OCTOBER, 1953 RESEARCH BULLETIN 524

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

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A Study of the Transmitting Ability of Brown Swiss Sires

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Publication Authorized July 18, 1953

COLUMBIA, MISSOURI

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ABSTRACT

An analysis was made of the production records of ancestors in the first three generations of the pedigree of 864 proved Brown Swiss sires, as reported by the Bureau of Dairy Industry, U.S.D.A., from 1942 to 1950, in an effort to determine the most accurate prediction index for the transmitting ability of an unproved sire.

All records were standardized to a 2 times milking, 305-day lactation, mature equivalent basis by using the age conversion factors derived by the Bureau of Dairy Industry for Brown Swiss cattle. Both D.H.I.A. and H. I. R. records were used.

The 864 proved sires studied had an average of 9.4 daughter-dam pairs. The total tested females (dams and daughters) was 16,243. Their records averaged 9,755 pounds of milk, 388 pounds of butterfat, with an average butterfat test of 4.0 percent. These values were construed to represent a fair estimate of the breed average for Brown Swiss on 2x-305-M.E. basis.

This study shows little evidence of assortative mating in the breed. Both high and low producing dams were mated with bulls that have prediction indexes for milk and fat of about the same level. The breeding of low producing cows to sires of high inherent production is a responsible factor for the upward trend in the breed's average production.

Correlating the proved sire's prediction index with his actual proof index resulted in essentially the same correlation coefficient value as the prediction index correlated with the production of his daughters. The coefficient for the former was + 0.244 and + 0.237 for the latter. The sires' actual proof equal-parent indexes were correlated with the index of their sires' (+ 0.165) and with their dams' production records (+ 0.179) at sufficiently high levels to be statistically significant.

The multiple regression equation of $Y = 526 + .06X_1 - .05X_2 - .22X_3 + .28X_4 - .30X_5 - .04X_6$ will account for approximately 12 percent of the variance in the indexes of the proved sires. However, the multiple regression coefficient obtained for this equation (+ 0.351) is not statis-

*This bulletin is a report on the Department of Dairy Husbandry research project number 84, entitled 'Dairy Cattle Breeding." It is a contribution from Missouri Agricultural Experiment Station as a Collaborator under North Central Regional Cooperative Research Project No. NC-2, "Improvement of Dairy Cattle Through Breeding."

The authors are indebted to Dr. Gordon E. Dickerson, former professor of animal husbandry at University of Missouri, for his counsel and guidance on this study.

tically significant. This multiple regression equation was derived when using all of the six tested ancestors of the proved bulls. One was also derived when using only the sire, dam, and the maternal grandsire of the proved sires. It is $\hat{Y} = 174.5 + .083X_1 + .256X_2 + .216X_3$. The multiple regression coefficient obtained for this equation (+ 0.320) is statistically significant at the 1 percent level. There were 138 bulls in the latter group as compared to only 46 where all six of the ancestors were tested.

A simple, quick and accurate method of predicting the future production index of bulls is merely ½ the sire's index plus ½ the dam's record. This prediction correlated with the bull's actual proof indexes gave a coefficient of + 0.306 which is statistically significant at the 5% level. While this is an arbitrary method of predicting the transmitting ability of a bull, it is easier for breeders to handle than the more complicated multiple regression equations.

INTRODUCTION

There are approximately 24 million milk cows in the United States at this time. The annual production of milk is about 120 billion pounds. Average production of milk per cow (1950) was 5,292 pounds, containing 210 pounds of butterfat. Such a production level contrasts sharply with the average production of 9,172 pounds of milk and 370 pounds of butterfat annually from cows tested in the dairy herd improvement associations of this country. Production per cow is closely related to income the dairy farmer receives.

An analysis of records on over 900,000 cows tested in dairy herd improvement associations in 1950 showed that cows producing 200 pounds of butterfat annually consumed $119 worth of feed and returned $108 over feed costs. On the basis that feed makes up about half the cost of milk production, such cows fall $11 short in paying their way. The 370 pound butterfat producer, among D.H.I.A. tested cows, consumed $147 worth of feed and returned $212 over feed costs to their owners. After other expenses chargeable to milk production, such as labor, housing, interest, depreciation, etc., were deducted these cows had a net income of $65 per head.

Through intelligent methods of selection based on milk production and feed records, the continued use of good sires and culling of low producing cows, dairy herd improvement association members have improved their herds to profitable levels of production. Unfortunately, only about 5 per cent of the milk cow population of this country is so tested (1,186,615 cows in 40,000 herds.—Report of the Chief of the Bureau of Dairy Industry, U.S.D.A., 1951).

The inheritance for higher milk production may be markedly improved by the use of dairy sires capable of transmitting improved production characteristics to their daughters. It is realized that progeny receive a sample half of the characters (genes) from both the sire and dam. A sire may be the parent of many offspring but the dam usually has only two or three female offspring in the herd. Hence the efforts to build higher production in our dairy cattle is heavily centered around the selection and use of dependable transmitting sires.

The most rapid way to realize hereditary improvement in milk produciton is through selection of bulls that transmit a preponderance of genes for high milk and butterfat production. One of the greatest needs of the dairy cattle breeder today is a method of selecting herd sires which can be relied upon..

Lush (1953) emphasized that permanent improvement from phenotypic selection is proportional to the additively genetic (heritable) fraction of the observed variance and that this varies for different traits. Dobzhansky (1937) suggested "that most, and possibly all, genes have manifold effects." These factors make efficient selection a complicated and uncertain procedure in dairy cattle, which are recognized as possessing a great deal of heterozygosity for practically all characteristics.

Proved sires have played an important role in dairy cattle improvement and represent the only means of very accurately predicting a sire's transmitting ability. As a rule, only about 10 percent of the active sires in use are proved. This situation is changing rapidly due to the widespread use of artificial insemination for dairy cattle where an attempt is being made to use all proved sires. In 1951 there were 4,077,706 cows enrolled in artificial breeding units. The associations own or lease 2,102 bulls, one for each 1,940 cows. About 30 percent of these bulls are proved in D.H.I.A. Their daughters averaged 459 pounds of butterfat, as compared with 419 pounds for the dams of the daughters.

Every proved sire was once an unproved sire and some breeder had to select him on the basis of his ancestry and their performance. This method of selection will have to continue as it is practically and biologically impossible to obtain even preliminary proof on the daughter-dam production of a given sire until he is around 5 to 6 years of age.

Not all sires, even though proved, increase production. This is to be expected when the variation in inheritance, different levels of production of dams, (which are culled constantly in D.H.I.A.; whereas the first crop of daughters are unselected) and environmental differences are fully appreciated.

About 30,000 sires have been proved in D.H.I.A. work in this country to date. A proved D.H.I.A. sire is one with at least 5 daughter-dam production record compilations. Roughly about 52 percent of the sires proved increase or maintain the production of their daughters as compared to the dams to which the bull is mated. Over 40 percent of these proved sires have an average of over 400 pounds of butterfat on their daughters and the number of sires with daughters below 300 pound butterfat level is becoming increasingly smaller each year in D.H.I.A. associations.

Through the use of such a program, the production per cow in D.H.I.A. has increased from 5430 pounds of milk, 215 pounds of fat in 1905 when the first D.H.I.A. association was organized to 9172 pounds milk, 370 pounds butterfat. In 1905 the average milk cow was estimated to yield 146 pounds of butterfat annually and in 1950 the average was 210 pounds, an increase of 64 pounds in 46 years as compared to 155 pounds per cow during the same period for D.H.I.A. cows. Thus, with improved breeding and feeding practiced, the program has been about 2½ times as rapid. It must also be realized that the average milk cow has improved somewhat in inherited ability through the influence of testing in the D.H.I.A. associations and under the program of the purebred registry associations.

Since the majority of the sires in use are unproved, and since all sires are selected on the basis of ancestry, the problem of more reliable selection methods as applied to young bulls is apparent.

It is a challenge to all students of dairy cattle breeding to bring forth facts that will assist in the selection of bull calves that will in a high majority of cases prove successful. The ancestry of the calf as shown by the pedigree has served as the basis for this study to arrive at a method for predicting the transmitting ability of Brown Swiss bulls.

PREVIOUS WORK

Milk Production

As stated by Rice (1948) the milk production of a cow is influenced by both *heredity* and *environment*. Environment is directly responsible for the expression of production, but the potential ability of the cow to produce milk is influenced by heredity.

