true producing ability. The variance of averages of N records is (1 + (N - 1)V)/N times the variance of a single record, where V is the repeatability of records of the same cow. Each cow's phenotype should be multiplied by the inverse of its variance, N/(1 + (N - 1)V) to be weighted properly. A convenient way of accomplishing this weighting was to express each cow's phenotype as her most probable producing ability:

$$[NV/(1 + (N - 1)V)] \text{ (cow's average - herd average)}$$

The index derived was: $I = X_1 + .4X_2 + b_3X_3 + b_4X_4 + b_5X_5$; where X_1 and X_2 are the real producing abilities of the cow and her dam and X_3, X_4, and X_5 are the sums of the real producing abilities of the cow's daughters, maternal sisters, and paternal sisters.

Progress to be expected by using the index by Legates and Lush (1954) for selections would generally be about 1.10 to 1.15 times faster than making the selections on the cow's own performance alone. The exact ratio for a specific situation would depend on the number of records on the individual, on the number and kinds of relatives, and the amount of information on each. Genetic improvement = (G - G) = $r_{IG} \cdot z/b \cdot \sqrt{G}$ where *b* is the fraction of the population saved for breeding, *z* is the height of the ordinate of the normal curve at the point of truncation, *G* is the breeding value for fat production and *I* is the index or basis for selection.

Harvey and Lush (1952) constructed a selection index for type and fat production using the same data used by Legates and Lush (1954). Partial regression coefficients are given for type and production on a cow and her daughter with type equal in importance to production and type one-third as important as production. Partial regression coefficients are also given for type and production where production is expressed as the cow's most probable producing ability. Regressing a cow's records in this way would increase the weight applicable to production.

McGilliard (1962) constructed a selection index on an intra-herd basis using deviations from the herd average of information on the cow, her dam, daughters, maternal sisters, and paternal sisters. One index was constructed for fat-corrected milk production and another was constructed for type. Each index could be used independently or combined in a third index which weights the type index and the production index according to their economic importance and their standard deviations. In this study McGilliard's production index will be used and type will not be considered.

Dunbar and Henderson (1954) compared "approximate indexes" which included five requiring solutions to equations with varying subsets of data, and in certain instances, with records expressed as deviations from respective annual averages. Other "approximate indexes" examined, which required particular tabulations of the data, were the index described by Legates and Lush (1954), a modification of their index, estimated and real producing abilities, the individual's production average, and a ranking by the herd owner. The ranking of 57 cows indexed by the application of Henderson's procedure to 452 records on 142 cows accumulated during an 18-year period served as a basis for comparing certain "approximate indexes." These comparisons indicate that there is an advantage in combining the available information such that only a single set of equations need be solved, and also, in the absence of computing facilities for such a procedure, certain approximate indexes are accurate enough for practical purposes.

Lorenz (1960) studied a random sample of 5,502 Spotted Mountain cattle of Upper Swabia. The first annual yield of the daughters was compared with the average yield of their dams and with the average yield of their dams and granddams. Theoretically and practically it was concluded that the data on the yields of the granddams added little to the accuracy of estimates based on the yields of the dams; data on the half sibs of the dams were of no importance.

Mitchell et al. (1960) studied two breeding programs used by the Ayrshire Association in locating superior or Approved Dams. The "Original Plan" used production information of the daughters and the "Index Plan" used production information on daughters, dams, and herd averages. The results of the study demonstrated that the "Index Plan" does better than the "Original Plan" in picking out the genetically superior cows. It was concluded that the index was twice as effective as the "Original Plan."

Four methods of poultry selection were compared by Osborne (1957). With low heritability values a selection index with weights to individual phenotypes and family averages markedly excels selection on lines disregarding individual phenotypes.

Cooper (1962) in a study of the pedigree information of A. I. sires indicated that the Equal Parent Index is a fairly good indicator of how the bull's daughters will do in an A. I. proof, but is not a good indicator of the A. I. daughter level. An A. I. proof is usually computed as the deviation of the average production of all daughters of a sire from the average production of the contemporaries of the daughters. The A. I. daughter level is the average actual production of the daughters of a sire, such as 12,500 pounds of milk and 490 pounds of butterfat.

The study also showed that the bull's A. I. proof can be predicted from the dam's first record better for Holsteins than for Jerseys. Indications from this study are that the dam's average record is a reasonably good indicator of how the bull's A. I. daughters will produce. The three independent variables: (1) the dam's average record, (2) the sire's proof, and (3) the paternal grandsire's proof accounted for 36 percent of the variation in the dependent variable. These were all actual records, and no corrections were made for herds, years, or seasons.