Aside from cross-breeding, experiments by Gowen (1918), Bowker (1919), Ellinger (1923), and Cole (1925), the majority of the inheritance studies which have been made on yield of milk have centered around the influence of the sire and the effect which he has on the production of his daughters, such as the work by Turner (1927), Copeland (1931), Gowen (1918), Lush and Schultz (1938), Madsen (1932), Eldridge (1949) and others. From an economic standpoint such studies were undoubtedly merited, as the effect of the sire appears to be equivalent to the combined influence of all the cows with which he is mated.

Inheritance of Milk and Fat Secretion

One of the early studies on the inheritance of different levels of milk production was made by Wilson (1911). He concluded that quantity of milk production and butterfat test were inherited independently of each other.

There have been attempts to establish the number of genes controlling milk and butterfat production, but as Gowen (1927) pointed out in his review, there are probably several genes affecting each of several different physiological bases of lactation.

Turner (1927) advanced a hypothesis to explain the mechanism of the inheritance of milk and fat secretion as follows: (1) Milk and fat secretion of the dairy cow is influenced by many genes. Yearly milk production is dependent upon the ability of the cow to consume large quantities of feed, and she must have large quantities of milk secreting tissue with storage space in the udder for the milk as it accumulates. Total milk yield is influenced by the rate of decline of milk secretion after the peak of production has been passed. (2) Many of the genes favoring high production are dominant. This conclusion was arrived at on the basis of work by Gowen (1918) who demonstrated that Angus cross-bred daughters were much higher producers than their low-producing Angus dams. Results similar to these were reported by Cole (1925) in an Angus x Jersey cross-breeding experiment, by Castle (1919) for the Bowlker Holstein-Friesian x Guernsey cross-bred herd and by Ellinger (1923) in the cross of Red Danes with Jerseys. (3) All genes do not have the same effect.

Present knowledge of the cow's mammary gland, size of the cow, her physiology and endocrine set-up indicates that there may be innumerable genes influencing milk production, ranging from those which have only minute effects to those having large effects on total production. The total number of genes or the "gene frequency" for certain characters seems to be the most acceptable viewpoint in explaining genetic differences in cattle.

Early Recognition of Environmental Influences

Crowther (1905) presents a complete review of the work done by many investigators, including studies on the influence of the interval between successive milking, day and night yields, age, period of lactation, season of the year, feed, manner of feeding, weather, and sexual excitement. This emphasizes the fact that fifty years ago dairy scientists were already aware of the many environmental and physiological factors affecting milk production.

Ellinger (1923) reported on data collected in Denmark on a herd of 700 purebred Jersey, Red Danish and crossbred cows. He analyzed data and found that variation in length of lactation was more highly correlated (Jersey $r = +0.891$, Red Dane $r = +0.943$) with the interval between the preceding birth and the time of breeding than it was with maximum yield (effectively 0) or with persistency. A negative correlation of —0.33 was found between milk production and butterfat percentage of Jerseys. The relationship was essentially zero for Red Danes.

Measurements of Variability of Production Records

Rietz (1909) probably made the first statistical analysis of butterfat production. His work was based upon the 7-day tests of the Advanced Register of the Holstein-Friesian Association of America, so the data are not suitable for direct comparisons with current 305 day D.H.I.A. and H.I.R. lactation records.

Roberts (1918) studied the correlations between milk yield and butterfat test showing a significant negative correlation between the two The milk yield increased with age and fat percent remained fairly constant with a tendency to decrease small amounts with increasing age.

Gowen (1920a) studied 1741 milk production records for Jerseys. He found that the correlation between any one lactation and any other lactation ranged from + 0.7306 between the age groups 5-6 and 6-7 to + 0.2144 between the age groups 4-5 and 10 or over. The mean value for the correlation coefficients of a lacation at one age with the production in a lactation at any other age was + 0.5352. He stated that from the standpoint of inheritance, the best record is the most suitable measure of the genetic constitution of an individual.

Krizenecky (1934) summarized a large amount of published data and some original data of his own to obtain the following coefficients of variability.

	Minimum	Maximum	Average
Milk yield	11.00	31.75	21.673
Fat percentage	3.83	12.69	8.576
Fat production	12.65	32.06	21.882

Heritability

Lush (1940) defined the degree of heritability as "the fraction of the observed variance which was caused by differences in heredity." He states that this fraction may result from additive gene effects, interaction of allelic genes (dominance), and interaction of non-allelic genes (epistasis). His work shows that there are two main ways of estimating heritability which are as follows:

Correlations Between Relatives. Geneticists appear to be wary of the use of this method. In a well designed experiment the environmental correlations between relatives will be made zero, but this is not always possible. Environment is most difficult to control under both experimental and practical conditions.

Correlations Between Offspring and Ancestors. He suggests that the resemblance between parent and offspring is generally most useful because (A) it is expected to be fairly high if the characteristic is highly heritable and (B) it does not include dominance deviations.

According to Lush and Strauss (1942) a daughter gets only a sample half of the inheritance her dam has. Therefore the regression of daughter on dam must be doubled to estimate what fraction of the differences between the records of the mates of a sire were due to differences in the heredity of those mates.

Lush (1940) pointed out that a dependable estimate of the heritability of a characteristic is perhaps the most important consideration in deciding which of several possible breeding plans is likely to be most effective. He suggests that if the desired characteristics are highly hereditary the best method will be mass selection with little real use for pedigree, relatives or progeny test. Whereas if heritability is low, but there is not much epistatic variance either, considerable use of pedigree and much use of progeny tests and selection on a family basis would be a better plan.

Correlations Between Production Records of Relatives

Gowen (1934), using Register of Merit, 365-day records of Jersey cows calculated a number of statistical measures on milk production. He found from the correlations between relatives that 50-70 percent of variation in milk yield was due to differences in inheritance and about 75-85 percent of the variation in butterfat percentage was due to inheritance. Only 10 percent of the variation in milk production was believed due to environment common to sisters and 20-45 percent to environment common to the cow herself.

Gowen (1925b) also found from Guernsey AR records that the correlation between sire's daughters and son's daughters was as follows:

Milk production	+ 0.262
Fat percentage	+ 0.183
Fat yield	+ 0.285

Copeland (1931) studied the ROM records of 694 Jersey cows, their daughters, their ROM sons, and their paternal half-sisters. The correlation coefficients which he obtained are as follows:

Between Records of:	Correlation Coefficient
Dams and daughters	0.4044
Dams and son's daughters	0.3415
Maternal sister; both full and half and brothers' daughters	0.3679
Dam's sisters and dam's daughters	0.4046

He concluded that selection of females from high producing dams should result in a herd that should at least exceed the breed average.

Madsen (1932) studied the correlations between the average production of milk and butterfat of the daughters of bulls and the average production of various animals in the pedigree. The correlations he arrived at are as follows:

Between records of:	Correlation, Milk	Coefficients, Fat
Bulls daughter's and bull's dam	0.173	0.183
Bulls daughter's and bull's paternal grandam	0.018	0.055
Bulls daughter's and bull's maternal grandam	0.077	0.170
Bulls daughter's and bull's sire's daughters	0.255	0.324
Bulls daughter's and bull's paternal grandsire's daughters	0.202	0.193
Bulls daughter's and bull's maternal grandsire's daughters	0.194	0.258

It should be pointed out that each of Madsen's (1932) correlations was calculated from a different sample of bulls. In no case were these several correlations between groups calculated simultaneously on a single sample of bulls, as was done in the studies to be herein reported.

Gifford (1930), using Holstein AR records, found the correlation coefficient between individual daughters and their respective dams to be 0.322 ± 0.013. A correlation of 0.284 was obtained for sire's progeny on maternal grandsire's progeny.

Lush and Schultz (1938) studied 303 Holstein-Friesian sires that had been proved in Iowa cow testing associations. Their results are shown in the table below.

AVERAGE PRODUCTION AND CORRELATIONS ARRIVED AT BY LUSH AND SCHULTZ (1938) FROM THEIR STUDY OF HOLSTEIN BULLS PROVED IN IOWA

	Pounds of Butterfat	
	Mean	Standard Deviation
Mates	416	78
Daughters	430	82
Increase	+ 14	68

Correlations between:

Mates and daughters	+ 0.64
Mates and increase	—0.38
Daughters and increase	+ 0.47

Lush and Schultz (1938) also determined correlation coefficients between the bull's daughters and the A.R. records of his ancestors. The performance of the bull's daughters correlated with the bull's sire was —0.02; with his dam + 0.24; with his paternal grandsire + 0.06; with his paternal grandam + 0.10, and with his maternal grandsire + 0.03. This showed the relation between the bull's pedigree and his performance to be positive but slight. These correlations are lower than those found by Copeland (1931) and Madsen (1932).

Eldridge (1949) developed a multiple regression method of sire selection. This was done by combining the records of all ancestors (the first six in the pedigree) to arrive at a single multiple correlation prediction for the bull's own performance.

This study by Eldridge involved 1,451 Holstein-Friesian bulls that were proved in New York prior to February 1, 1947. The following regression equations for predicting the average production of the daughters of the bulls were developed:

$$(1)\quad \widehat{YA} = 30 + 0.75X_1 + 0.03X_2 + 0.01X_3 + 0.34X_4 - 0.21X_5 \qquad R = 0.701$$

$$(2)\quad \widehat{YB} = 0 + 0.75X_1 + 0.01X_3 + 0.23X_4 - 0.22X_5 + 0.24X_6 \qquad R = 0.689$$

The symbols used are as follows: X_1 = average production of the mates of the proved bull; X_2 = average production of the maternal half sisters of the proved bull; X_3 = average production of the dam of the proved bull; X_4 = average production of the paternal half-sisters of the proved bull; X_5 = average production of the dams of the paternal half-sisters of the proved bull; X_6 = average production of the paternal half-sisters of the bull's dam, and Y = average production of the daughters of the proved bull.

This study indicates the average production of the paternal half-sisters to be quite important when selecting a young dairy sire. The production of his dam or of his maternal half sisters showed no relationship to the production of his own daughters.

Benson and Tyler (1950) showed a correlation of 0.20 between the production records of the daughters of Ayrshire sires and the production records of the sires' dams. They also arrived at a correlation of 0.20 between the production records of the mates of these same bulls and the production records of the dams of the bulls. These data indicate a strong tendency for bulls and cows of the same production level to be mated together. Goodale (1926) showed the same to be true when he found those sires whose daughters average the largest yield of butterfat were mated to cows with superior production.

Theoretical Studies on the Inheritance of Production Characteristics

Copeland (1938), Berry and Lush (1939), Berry (1945) and Graves (1947) discussed which record of a cow's production was the best estimate of her ability. Apparently, from their conclusions, the right answer can vary.

The extent to which any record or average of records may be used to indicate the production of progeny and the effect of selection on progress in breeding were considered by Lush and Schultz (1936), Lush and Arnold (1937), Lush, Norton and Arnold (1941), Lush and Straus (1942), Seath (1940), Dickerson and Hazel (1942) and Johansson (1947).

Heritability of butterfat production from these studies varies from 20 percent to almost 50 percent and averages around 30 percent.

The following workers, Fisher (1918), Wright (1921a), (1921b), (1921c), (1921d), (1921e), (1921f), (1922), (1923), (1934), Dickerson (1940), and Lush (1944), (1946), have laid the foundations for the application of statistical methods to the Mendelian theory of inheritance. For example, Wright (1923) states that the theoretically perfect correlation coefficient between any full sisters or between a parent and one of its offspring is + 0.50 for a characteristic inherited completely by additive genes in a population breeding at random. Lush (1944) presents the following formula to account for the correlation that should exist under the previously mentioned conditions between the average of a group of daughters of a sire, X, and the average of their dams, Y.

$$rXY = \frac{r + (n - 1)\,v}{\sqrt{1 + (n - 1)\,u}\;\sqrt{1 + (n - 1)\,w}}$$

When the mating is at random no correlation exists between the dams, "u" in this formula, and none exists between individual daughters and randomly selected dams other than their own, "v" in the formula. The other symbols are: w = the correlation between the daughters of a sire (half-sisters) which is 0.25, r = the correlation between parent and progeny which is 0.50, and n = the number of daughter-dam pairs of a sire. Under the specified conditions of random mating the formula can be simplified to

$$rXY = \frac{r}{\sqrt{1 + (n - 1)\,w}}$$

and substituting the theoretical values for r and w it becomes:

$$rXY = \frac{0.50}{\sqrt{1 + 0.25\,(n - 1)}}$$

It will be noted from this formula that as the number of daughter-dam pairs increases the correlation between the average of the dams (phenotype) and the average of the daughters decreases, approaching zero as a limit as the number of daughter-dam pairs approaches infinity. While this is decreasing to approach zero, the correlation coefficient between the average of the daughters and the genotype of the sire approaches 1.0.

Measuring the Transmitting Ability of Dairy Sires

The transmitting ability of dairy sires has long been under scrutiny. Rice (1948) and Lush (1943) have ably traced the early history of livestock breeding when it was considered most logical to evaluate a sire by the performance of his progeny.

Hanson (1916) was one of the early proponents of the sire index based on the theory that offspring "average" midway between the two parents. This was the forerunner of what is known today as the equal-parent index. The formula for the equal-parent index is

Transmitting ability of a sire = 2 (average of daughters) —(average of dams).

Yapp (1924) suggested the use of age-corrected records is computing an equal-parent index. He also recommended the use of FCM (4% fat corrected milk) records. He also supported Hanson's (1916) contention of the daughters being half way between the sire and dams. This general type of equal-parent formula has been used most widely.

It is a marked improvement in simplicity over the method advanced by Pearl, Gowen and Miner (1919). These workers presented the quartile system. They plotted the yearly records and divided the distribution into quartiles or octiles and classified each sire according to the position of each dam and daughter pair. The ultimate measure was the difference between the two groups of records.

Turner (1925) advanced the following formula to be used in measuring a sire's transmitting ability.

$$\text{Sire's transmitting ability} = \frac{\text{Daughter's fat production} - 0.15 \text{ x dam's fat production}}{0.85}$$

This formula was arrived at as a result of Turner's (1925) study of Guernsey sires with Advanced Registry daughters. He concluded that a sire's ability to transmit fat production to his daughters is best measured by the above formula.

By grouping the sires into classes on the basis of their daughters' yearly fat production, and then determining the level of production of daughters from dams of varying production, it was found that for each 100 pounds of fat increase in the dam's record the daughter's production was increased only approximately 15 pounds.

Davidson (1925) made a study of Jersey Register of Merit records to determine the relationship between the average production of the first few daughters of a bull and his relative breeding value. He concluded that "**On the average,** the first six tested daughters of a Jersey sire are the smallest number of tested daughters, the average of whose production closely approximates the average production of the first fifteen tested daughters of the sire." His work shows that little information was to be gained after the first eight or ten daughters were tested.

Copeland (1932) studied the production records of Jersey cows grouped according to their sires. Each bull used had a minimum of 20 Register of Merit daughters. The correlation of production records of future daughters increased markedly up until eight or ten daughters had been tested. Correlations then became smaller and variations decreased.

Goodale (1927) had given a slightly different formula (from Hanson's and Yapp's) based on the assumption that the daughter would exceed the lower parent by 7/10 of the difference in potentiality for milk production and 4/10 in that for butterfat percentage (instead of ½ as in the Hanson and Yapp formula). The theoretical basis is predicted in results obtained by Gowen from crosses between a beef breed and dairy breeds. The formula changes abruptly, depending on whether the daughters are below or above the dam.

The formula is as follows:

Milk	Fat
O > D S = 10/7 O —3/7 D	5/2 O —3/2 D
O < D S = 10/3 O —7/3 D	5/2 O —2/3 D

O = daughters; D = dams; S = sire

This is known as the Mount Hope Index.

None of the formulae so far considered take account of the fact that a sire index based on many daughters is better than one based on a few. To remedy this situation Wright (1931) proposed the following formula to be used for the evaluation of sires.

$$S = A + \frac{n}{n+2} (2\,O - D - A)$$

S = sire; A = breed average; O = daughters; D = dams; n = number of dam-daughter comparisons.

While a formula of this type may appear somewhat complex, it does present mathematical considerations which should be appreciated by the breeder and research worker. If the daughters of two sires were found to average the same, but in one case they were better than their dams and in the other poorer, most breeders would prefer the sire of the former. Also sires with large number of dam-daughter comparisons are favored over those with only a few.

La Master (1932) proposed the ranking of bulls on a percentage basis. He used Jersey R.O.M. records for his study. A record of 400 pounds butterfat on 3X at under 2½ years of age is expressed in terms of the breed average by dividing 400 by 356.17, the average for the breed for this age and class. The result expressed in percentage is 112.3. The percentage is figured for each daughter of a bull. They are then totaled and an average is arrived at for the bull.