Barr (1962) studied the daughters of 28 Holstein Friesian bulls as well as the pedigree information of the bulls. There were 19,033 lactations studied. Analysis of variance of the deviations from regressed adjusted herd-year-season-stablemate averages were effective in removing environmental effects within herds. A selection index using the information on the parents and grandparents was used to estimate the bull's breeding value. The product-moment correlation coefficient between the index and the bull's A. I. proof was .32. The selection index gave about as much information as eight or nine daughters.

SOURCE OF DATA

The proofs of the bulls used in this study were obtained from the D.H.I.A. Proved Sire List published by the Agricultural Research Service, U.S.D.A., and the records of the female relatives of the bulls were obtained from the Type and Production Year Books of the Holstein-Friesian Association of America. These were H.I.R. or D.H.I.R. records. Advanced Registry records were not usable because all cows in the herd need not be tested in A. R. and, thus, herd averages were not available.

Sendelbach *et al*. (1957) used 51 sires with 100 or more A. I. daughters to study the number of A. I. daughters necessary to predict a sire's A. I. performance. The results indicated that 20 to 30 A. I. daughters are sufficient to estimate future A. I. daughters with reasonable accuracy. The ability to predict the performance of A. I. daughters from natural service records was low.

One hundred twenty-six Holstein-Friesian bulls met the qualifications of having an A. I. Proof with at least 25 daughters and a Natural Proof with at least 5 daughters, and also pedigree information available on the dam of the bull. Pedigree information on the dam had to be available for the bull to qualify, while the bull's maternal granddam, maternal half sisters of the bull, and maternal and paternal half sisters of the dam of the bull were also used when they were available.

The bull's dam's records, the bull's maternal granddam's records, the bull's maternal half-sisters' records, and the records of the maternal sisters of the dam of the bull were obtained from the Type and Production Year Books. Since this study consists of the evaluation of the maternal side of the bull's pedigree, hereafter the bull's dam will be referred to as the cow, the bull's maternal granddam as the dam of the cow, the bull's maternal sisters as the daughters of the cow, and the maternal and paternal sisters of the dam of the bull will be referred to as the maternal and paternal sisters of the cow. There were a total of 634 non-paternal sister relatives of the cow with a total of 2,890 lactations. For each lactation a herd average during which that lactation occurred was recorded. If a cow completed her lactation in a given testing year, the herd average for that year was used regardless of whether the cow had started her lactation in the previous testing year.

The records of the paternal sisters of the dam of the bull were in the form of contemporary deviations obtained from the proof of the bull's dam's sire. This information was obtained from the D.H.I.A. Proved Sire List. There were 5,910 paternal sisters of the bull's dam.

Of the 126 cows, 79 had dams with records, 103 of the cows had a total of 258 daughters with records, 78 cows had a total of 171 maternal sisters with records and 76 cows had a total of 5,910 paternal sisters.

Table 4 shows that the cows are the most selected group and have a larger average deviation from the herd

TABLE 4

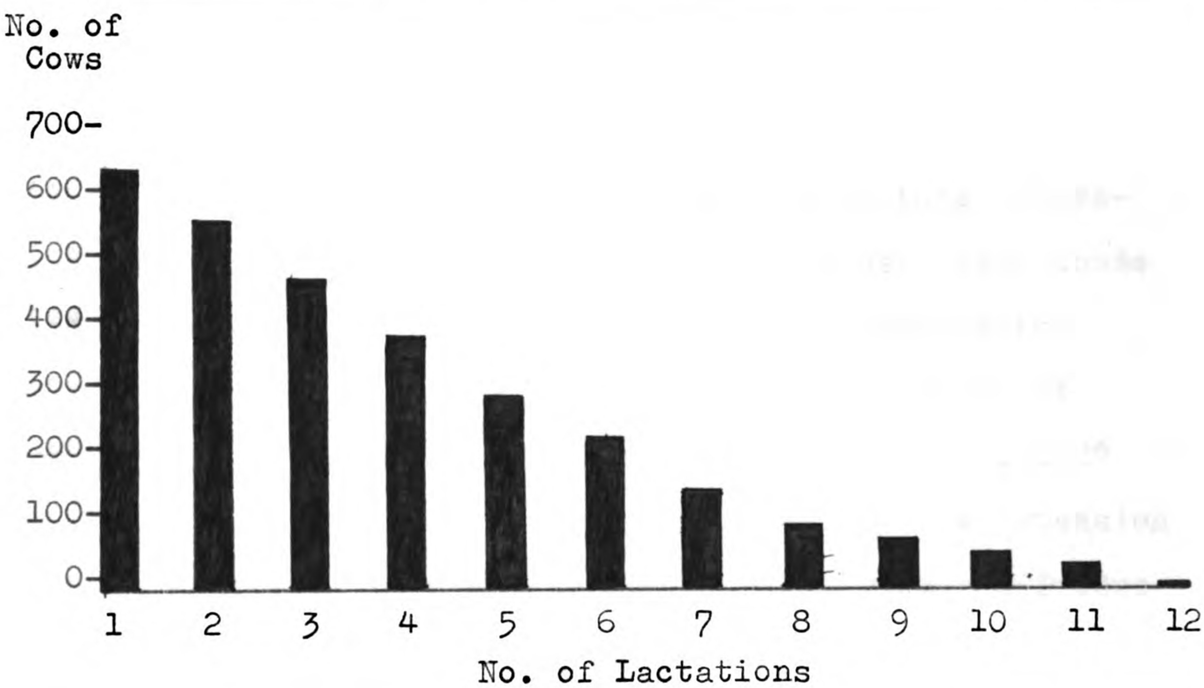
Numbers and Averages of Lactations

	No. of Cows	No. of Lacts.	Avg. No. of Lacts.	Avg. Deviations First	All
Cow	126	704	5.63	1,847	1,420
Dam	79	385	4.87	1,432	1,117
Daughters	258	1,043	4.04	1,176	684
Maternal Sibs	171	758	4.43	947	531
Paternal Sibs	5,910	---	----	---	186
Total	6,544	2,890	4.56	1,279	845

average than their relatives. The maternal sisters of the cow on the average have more records in a lifetime than the daughters of the cow, however, the daughters' average deviation is larger than the maternal sisters'. Many of the daughters of the cow may still be making records.

The distribution of lactations per cow is indicated in Chart 1. Chart 1 indicates that the cows used in the study are a select group with 5 of the 634 cows having at least twelve lactations. Over half of the cows had four or more lactations and one-third of the cows had six or more lactations.

Chart 1--Distribution of Lactations



METHODS AND RESULTS

Standardizing the records

A cow's records as published in the Type and Production Year Book consist of 90 to 365 days duration if H.I.R. and 90 to 305 days duration if D.H.I.R. Incomplete lactations of less than 305 days and the frequency of milking are indicated.

Herd averages are published annually and from 1956 to the present were calculated as 305-day, 2X, mature equivalent herd averages. From 1929 to 1955 the herd averages were merely averages of the actual annual milk and fat production with the average number of days in milk and the frequency of milking indicated.

Each lactation was converted to a 3.5 percent fat corrected milk basis and to a 305-day, 2X, mature equivalent basis. The mature equivalent factors used were those published in the Holstein-Friesian Type and Production Year Book (1959). Yearly herd averages which were not 305-day, 2X, mature equivalent herd averages; i.e., 1929 thru 1955 were extended to a 305-day basis by the extension factors published in the Holstein-Friesian Type and Production Year Book (1959) and multiplied by a factor of 1.10 to be considered 305-day, 2X, mature equivalent herd averages. According to the D.H.I.A. Proved Sire List, the factor used by the U.S.D.A. is 1.09. Herd averages which were 3X were converted to 305 days and considered as 305-day, 2X, mature equivalent herd averages.

Herd to herd differences which are estimated to be 80 to 90 percent environmental and 10 to 20 percent genetic (Lush and McGilliard, 1955; Robertson et al., 1961; Robertson and Rendel, 1954; and Firchner, 1959) were removed by deviating every 305-day, 2X, mature equivalent record from the corresponding 305-day, 2X, mature equivalent herd average.

Indexing the bulls

Selection indexes for dairy cattle by Tabler and Touchberry (1955, 1959), Legates and Lush (1954), Harvey and Lush (1952), Eldridge and Salisbury (1949), Barr (1962) and McGilliard (1962) have been discussed earlier. The selection index used in this study (McGilliard, 1962) was constructed on an intra-herd basis using all records as deviations from the herd average. The herd average hereafter will be considered as the average 305-day, 2X, mature equivalent production of all the cows during the testing year of the herd. The cows, dams, daughters, maternal sisters, and paternal sisters records are expressed as fat-corrected milk. The paternal sisters are weighted independently of the other combinations of relatives present and are additive while the weights for the other relatives are dependent upon the number of individuals in each group and the combinations present. Figure 1 shows the relationships between the groups of relatives used in the index. The symbols used in Figure 1 are:

G--genic value for milk production of the individual in question.

P--phenotypic value of the individual in question (reference may be to the average of all records or the first record of the individual).

E--the combined effects of environment, dominance, and epistasis.

A_{1G}--genotype of the first offspring of the young sire.

A_{1P}--phenotype of the first offspring of the young sire.

$\bar{\ }$--represents the average of the class involved ($\bar{A}_P$ is the average production per lactation of the daughters of the young sire).

B--the young sire.

S--the sire of the young sire.