Heizer (1933) made a genetic study of the Penshurst Farms Ayrshire herd. During this study he developed the following formula for predicting a sire's transmitting ability.

$Y = 3/8\,X + 3/8\,I + 2/8\,B$ where Y = daughters production
X = dams production
I = sire's index
B = breed or herd average

Allen (1944) revised the general idea of equal-parent indexes by placing more consideration on the regression of daughters on dams. He devised a set of expectancy tables making it possible to arrive at an expected level of production of the daughters of a sire based on the level of production of their dams.

This same idea of expected values was set up by Ward (1945) from New Zealand dairy cattle.

Rice (1944), on the basis of regression of progeny on parents, suggested a modification of the equal-parent index. He incorporated the breed average into the index in order to allow for the normal regression back to the average and to provide an index more in line with actual production records of cows. This regression index was based on a theoretical regression of 0.50.

The extent to which regression enters into the breeding of cattle is not quite clear. Johannsen (1911) pointed out that regression is most noticeable in a population possessing a heterozygous condition and gradually diminishes as the percentage of homozygosity increases. Another conception, perhaps best brought out by Lush (1945), is that regression is due to "an insufficient amount of knowledge regarding, or an inadequate sample of the population, and that as the number under observation is increased, the probable error is thereby reduced and is less marked." A third conception, explained by Yapp (1938), is to divorce regression from heredity. (Some workers hold to the opinion that regression has no part in the problems of breeding. They contend that when a group of daughters produce less milk and butterfat than their dams it is because they were sired by a bull with a lower genetic value for production than the dams and not due to some mysterious phenomena called regression.)

Dickey and Labarthe (1945) applied both the equal-parent and the regressed equal-parent concept to the production records in the pedigrees of a group of proved Holstein bulls. The correlation coefficient between predicted butterfat production, using the equal-parent index, was + 0.531 and, using the regressed index, was + 0.606.

Nearly all of the proposals for expressing numerically the transmitting ability of a dairy sire are special forms of the following general equation proposed by Lush (1944).

$$I = a + c\,(X - bY) \quad (1)$$

Where: I = the index or measure of a sire.

a = a constant which brings the average of the whole group of indexes to the desired level but does not alter the difference between any two sires.

c = a constant which can be used to expand or contract the variability of I without changing any correlation between it and other variables.

X = the average record of the daughters of a sire.

Y = the average record of the dams of those daughters.

b = a constant which determines the relative emphasis on Y as compared with X.

When only the average of the daughters is used as the proof of a sire, equation (1) becomes I = X; i.e., *a* and *b* are both zero while *c* is 1.0. The equal-parent index sets *a* equal to zero but *b* to 0.5 and *c* to 2.0; i.e., $I = 2(X - 0.5Y)$. Rice's (1944) regression index is simply to let c = 1.0, b = 0.5, and a = b times the breed average; whence I = 0.5 (breed average) + X —0.5Y. Turner (1925) proposed to let $I = \frac{100}{85}(X - 0.15Y)$; i.e., a = zero, b = 0.15, and $c = \frac{100}{85}$. These examples show that the diverse types of indexes are all included as special cases of equation (1).

Lush(1944) stated that "the real accuracy of an index is measured by its correlation with the true transmitting ability (G) of the sire for which it is computed. The amount of improvement made in the offspring by selecting bulls with equal intensity, but according to I_1 to I_2, ... or to I_n, is strictly in proportion to rGI_1, $r\ GI_2$ . . . . or rGI_n."

METHODS AND MATERIALS

Eight hundred sixty-four Brown Swiss bulls reported proved by the Bureau of Dairy Industry from 1941 through 1950 through D.H.I.A. and H.I.R. testing were used as the source of material providing information for this study.

By definition a proved sire is one with five or more unselected dam and daughter comparisons. The comparisons that are made are for total pounds of milk, percent butterfat, and total pounds of butterfat.

An example of a sire's proving when published is as follows:

Colonel Harry of J. B. 48672	No. of records	Lbs. milk	Percent fat	Lbs. fat
72 Daughters	92	11,795	4.3	508
65 Daughters	85	11,881	4.3	514
65 Dams	248	11,518	4.1	478
Difference (*35-53-40)		+ 363	+ .2	+ 36

*The numbers in the parenthesis mean that 35 of his daughters produced more milk than their dams while 53 tested higher and 40 of them produced more total pounds of butterfat than their dams.

All production records used in the proving of bulls are on the basis of twice-a-day milking. They are figured to a mature equivalent age and are of 305 days lactation in length.

The term "proved sire" does not necessarily mean that a bull is a desirable one. It means only that he has at least five tested daughters compared with their tested dams on a comparable basis. The bull may prove to be a transmitter of high, medium, or low production.

An equal-parent index was computed for each of the proved sires by means of the Hanson Index (1916) "Equal Parent Index" which is as follows: Two times the daughters' production minus that of the dams. This equal-parent index was used as the inherited level of production for the bulls. No corrections or considerations were made for the variable environmental conditions such as feeding and management that acted to influence the proofs. To make such corrections was impossible since the conditions surrounding the daughters and their dams for each bull was unknown.

A two-generation pedigree for each bull was compiled from the "Herd Record" books of the Brown Swiss Cattle Breeders of America. This made a total of three bulls and three cows available for study in the ancestry of each of the proved sires. An equal-parent index was figured for each bull appearing in the pedigrees if he had been proven. The index was figured in the manner outlined above. This was used as the level of inheritance for milk and butterfat production and test for each of these bulls.

Production records were looked up for each cow appearing in the pedigrees where a known record was available. All records used were made on either Registry of Production (official test) or Herd Improvement Registry (herd test). All records used in this study were on the basis of 2X, 305 days, M.E.

The conversion factors used to compare records (sire's proof and cows in pedigree) on the same basis are as follows:

To convert a 365-day record to a 305-day basis multiply by 0.85.

To convert a 4-times-a-day milking to 2-times-a-day milking multiply by 0.74.

To convert a 3-times-a-day milking to 2-times-a-day milking multiply by 0.83.

The following age conversion factors as compiled by the Bureau of Dairy Industry, U.S.D.A. were used to compute the records to a mature equivalent age.

Age	Factor	Age	Factor	Age	Factor
1-6	1.718	6-6	1.006	11-6	1.096
2-0	1.538	7-0	1.000	12-0	1.114
2-6	1.400	7-6	1.000	12-6	1.132
3-0	1.286	8-0	1.000	13-0	1.144
3-6	1.196	8-6	1.000	13-6	1.156
4-0	1.136	9-0	1.006	14-0	1.168
4-6	1.088	9-6	1.012	14-6	1.174
5-0	1.052	10-0	1.030	15-0	1.180
5-6	1.028	10-6	1.048	15-6	1.186
6-0	1.012	11-0	1.072	16-0	1.192

The proving and pedigree of Onward No. 42600 is being presented to illustrate how the pedigree of each of the proved sires was compiled.

Onward 42600

	Milk	%	Fat
16 Daus.	10,465	4.3	450
16 Dams	11,157	3.9	437
Diff.	—692	+.4	+13
Index	9,773	4.7	463

A.
Inkwyl 32960

	Milk	%	Fat
6 Daus.	8,766	4.4	385
6 Dams	9,124	4.3	397
Diff.	—358	+.1	—12
Index	8,408	4.5	373

B.
Mardell Baron
7 records average:
10,089M. 4.7% 475F.

C.
Swiss Betty Boy 27137

	Milk	%	Fat
36 Daus.	10,352	4.2	436
36 Dams	11,724	4.2	489
Diff.	—1,372	.0	—53
Index	8,980	4.2	383

D.
Myrtle Mardell 25439
8 records average:
12,422M. 4.3% 529F.

E. 17460
Baron of Spring Valley

	Milk	%	Fat
11 Daus.	11,275	4.2	476
11 Dams	10,907	4.3	467
Diff.	+368	—.1	+9
Index	11,643	4.1	485

F.
Myrtle Mardell 25439
8 records average:
12,422M. 4.3% 529F.

All records appearing in the above pedigree are 2X, 305 days, M.E. basis.