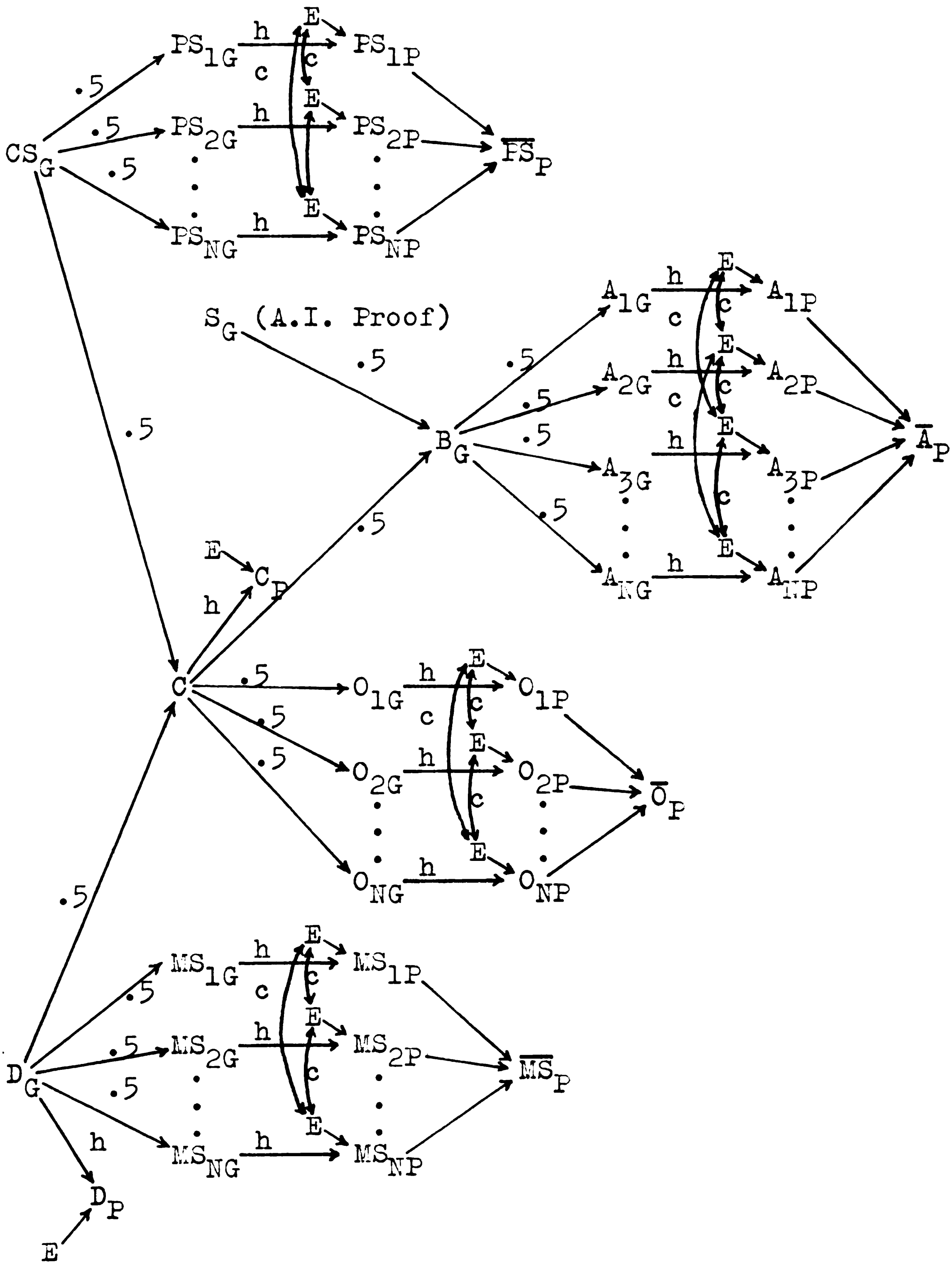
C--cow, the dam of the young sire.

D--dam of the cow.

CS--cow's sire.

c--environmental correlation between half sibs.

Figure 1--Path Diagram Indicating the Theoretical Correlations Between the Phenotypes and Genotypes of the Young Sire and Its Close Relatives



h--square root of heritability or the correlation between the genotype and phenotype.

.5--represents Mendelian segregation if no intense inbreeding is present. Under all conditions Mendelian segregation is represented by (1/2) $\sqrt{1 + f'/1 + f}$ where f' and f are the inbreeding coefficients of the parent and offspring respectively. It is assumed here that f' equals f or Mendelian segregation is equal to .5.

All of the cow's records are averaged to produce an average deviation. The daughters and maternal sisters average deviations are averaged to form one overall average deviation for the respective classes. The appropriate weights are applied to each of the five classes of relatives to produce an index or estimate of the cow's genetic ability. For example: a cow averages 1,000 pounds of milk above the herd average, her dam is 500 pounds of milk below herd average, three daughters average 400 pounds of milk above herd average and four maternal sisters average 100 pounds of milk above herd average. Sixty paternal sisters average 90 pounds of milk above herd average. The weights for this combination are found in Table 5.