A predicted inherited level of production for Onward is arrived at by an equal-parent method as follows:

$$\text{Equal-parent predicted level of production} = \frac{A + B + C + D + E + F}{6}$$

A regressed predicted inherited level of production is arrived at as follows:

$$\text{Regressed predicted level of production} = \frac{\frac{A + B + C + D + E + F}{6} - \text{Breed Average}}{2}$$

Theoretically the proved sire would have received 0.50 of his inheritance from his sire and 0.50 from his dam while each of his four grandparents would have contributed equally with 0.25 of his inheritance. However, in the selection of future herd sires, many breeders give about as much weight to the performance of the grandparents as they do to the immediate parents. This is particularly true if the sire and dam are young. Thus each of the six nearest ancestors, when tested, was given equal weight as purely arbitrary values in predicting the inherited level of production of these proved sires.

RESULTS

Breed Average

An average milk and fat production for the breed was arrived at by the use of the provings of all the bulls proved. There was an average of 9.4 daughter-dam pairs per bull. This made an average of 18.8 cows used in the proving of each bull. Thus the records from a total of 16,243 cows were used in computing the breed average in the following manner.

$$\text{Breed average} = \frac{\text{Bulls Daughters} + \text{Bulls Mates}}{2}$$

Bulls Daughters Average: 2X —305d —M.E., 9,718 lb. M., 4.0%, 390 lb. F.
Bulls Mates Average: 2X —305d —M.E.; 9,792 lb. M., 3.9%, 386 lb. F.
Breed Average: 2X —305d —M.E.; 9,755 lb. M., 3.95%, 388 lb. F.

All of the records on these 16,243 cows used in computing the "breed average" were made in either Herd Improvement Registry (H.I.R.) or Dairy Herd Improvement (D.H.I.A.) Since the big majority of the records used in this study were made in H.I.R. or D.H.I.A. the average of 388 pounds of butterfat will be used throughout this study to represent the breed average.

The production averages shown in Table 1 are presented for comparative purposes only. The actual 2X, 305 day H.I.R. records for the various age groups shown in this table were taken from the 1950 "Annual Report" of the Brown Swiss Cattle Breeders Association. The United States Department of Agriculture age conversion factors were used in arriving at the 2X—305d—M.E. production figures.

TABLE 1--BROWN SWISS H.I.R. PRODUCTION AVERAGES - 305 DAY 2X MILKING, M.E.

Age Class	No. Cows	Lbs. Milk	*Actual Av. %	Lbs. Fat	Lbs. Milk	**M.E. Av. %	Lbs. Fat
Mature	7354	10,437.8	4.01	418.24	10,437.8	4.01	418.24
5 years	2776	10,089.2	4.00	403.53	10,492.8	4.00	419.67
Sr. 4 years	1488	10,005.5	4.02	402.08	10,705.9	4.02	430.23
Jr. 4 years	1941	9,501.2	3.95	375.66	10,793.4	3.95	426.75
Sr. 3 years	2241	8,821.9	4.05	357.04	10,233.4	4.05	414.17
Jr. 3 years	1854	8,927.5	3.93	350.83	11,079.0	3.95	435.38
Sr. 2 years	2063	8,190.0	4.07	333.47	10,999.2	4.07	447.85
Jr. 2 years	2418	7,932.1	4.05	320.94	11,652.3	4.05	471.46
12 yrs. & over	595	9,883.9	3.88	383.82	11,544.4	3.88	448.30
Weighted Average	22,730	9,519.4	4.01	381.27	10,461.7	4.11	430.06

*Figures were taken from the 1950 "Annual Report" of the Brown Swiss Cattle Breeders' Association.

**U.S.D.A. conversion factors were used in arriving at these mature equivalent figures. These production averages are higher than those shown in Table 2. These are for one year only, whereas those shown in Table 2 cover a nine year period.

It will be noted that the average mature record for these 22,730 cows is 430.06 pounds of butterfat. This is 42 pounds higher than the average obtained through the use of the mates and daughters of the proved sires. All of the records used in computing the higher average were made in H.I.R. Many of the records used in arriving at the lower average were made in D.H.I.A. It is generally assumed that the feeding and management conditions for herds on H.I.R. are at a higher level than for the herds on D.H.I.A. So at least part of the difference in the averages is probably due to superior environmental conditions in favor of the H.I.R. cows.

Yearly Sire Provings

Table 2 shows that there has been a definite upward trend in the level of production of the proved sires from 1942 through 1950. Not only have the sire indexes moved higher from year to year but with the passing of time the bulls have been mated with higher producing cows. This has resulted in a higher average milk and butterfat production of the daughters being born from year to year.

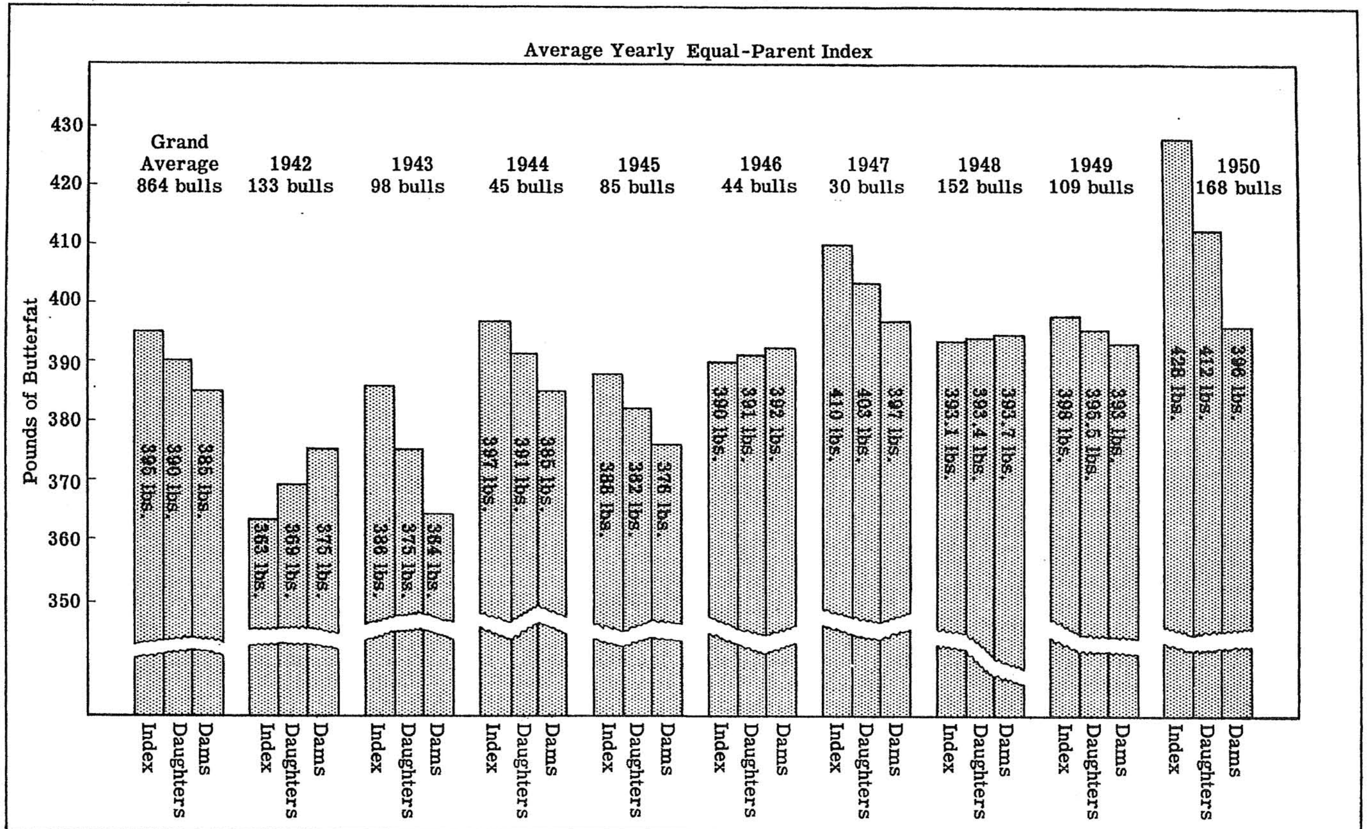
At least part of this trend of increasing production is probably due to improving conditions related to the feeding and management of the milking cows. During the years of World War II there were shortages of labor, feed and equipment. Some of these shortages have now been eliminated. Beef prices have been relatively high during this period and encouraged the elimination of lower producers for meat purposes. This will make for a higher average level of production. Increases in production through this channel would be due to improved environmental conditions for the lactating cows and not due to an increased inherited level for higher production.