The cow's index would be 276. The standard deviation of the index is approximately 720 pounds of milk, and it has an expected mean of zero with a random sample of cows.

TABLE 5

Index Weights for a Cow with 3 Daughters, 4 Maternal Sisters and 60 Paternal Sisters[a]

Cows Wt.	Dams Wt.	Daus. No.	Daus. Wt.	M.S. No.	M.S. Wt.	P.S. No.	P.S. Wt.
.18	.14	3	.29	3	.08	52	.43
.18	.14	3	.29	4	.10	59	.44
.18	.14	3	.29	5	.12	69	.45

[a]McGilliard, 1962.

The index of 126 dams of the A. I. bulls was calculated using all records and first records to see the value of each. The respective indexes were correlated with the A. I. Proof, daughter-dam comparison and the natural proof expressed as deviations from contemporary herd mates.

The proofs ranged in numbers of daughters from 25 to 1,326 for the A. I. Proof and the daughter-dam comparison and natural proof ranged from 5 to 120 daughters. To correct for unequal numbers, the A. I. Proofs were regressed with the factor N/(N + 12) and the non-A. I. Proofs were regressed by the factor N/(N + 16).

The correlations between the two indexes on the dam and the three proofs on her son are given in Table 6. The index on first records seems to be of as much value as the index on all records, as correlated with the A. I. Proof. The A. I. Proof and the natural proof as deviations from contemporaries correlate quite closely with the two indexes, while the daughter-dam comparison seems to be of little value since it correlates -.085 using first records index and -.019 using the index with all records.

TABLE 6

Correlations, Means and Standard Deviations of Indexes and Proofs

	Index	Index	A. I.	D.-D.	Nat. Pr.
Index (1st. Recs.)			.148	-.085	.133
Index (All Recs.)			.149	-.019	.092
A. I. Proof				.299	.332
Dau.-Dam Comp.					.265
Means	832	599	35	217	141
Std. Dev.	822	725	543	577	629

Components of variance

The accuracy of the index depends upon the proper weights being applied to each of the records of the relatives. A variance-covariance matrix using first records and one using all records was computed by using the average deviation of each animal and the average of the daughters' and maternal sisters' average deviation. If more than one daughter, one maternal sister, or one paternal sister were available, they were averaged to produce an average deviation for the daughter class, maternal sister class, and paternal sister class. The five groups of relatives, using first records and all records, were correlated with the bull's adjusted A. I. Proof. The A. I. Proof was adjusted for the numbers of daughters present by using the regression $N/(N + 12)$ where $\underline{N}$ is the number of daughters in the proof.

The product moment correlations in Tables 7 and 8 demonstrate the phenotypic relationships observed between the five groups of relatives used in the selection index. With no environmental variation these would be expected to be equal or greater than zero, but not negative. The product moment correlations between the A. I. Proof of the bull and the five groups of female relatives (Tables 7 and 8) demonstrate the observed relationship between the genotype of the bull and the phenotypes of the five groups of female relatives. The variances of the five groups of relatives and the A. I. Proof of the bull are located on

TABLE 7

Variances, Covariances, and Correlations
Using All Records

	Cow	Dam	Daus.	M. S.	P. S.	A.I. Proof
Cow	41,743	5,556	4,064	11,718	1,709	11,146
Dam	.139	49,827	-514	6,197	877	-10,058
Daus.	.120	-.004	26,819	-1,053	2,369	23,822
M. S.	.335	.186	-.036	34,038	2,278	6,505
P. S.	.067	.039	.099	.105	14,067	-842
A. I. Pr.	.101	-.081	.257	.068	-.012	294,523

(Data expressed in 10 pounds)

TABLE 8

Variances, Covariances, and Correlations
Using First Records

	Cow	Dam	Daus.	M. S.	P. S.	A.I. Proof
Cow	61,320	35	-1,922	12,285	2,269	24,381
Dam	.001	58,314	-2,824	8,882	-925	-20,431
Daus.	-.038	-.061	39,170	2,837	6,314	14,704
M. S.	.273	.238	.076	38,447	-591	12,994
P. S.	.086	-.037	.222	-.025	14,067	-842
A. I. Pr.	.181	-.152	.132	.128	-.012	294,523

(Data expressed in 10 pounds)

the diagonal of Tables 7 and 8. The variance of the daughter, maternal sister, and paternal sister groups is the variance of the average of _N_ cows in each group. In this data _N_ ranges from 1 to 999 cows. The variance of a single cow in the daughter, maternal sister, and paternal sister groups was obtained by components of variance (Tables 9 and 10) and was 53,017 for first records and 40,945 for all records.

TABLE 9

Components of Variance--First Records

Corrected Sums of Squares	u	d^2	e^2	S. S.
Total	0	550.6931	553	34,467,937
Between	0	550.6931	229	17,290,303
Residual	0	0	324	17,177,634
Components				
			e^2 = 53,017	
h^2 = .599			d^2 = 9,351	

The product moment correlations between the relatives and the bull's A. I. Proof (Tables 7 and 8) indicate that the selection index does not evaluate the data adequately. The cow's phenotype alone, using first records as deviations from the herd average, is a better indicator of the bull's A. I. Proof than the selection index, with a correlation of .181 (Table 8) compared to the correlation of .148 (Table 6) between the selection index and the A. I. Proof. The cow's daughters, using all records as deviations from the herd average, are much more accurate than the selection index with a correlation of .257 (Table 7) as compared to the correlation between the selection index and the A. I. Proof of .149 (Table 6).

TABLE 10

Components of Variance--All Records

Corrected Sums of Squares	u	d^2	e^2	S. S.
Total	0	550.6931	553	26,069,548
Between	0	550.6931	229	12,803,524
Residual	0	0	324	13,266,024

Components

$e^2 = 40,945$

$h^2 = .528$ $d^2 = 6,223$

Components of variance using daughters within dams was used to estimate the variance of a single daughter, a single maternal sister and a single paternal sister. The

components of variance were estimated from daughters within dams which also included the cow and her maternal sisters within the dam. Each dam had an average of approximately 3.3 daughters and there were 230 dams with daughters in the analysis. As would be expected, the variance of the first records was larger than the variance of the average of all records as shown in Tables 9 and 10. This also yielded the intra-class correlation which estimated the heritability of first records as .599 and the heritability of all records as .528. Other estimates of heritability are much lower and indicate that the heritability of first records to be higher than that of all records as shown in Table 11. The paternal sister correlation was computed as four times the correlation between

TABLE 11

Heritability Estimates

Method of estimation	First Records	All Records
Intra-class correlation	.599	.528
Paternal sister correlation	.171	.167
Daughter-dam regression	.079	.310

the cow and her paternal sisters. The daughter-dam regression was calculated as two times the regression of daughters on cows, which also included combining the cow and her maternal sisters and regressing them on the dam.

The cows which indexed above two standard deviations using all records had sons which had an average A. I. Proof of +300 pounds of milk above an expected mean of zero and the standard deviation of the A. I. Proof was 543 pounds of milk. The top bull had a dam which indexed -277 and would not have been included in a young sire program. Three of the top ten bulls would have been chosen for a young sire program.

With the index using first records, the nineteen cows which indexed above two standard deviations of milk would have yielded four of the top ten bulls for a young sire program. The nineteen dams which were two or more standard deviations above the mean yielded sons with a mean A. I. Proof of +175 pounds of milk where a standard deviation of the A. I. Proof is 543 pounds of milk. Table 12 compares the two methods of selection, first records and all records, and shows an advantage to using all records.

TABLE 12

Indexes Above Two Standard Deviations
And the Son's A. I. Proof

	All Records		First Records	
	Cow's Index	Son's Proof	Cow's Index	Son's Proof
1.	2,998	862	4,341	862
2.	2,546	180	2,671	1,017
3.	2,466	722	2,665	-40
4.	2,454	52	2,500	180
5.	1,985	-43	2,234	772
6.	1,924	1,194	2,216	-1,072
7.	1,807	-40	2,192	-11
8.	1,799	431	2,185	52
9.	1,670	-425	2,139	-417
10.	1,639	1,245	2,101	548
11.	1,588	-243	2,096	-158
12.	1,569	360	2,065	-263
13.	1,499	-11	2,063	431
14.			2,031	1,245
15.			1,892	427
16.			1,890	-243
17.			1,817	1,194
18.			1,768	-425
19.			1,698	-771

DISCUSSION

There are two types of selection indexes published for selection of dairy cattle, namely, those for the selection on type and production and those for the selection on milk and/or fat production. Of the indexes which deal with production, McGilliard's (1962) best met the purposes of this study. The index was designed to be applied to cows with information on themselves, and any other additional information on her close female relatives is also used.

The index of Legates and Lush (1954) was constructed from Jersey data for fat production. In this index the five categories of relatives are combined additively and independently, thus indicating the members of the pedigree to be somewhat independent and the correlations between them to be small. The correlation between the index value and the individual's genotype may be smaller by combining the relatives additively and independently than if the correlations between the categories are used and the weights are dependent upon the information available in all categories. McGilliard's (1962) selection index combines the paternal sisters additively and independently of the other sources of information. The weights for the cow, her dam, daughters, and maternal sisters are all dependent upon the numbers and the amount of information in all the categories.

Barr (1962) published an index on young sires utilizing the information on the sire's and dam's side of the pedigree. Three elements on the sire's side and four on the dam's side of the pedigree were combined in a correlation matrix and the solutions for a given sire may be attained. This is good for living animals, but for the selection of dams to be bred for future young sires, the index by McGilliard (1962) is advantageous.