Wilson (1949) showed that a greater increase was made in the productivity of Brown Swiss cows than that of any other breed. Since all breeds were subjected to essentially the same environmental conditions during this period, it can be assumed that at least part of the gain registered by Brown Swiss was due to an increased inherited level for higher milk and butterfat production.

Production Levels of Mating

It is generally assumed that cows of higher producing ability are mated with bulls born from ancestors of similar or higher productivity. Benson and Tyler (1950) showed a correlation of 0.20 between the production records of the mates of a group of Ayrshire bulls and the production records of the dams of the bulls. Thus, showing a strong tendency for bulls and cows of the same production level to be mated together. Goodale (1926) found the same to be true when he found those sires

TABLE 2 - COMPARISON OF INDEXES BROWN SWISS SIRES PROVED-1942-1950



whose daughters average the largest yield of butterfat were mated to cows with superior production.

Tables 3 and 4 indicate that the condition described by Benson and Goodale does not exist to as great an extent in the Brown Swiss breed.

TABLE 3--ASSORTATIVE MATING BULLS WITH FOUR OR MORE TESTED ANCESTORS

Bulls' Prediction Index Lbs. Butterfat Range	Av.	Number of Bulls Proved	Average of Bulls' Mates Lbs. Butterfat	Number of Bulls Increasing Production	Per Cent of Bulls Increasing Production
250-299	278	1	289	0	0
300-349	327	2	371	0	0
350-399	384	26	397	13	50
400-449	415	74	399	34	46
450-499	474	116	397	72	63
500-549	520	66	405	43	65
550-599	565	11	419	7	64
600-649	604	1	453	0	0

Bulls' prediction index correlated with mates' production = +0.074

TABLE 4--ASSORTATIVE MATING BULLS WITH FOUR OR MORE TESTED ANCESTORS

Mates' Range Lbs. Butterfat Range	Av.	Number of Bulls Proved	Average of Bulls' E.P. Prediction Index Lbs. Butterfat	Number of Bulls Increasing Production	Percent of Bulls Increasing Production
250-299	283	10	441	9	90
300-349	330	36	457	27	75
350-399	377	99	470	56	57
400-449	422	101	468	54	53
450-499	465	45	471	21	47
500-549	518	6	468	1	17

Table 3 shows that when the bull's predicted level of butterfat production is correlated with the actual production records of his mates, the very low correlation figure of 0.074 is obtained. Thus Benson's correlation of 0.20 with Ayrshires shows a degree of association more than seven times as great between the level of production of the bulls mates and that of his dams as compared with the values shown in Tables 3 and 4.

From Table 3 it will be observed that bulls with predicted index levels ranging from 350 to 399 pounds of butterfat were mated with cows averaging 397 pounds of fat. The same table shows that bulls with prediction indexes ranging from 500 to 549 pounds of fat were mated with cows averaging only 405 pounds of butterfat. This represents a spread of 200 pounds fat (from 350 to 549) in the prediction indexes of the bulls but a spread of only 8 pounds (from 397 to 405) in the average production of the bulls' mates.

In Table 4 it is shown that cows ranging from 300 to 349 pounds of fat were mated with bulls whose prediction indexes average 457 pounds of fat. Also cows ranging from 450 to 499 pounds of fat were mated with bulls whose prediction indexes average 471 pounds of fat. This represents a spread of 200 pounds of fat (from 300 to 499) in the average production of the cows but a spread of only 14 pounds of butterfat in the predicted indexes of the bulls'.

The material in both Tables 3 and 4 shows a very low degree of association between the level of production of the bulls and their mates.

Correlation Coefficients Between Relatives

The development of methods for selecting bulls, using production information in the pedigree, has been accomplished for the most part by the use of the theoretical genetic correlation existing between relatives, (Fisher 1918), instead of the actual correlations found for the measured characteristics. Some of the results of correlation studies have been used to modify a few of the methods which were developed on purely theoretical foundations.

There were 296 bulls proved where at least four or more of the six nearest ancestors were tested. There were only 46 with all of the six nearest ancestors tested. In order to get a suitable number from which to work with and yet still have a reasonably complete picture on the production of the ancestry it was decided to use all of these bulls with at least four or more tested ancestors in the first two generations for the purpose of determining correlation coefficients between relatives.

The equal-parent indexes of these 296 proved sires were correlated with the average production of each of the first six ancestors. This was done for pounds of milk, butterfat percentage and total pounds of butterfat. The correlation coefficients, standard error of estimate and significance of the correlations are shown in Table 5.

TABLE 5--CORRELATION OF THE PROVED SIRES EQUAL-PARENT INDEX WITH THE PRODUCTION OF EACH OF HIS SIX NEAREST ANCESTORS

		Milk		Test		Fat	
Ancestor	Number	Correlation Coefficient	Standard Error of Estimate	Correlation Coefficient	Standard Error of Estimate	Correlation Coefficient	Standard Error of Estimate
			Pounds		Per Cent		Pounds
Sire	451	0.153**	2,480	0.318**	0.459	0.165**	103.0
Dam	521	0.087	2,480	0.217**	0.346	0.179**	102.5
Paternal Grandsire	271	-0.107	2,465	0.195**	0.376	-0.109	106.0
Paternal Grandam	554	0.051	2,350	0.142*	0.352	0.154**	99.0
Maternal Grandsire	221	0.099	2,220	0.150**	0.401	0.117*	96.5
Maternal Grandam	332	0.073	2,400	0.143*	0.360	0.135*	102.0

**Significant at 1% level.
*Significant at 5% level.

There are no other correlations on Brown Swiss cattle of similar nature available for comparison. These are lower though than the correlations reported for other breeds. They are particularly lower than the ones reported by Copeland (1931) for Jerseys. However, all of them but one are significant at either the 5% or 1% level for both butterfat percentage and total pounds of butterfat.

The correlation coefficient between the bull's index and the index of his sire is + 0.165. This value expresses the relationship between the index of the bull and that of his sire. The square of this correlation coefficient is 0.0272. It is apparent, therefore, that approximately 3 percent of the variation in bulls' indexes can be accounted for by their sires.

The highest correlation coefficient obtained was that between the bull's index and the production of his dam. This correlation of + 0.179 only differs slightly from the one correlating the bull with his sire. Both correlations (with the bull's sire and with his dam) are highly significant. Many of the dams of the bulls were sired by proved sires. Since these two correlations are so nearly the same, it can be assumed that the dams were not a highly selected group. They were apparently "average" of the daughters of their sires. This is in direct contrast with the findings of Eldridge (1949). His coefficient of correlation was only approximately one-half as high for the dam ($r = 0.149$) as for the sire ($r = 0.352$) when their son's performance was correlated with that of their own. In his work the dam's record was higher than the average of her sire's daughters in 113 out of the 141 examples used. This is 80.1 percent of the cases. In contrast to this only 57.7 percent of the dams of the proved Brown Swiss bulls used in this study exceeded the average of the daughters of their sires.

This means that on the average the dams of the proved Brown Swiss bulls received an "average" sample of genes for production from their sires. Furthermore they were apparently subjected to environmental conditions that were but little different from those of their paternal sisters.

Whatever interpretation might be given to the magnitude of these coefficients, the greatest reason for determining them lies in the demonstration of the fact that such values exist.

Correlation of Predicted Indexes With Actual Indexes

The problem in selecting any young bull is to predict the level of milk and butterfat production that he will transmit to his offspring. The attempted prediction is almost universally made on the basis of the production records of the ancestry of the young bull in question. With this in mind a prediction index was calculated for each of the 864 proved sires. The summary is presented in Table 6.