The A. I. Proofs of the sires were adjusted for unequal numbers of daughters by using the regression N/(N + 12) which was used by Henderson and found by Specht (1957) to be the correct regression for Michigan data. This regression assumes no environmental correlations between paternal half sisters. The correlation between single paternal sisters in this data was .062 which yields a regression of N/(N + 15). This is in close agreement with the regression factor used on the natural proofs, i.e., N/(N + 16), which are assumed to be larger than that used on A. I. Proofs.

The correlations between the natural proofs and the A. I. Proofs in this study were low and in the order of .30. The dam's index correlates lowest with the daughter-dam comparison, intermediate with the Natural Proof expressed as a contemporary comparison and highest with the A. I. Proof. The dam's index correlated .149 with the

A. I. Proof or approximately one half the correlation between either natural proof and the A. I. Proof.

If the sire of a bull were an artificially proven sire, his proof may be a much better indicator of his genetic ability than a selection index is of a cow's genetic ability. Thus, the sire's side of the pedigree may be of more value than the dam's in estimating a bull's genetic ability. When consideration is given to the sire's and dam's side of the pedigree, it would appear that a complete pedigree on a young sire may yield information approximately equal to that obtained from a natural proof. Barr (1962) found a correlation of .32 between a complete pedigree of a sire evaluated by an index and the sire's A. I. Proof. The pedigree would be available before the natural proof and even before the bull is of service age. It may be cheaper and may indicate the genetic potential as well as a natural proof. Early selection on the basis of such an index would seem to be the most economical and practical way of selecting sires in the future.

When the first records of the cow and her relatives were put in the selection index, it correlated with the A. I. Proof, .148 which is slightly less than .149, the correlation obtained by using all records. The advantage of using first records is that an estimate of an individual's ability is obtained in the first lactation and less environmental variations effect first records. Johansson (1955) analyzed 4,912 daughter-dam pairs with first, second, and third lactations and the results show that the first lactation record is significantly superior to the second and slightly superior to the third lactation as an indicator of the cow's inherent capacity for milk yield. Putman et al. (1943) from the results of 3,388

TABLE 13

Heritabilities of Lactation Records[a]

Lactation Number	Heritability
1	$.33 \pm .06$
2	$.10 \pm .05$
3	$.24 \pm .04$

[a]Johansson, 1955.

dam-daughter pairs found the correlation between first records and the average of all records to range from .874 to .951, and concluded that there were insignificant differences between using first records and all records.

Rennie and Bremner (1961) studied Jersey data in Canada to determine the validity of selection of sires on the basis of only first lactation data and the bias that this may introduce. The data indicated that sire programs based on records of two-year-old cows appear to identify properly those sires of superior breeding value for production at all ages. On the average, high production during the first lactation is followed by a high level of production in subsequent lactations.

The heritability of deviations of first lactations and all lactations from herd averages would appear to be higher than the heritability of undeviated production records since some of the environmental variance is eliminated by deviating records from the herd averages. If heritability exceeds .40, then the correlation between an individual's phenotype and genotype will exceed .63 and it will require a large number of relatives to be of much value in obtaining a better estimate of the individual's genotype. For practical purposes, if the true heritabilities were as indicated by the components of variance, it would be of little value to pay attention to anything other than the individual's own phenotype. The heritability estimates obtained by the components of variance seem to be biased since the daughters and dam tend to be in the same herd and may have environmental correlations. Selection indexes or the added information of relatives is of greatest value where heritability is less than .40 and as it approaches zero.

The bulls in this study came from herds which had herd averages which ranged from 9,000 pounds of milk to 18,000 pounds of milk. If 10 to 20 percent of this difference between the high and low herds is genetic, then the cows indexed in herds with high herd averages would be penalized to the extent of this difference, since all records were deviated from the herd averages and then assumed on an equal genetic basis. In this study the standard deviation of deviations from herd averages is assumed equal in herds with high and low herd averages. If the standard deviation is greater in herds with high herd averages, then cows indexed from high herds may be biased downward due to the genetic differences between the herd averages and biased upward due to a larger standard deviation of the index. The combined effect of both biases is undetermined. This may be especially true of data of the type used in this study because of the large number of bulls in studs which are from herds with high herd averages.

The amount of preferential treatment given animals in the pedigrees of bulls in artificial breeding studs is difficult to determine and there is no way to correct for it. It would seem that such bias does occur and would be more likely to occur in the records of the dam of the bull.

With large numbers of daughters, maternal sisters, and paternal sisters, this bias could be reduced a little. The use of first records would tend to reduce the amount of bias due to preferential treatment since the first lactations usually would have occurred before a son was available or of known superior quality to qualify for A. I. service. Usually the only preferential treatment that may occur with first records is that to half sisters of the bull or daughters of the dam of the bull.

Due to small numbers there may be large sampling errors in the calculated covariances in Tables 7 and 8. The covariance with the largest numbers was 126 and the covariance with the smallest numbers was 54. The covariances in these matrices indicate the possible causes of discrepencies between the actual data and the selection index by McGilliard (1962). Theoretically, none of the covariances should have been negative, instead those between the paternal sisters and the maternal sisters and the covariance between the paternal sisters and the dam should have been zero and the rest should have been positive. The sign of the covariances between the A. I. Proof and the female relatives of the bulls determines whether the weight for the category will be positive or negative. Using all records and first records, it can be seen that the proper weights for the dam and paternal sisters should have been negative. The covariance between the paternal sisters and the A. I. Proof is essentially zero and could be attributed to sampling errors. However, the covariance between the dam and the A. I. Proof is a very large negative and although some of it may be attributed to sampling error, it seems that the covariance would still remain negative giving the dam a negative weight.

The covariances in the matrices of first and all records give an indication of the environmental correlations present. The most evident ones are the ones between the maternal half sisters which seem to inflate the phenotypic correlations. The average of the maternal sisters correlated more closely with the dam than the cow correlated with the dam. The paternal sisters are not necessarily in the same herd with the other relatives. The magnitude of the paternal sister's covariances, which tend to be less biased with environmental correlations along with their relationship with the various relatives, appear to show the magnitude of the true covariances with most of the environmental correlations eliminated.

The superiority of using first records or all records cannot be demonstrated from these data due to the small numbers.

Artificial breeding organizations with adequate size and an adequate number of first services to sample enough young sires so as to make the maximum genetic gain are few. Due to the cost of such a program, it seems to be a practical and reasonable method to sample about 5 to 10 sires a year in an average size artificial breeding stud. The data from this study indicate that the selection of superior cows by the use of a selection index and the select mating of these dams to superior A. I. Proved sires may yield superior offspring. The top few indexed cows in a state or given area could also be judged as to physical appearance or type before the artificial breeding organization bred the cow and contracted for a bull calf for the young sire program.

An artificial breeding organization may not want to contract a first or second calf heifer pending her future production or a better estimate of her ability. This should not reduce the selection intensity which is available to such a breeding organization, due to the large numbers available. The cost of the calves would be less than naturally proven sires and a longer service life would be available. The young sire's pedigree may afford as much information as a natural proof in predicting his A. I. daughter production and the selection differential would be considerably higher on the young sires than it would on bulls with a natural proof.

SUMMARY

To study the value of selection indexes in a Young Sire Program, 126 artificially proven sires which met the qualifications of having at least 25 artificial daughters, 5 natural daughters, and pedigree information on the dam of the bull and her relatives were used. The dam's side of the pedigree was completely analyzed by compiling all the available production records on (1) the bull's dam, (2) the dam's dam, (3) the dam's daughters, (4) the dam's maternal sisters, and (5) the dam's paternal sisters. All records were converted to a 305-day, 2X, mature equivalent basis and were deviated from the 305-day, 2X, mature equivalent herd average.

The 126 cows (dams of the bulls) had 704 lactations which averaged 1,420 pounds of milk above herd average for all records and 1,847 pounds above herd average for first records. There were 79 dams with 385 lactations which averaged 1,432 pounds of milk above herd average for first records and 1,117 pounds of milk above herd average for all records. The 258 daughters had 1,043 lactations which had an average deviation of 684 pounds of milk for all records and 1,176 pounds of milk for first records. The 171 maternal sisters had 758 lactations with an average deviation of 531 pounds of milk for all records and

947 pounds above herd average with first records. There were 5,910 paternal sisters which averaged 186 pounds above the herd average.

The A. I. Proofs ranged in numbers of daughters from 25 to 1,326 and from 5 to 120 daughters for the Daughter-Dam Comparison and the Natural Proof. To correct for unequal numbers, the A. I. Proofs were regressed with the factor N/(N + 12) and the two non-A. I. Proofs were regressed by the factor N/(N + 16).

The dams of the bulls were indexed using first records and the average of all records by McGilliard's (1962) selection index. The index using first records correlated with the A. I. Proof +.148 and the index using all records correlated with the A. I. Proof +.149. The dam's index correlated approximately one half as much as the correlation between the A. I. Proof and either non- A. I. Proof.

If the sire's side of the pedigree would yield as much information as the dam's side, a complete pedigree with information on the dam and a sire which has an A. I. Proof may yield as much information on a young sire as a Natural Proof could yield.

The advantages of a young sire program are: (1) high selection intensity, (2) lower initial cost per sire,

(3) an earlier A. I. Proof on the sire, and (4) a longer A. I. service life.

The most practical and economical way of obtaining future superior sires is by the use of young sires. All the cows in a state or a given area could be indexed and the cows with the best indexes could be contracted and bred to a superior proven sire for the purpose of obtaining young sires.

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