TABLE 6--CORRELATION OF PROVED SIRES EQUAL-PARENT INDEX WITH HIS EQUAL-PARENT PREDICTION INDEX WITH NUMBERS OF TESTED ANCESTORS RANGING FROM NONE TO SIX

Number of Tested Ancestors	Records Predicted			(Means) Actual			Number of Pedigrees	Standard Error of Estimate			Correlation Coefficient		
	Milk	%	Fat	Milk	%	Fat		Milk	%	Fat	Milk	%	Fat
None				8,770	4.1	359	101						
One	11,223	4.0	452	9,272	4.1	380	127	2,040	0.34	85.0	0.170	0.262**	0.179
Two	11,470	4.1	465	9,516	4.0	384	177	2,480	0.37	100.0	0.099	0.339**	0.141
Three	11,407	4.1	464	9,366	4.1	382	163	2,540	0.36	104.5	0.092	0.310**	0.107
Four	11,432	4.2	476	10,124	4.2	421	158	2,300	0.34	108.5	0.133	0.283**	0.204*
Five	11,052	4.1	456	10,483	4.1	425	92	2,260	0.36	91.5	0.176	0.143	0.199
Six	11,001	4.2	460	10,768	4.2	451	46	2,200	0.33	91.5	0.247	0.311*	0.244

**Significant at 1% level.
*Significant at 5% level.

TABLE 7--CORRELATION OF PROVED SIRES REGRESSED INDEX WITH HIS REGRESSED PREDICTION INDEX WITH NUMBERS OF TESTED ANCESTERS RANGING FROM NONE TO SIX

Number of Tested Ancestors	Records Predicted			(Mean) Regressed			Number of Pedigrees	Standard Error of Estimate			Correlation Coefficient		
	Milk	%	Fat	Milk	%	Fat		Milk	%	Fat	Milk	%	Fat
None				9,268	4.0	374	101						
One	10,489	4.0	420	9,272	4.0	384	127	1,020	0.17	42.5	0.170	0.262**	0.179
Two	10,613	4.0	427	9,635	4.0	386	177	1,240	0.19	50.0	0.099	0.339**	0.141
Three	10,581	4.1	426	9,560	4.1	385	163	1,270	0.18	52.3	0.093	0.311**	0.107
Four	10,594	4.1	432	9,939	4.1	405	158	1,150	0.17	54.3	0.133	0.283**	0.204*
Five	10,403	4.0	422	10,119	4.0	407	92	1,130	0.18	45.8	0.176	0.144	0.199
Six	10,378	4.1	424	10,262	4.1	419	46	1,100	0.17	45.8	0.247	0.310*	0.244

**Significant at 1% level.
*Significant at 5% level.

The predictions were made on the theory of inheritance coming equally from the parents. The first six ancestors of each bull were used in arriving at the predicition indexes. On this basis a bull would receive 50 percent of his genes for transmitting milk and fat production from each his sire and dam. Twenty-five percent of his total potential would come from each of his four grandparents.

One hundred and one (11.7% of the total group) of the proved sires had no production testing in their six nearest ancestors. The average of the equal-parent indexes, based on the actual provings of these bulls, is 359 pounds of butterfat. This is the lowest production group of bulls in the study.

The group of bulls that transmitted the highest level of milk and fat production to their offspring was the group where all six nearest ancestors were tested. The average index for the group of 46 bulls is 451 pounds of butterfat. This is an increase of 92 pounds of fat over the group of bulls that had no testing in the first two generations of their pedigrees. The average predicted index for these bulls with six tested ancestors is 460 pounds of butterfat. This is only 9 pounds different from their actual provings. However, as noted from Table 6, the correlation coefficients existing between the predicted indexes and the actual proof indexes for this group of bulls with six tested ancestors are rather low. The correlation of 0.311 for butterfat percentage is significant at the 5% level. But neither of the correlations of 0.106 and 0.235 for milk and total fat production respectively are significant at the 5% level.

In general the correlation coefficients between predicted and actual indexes were nearly as high where only one, two, three or four of the six nearest ancestors were tested as they were where five or six of them were tested. For instance there were 127 bulls proved where only one ancestor was tested. The correlation coefficients for milk, percent butterfat and pounds of fat were 0.170, 0.262, and 0.179 respectively. Sixty-seven of the tested ancestors in this group were in the second generation with only 60 in the first.

A possible reason for the small existing correlation differences found between the bulls with little testing in their pedigrees and the ones with five or six tested ancestors is that the Brown Swiss breed appears to be relatively uniform for a level of production between 380 and 420 pounds of butterfat. Also, the number of bulls proved that had five or six tested ancestors was smaller than the groups with less testing in their pedigrees. Therefore a higher correlation coefficient would have to be obtained on these smaller groups of bulls in order for them to be significant. Thus if the breed has relatively fixed level of production at around 400 pounds of fat, it would be difficult to achieve the higher correlations necessary for significance with the smaller number of bulls.

Rice (1944) advocated the regressing of predicted indexes to the breed average when selecting young bulls. His proposal was to give the breed average and the equal-parent predicted index equal weight when arriving at the future transmitting level of milk and fat production for young bulls. Dickey and Labarthe (1945) predicted the transmitting ability of 214 Holstein proved sires by use of both the equal-parent method and the regressed method as advocated by Rice. Their correlation coefficient between predicted butterfat production, using the equal-parent index, was + 0.531 and, using the regressed index, was + 0.606. The squaring of these correlation coefficients shows that the relation between predicted index and actual proving of the bull was 36.7 percent association for the regression index as compared to 28.2 percent for the equal-parent prediction. This gave a definite advantage in predictability to the regressed method.

An advantage for the regressed index was not apparent in this study with the Brown Swiss proved sires. The results of regressing the bulls predicted indexes and their actual proof indexes to the breed average are shown in Table 7. As will be noted from the table, the correlations between the predicted and actual proof indexes when regressed to the breed average are the same as those shown in Table 6 for the equal-parent prediction and proof. This is to be expected since the breed average of 9,755 lb. M., 3.95% and 388 lb. F. was used as a constant to regress both the predicted and actual proof indexes. Introduction of the breed average to these proofs (predicted and actual) reduced the variability in them but did not change the relative standing of any of them with respect to one another. So the correlations were not affected by the regressions. Thus it is not readily apparent from their study how Dickey and Labarthe (1945) were able to obtain higher correlation coefficients by regressing their equal-parent predicted indexes if they used the breed average as a constant.

Correlation of Predicted Indexes with Proof Indexes, Mates and Daughters' Production

Tables 8 and 9 show the correlation of predicted indexes with the bulls proof indexes, the production of the bulls daughters and the production of the bulls mates. All of the bulls with four, five or six tested ancestors were used for this phase of the study. There were 296 such bulls. The correlations shown in Table 8 were made with equal-parent predicted indexes while the correlations presented in Table 9 were obtained through the use of regressed predicted indexes.

The results in those two tables again show the correlation coefficients to be the same regardless of whether the equal-parent or regressed

TABLE 8--CORRELATION OF PROVED SIRES EQUAL-PARENT PREDICTION INDEX, WHERE 4, 5 OR 6 OF THE BULLS' ANCESTORS WERE TESTED, WITH HIS PROVING (EQUAL-PARENT INDEX)

Number of Tested Ancestors	Records Predicted			(Means) Actual			Number of Pedigrees	Standard Error of Estimate			Correlation Coefficient		
	Milk	%	Fat	Milk	%	Fat		Milk	%	Fat	Milk	%	Fat
	Index			Index									
4, 5, or 6	11,247	4.5	467	10,336	4.13	427	296	2,290	0.335	95.5	0.142*	0.212**	0.244**
	Correlation of proved sires equal-parent prediction index with the daughters of the proved bulls												
	Daughters			Daughters									
4, 5, or 6	10,650	4.07	433	10,195	4.06	413	296	1,530	0.197	58.5	0.115*	0.248**	0.237**
	Correlation of proved sires equal-parent prediction index with the mates of the proved bulls												
				Mates									
4, 5, or 6				10,054	4.00	399	296	1,277	0.177	54.5	0.029	0.051	0.100

**Significant at 1% level.
*Significant at 5% level.

TABLE 9--CORRELATION OF PROVED SIRES REGRESSED PREDICTION INDEX, WHERE 4, 5, OR 6 OF THE BULLS' ANCESTORS WERE TESTED, WITH HIS PROVING (REGRESSED INDEX)

Number of Tested Ancestors	Records Predicted			(Means) Regressed			Number of Pedigrees	Standard Error of Estimate			Correlation Coefficient		
	Milk	%	Fat	Milk	%	Fat		Milk	%	Fat	Milk	%	Fat
	Index			Index									
4, 5, or 6	10,501	4.07	428	10,046	4.06	408	296	1,145	0.168	47.8	0.142*	0.212**	0.244**
	Correlation of proved sires regressed prediction index with the daughters of the proved bulls												
	Daughters			Daughters									
4, 5, or 6	10,202	4.03	410	9,975	4.03	400	296	765	0.099	29.3	0.115*	0.248**	0.237**
	Correlation of proved sires regressed prediction index with the mates of the proved bulls												
				Mates									
4, 5, or 6				9,904	4.00	392	296	638	0.089	27.3	0.029	0.051	0.100

**Significant at 1% level.
*Significant at 5% level.

method was used for predicting the future transmitting ability of the sires.

Table 8 again shows the increase in production that is currently being made by the Brown Swiss breed. The mates of these 296 proved sires averaged 399 pounds of butterfat per cow while the bulls' daughters average 413 pounds.

The correlations in Table 8 are noteworthy in that almost identical coefficients of correlation for butterfat production were obtained when the bull's predicted index was correlated with his actual proof index and also when it was correlated with the production of his daughters. The coefficients are 0.244 and 0.237 respectively. Gowen (1919), Copeland (1931), Schultz and Lush (1937), Eldridge (1949) and others have correlated the production of bull's ancestors with the production of his daughters. However, none of them calculated correlations between the bull's ancestors and a computed index based on the bull's actual proof. As stated above, though, the correlations are remarkably near the same whether the ancestors are correlated with the bull's daughters or with his own actual proof equal-parent index.

The Multiple Regression Method of Sire Selection

Many investigators have studied the correlations between the average production of different groups of relatives such as between dams and their daughters, or between the dam and the daughters of her son. There has been only one result (Eldridge 1949) reported however, in which the butterfat production of several relatives within each of the pedigrees of a large number of bulls have been used as the basis of estimating the transmitting ability of a bull. The most logical manner in which to utilize the production records of several relatives of a bull in estimating his transmitting ability is the method of multiple regression. By this method several different variables can be used simultaneously to estimate another variable.

From the 864 proved sires there were 46 whose six nearest ancestors were all tested. These 46 were used to develop the multiple regression equation for predicting the bull's transmitting quality. The method as outlined by Snedecor (1946) was used in the development of this equation.

The variables were assigned symbols as follows:

X_1 = Equal-parent index of the proved bull's sire.
X_2 = Average production of the dam of the proved bull.
X_3 = Equal-parent index of the proved bull's paternal grandsire.
X_4 = Average production of the paternal grandam of the proved bull.
X_5 = Equal-parent index of the proved bull's maternal grandsire.
X_6 = Average production of the maternal grandam of the proved bull.
Y = Equal-parent index of the proved bull.

The actual numerical mean values of the variables used are as follows:

X_1 = 450.72 pounds of butterfat.
X_2 = 496.15 pounds of butterfat.
X_3 = 383.78 pounds of butterfat.
X_4 = 534.63 pounds of butterfat.
X_5 = 428.30 pounds of butterfat.
X_6 = 462.22 pounds of butterfat.
Y = 450.52 pounds of butterfat.

The most important values used in the computation of the multiple regression equation are shown in Table 10.

TABLE 10--STATISTICAL VALUES FROM DATA USED IN SETTING UP THE SIMULTANEOUS EQUATIONS FOR DETERMING THE MULTIPLE REGRESSION EQUATION
(Snedecor Table 13.2 - 1946)

	Sire X_1	Dam X_2	Paternal Grandsire X_3	Paternal Grandam X_4	Maternal Grandsire X_5	Maternal Grandam X_6	Proved Bull Y
X	450.72	496.15	393.78	534.63	428.30	462.22	450.52
X_1 (1)	483.0	61,240.4	61,844.9	119,913.0	-79,720.4	28,224.4	53,907.7
		292,818.8	186,646.7	289,993.2	98,435.5	315,688.8	316,606.5
		0.209.1*	0.3313*	0.4135**	-0.8099	0.0894	0.1703
X_2		606.2	-1,711.1	60,063.0	-30,839.3	110,000.7	9,502.4
			234,235.7	363,962.5	123,543.6	396,212.3	397,364.1
			-0.0073		0.1650	-0.2496	0.0239
X_3			386.4	-3,426.5	-60.562.6	-9,254.4	-12,005.7
				231,994.6	78,748.3	252,551.0	253,285.2
				-0.0148	-0.7691	-0.0366	-0.0474
X_4				600.4	-118,943.3	150,815.9	137,881.9
					122,361.5	392,421.4	393,562.2
					-0.9721	0.3843**	0.3503*
X_5					203.8	-59,450.6	-33,889.2
						133,203.7	133,590.9
						-0.4463	-0.2537
X_6						653.6	43,842.7
							428,434.8
							0.1023
Y							655.5

(1) For example, in the row X_1, the upper value in each block is $S_{X_1X_2}$, $S_{X_1X_3}$, ---S_{X_1Y}. The next value is $\sqrt{(S_{X_1}^2)(S_{X_2}^2)}$, $\sqrt{(S_{X_1}^2)(S_{X_3}^2)}$ ---$\sqrt{(S_{X_1}^2)(S_Y^2)}$ and the third quantity is the correlation in each case, r_{12}, r_{13} ---r_{1Y}.
*Significant at 1% level
**Significant at 5% level.

In Table 10 are shown the simple correlations between the various ancestors of the bulls. For example, in the block made by the crossing marked X_6 is found the value + 0.0894. This value is the correlation coefficient which expresses the relationship between the equal-parent index of the sires of the proved bulls and the average of the production records of the maternal grandams of the proved bulls. The generally accepted symbol for the simple correlation coefficient is r, and in the example just given, the subscripts 1_6 identify which of the two variables are being correlated, r_{16}. In the same way, another set of values, X_2 and Y, are correlated, $r_{2\bar{Y}} = + 0.0239$.

It may well be assumed that most of these bulls were not used in the herds which they were born. Thus their actual proof indexes were made in herds different than the ones where their ancestors were tested. These simple correlations should theoretically be zero, if it were assumed that the ancestors in herds in which the bull was dropped were not related to the cows in the herd in which he was used. There are undoubtedly some cases in these data in which some relationship does exist, but, according to Lush (1936), the average coefficient of relationship between herds is low enough that for the general consideration of these correlations it can be assumed to be practically zero.

From the 20 correlation coefficients, 11 of which were positive and 9 negative, it is indicated that the cattle from herd to herd were largely unrelated genetically. The positive correlations that existed were probably due to similarities in production which resulted from environmental conditions being similar on many farms. The negative correlations existing further attest to the lack of assortative mating in the Brown Swiss breed. In other words, a herd owner does not necessarily buy bulls from other herds with a production level similar to that of his own herd as has been shown to be the case in Holsteins by Eldridge (1949) and in Ayrshires by Benson (1950).

The multiple regression equation derived is as follows:

$$\hat{Y} = 529 + .06X_1 - .05X_2 - .22X_3 + .28X_4 - .30X_5 - .04X_6$$

$\hat{Y}$ is the estimated average equal-parent index of the proved sires. When the appropriate values are substituted for the X's in the formula, the value of Y is solved and is as follows:

$$Y = 529 + (.06)\ (451) - (.05)\ (496) - (.22)\ (394) + (.28)\ (535) - (.30)\ (428) - (.04)\ (462)$$

$$Y = 450.5 \text{ pounds of butterfat.}$$

The coefficient of the multiple correlation, method outlined by Snedecor (1946), is obtained by substituting the appropriate values in the following formula.

$$R^2 = \beta YX_1 rX_1Y + \beta YX_2 rX_2Y + \beta YX_3 rX_3Y + \beta YX_4 rX_4Y + \beta YX_5 rX_5Y + \beta YX_6 rX_6Y$$

$R^2 = 0.1235$ for the above multiple regression equation

$$R = \sqrt{0.1235}$$

$$R = 0.351$$

According to Fisher (1946) the multiple correlation would have to be as high as 0.581 to be highly significant (1% level) and as high as 0.515

to be significant at the 5% level. Since the coefficient obtained is only 0.351, it is not significant.

The standard error of estimate is 97 pounds of butterfat and is shown in Table 11 under "standard deviation."

TABLE 11--ANALYSIS OF VARIATION IN MULTIPLE REGRESSION SIX VARIABLES

1 Source of Variation	2 Degrees of Freedom	3 Sums of Squares	4 Mean Square or Variance	5 Standard Deviation
Due to Regression	5	53,076	10,615	
Not accounted for	40	376,686	9,417	97.00 lbs. Fat
Total	45	429,762	9,550	97.72 lbs. Fat

$\frac{53,076}{429,762} = .1235$. Thus approximately 12% of the total variance in the bull's actual proof indexes could be accounted for by the multiple regression equation.

"R" is the symbol for the correlation coefficient when used in reference to a multiple regression equation and is similar to "r" in simple correlations. The magnitude of R is a measure of the success in estimating the actual proof index of these bulls when using the regression equation, since it indicates the relative amount of agreement between their estimated and their actual observed indexes. The square of the multiple correlation coefficient (R^2) represents the percent of the variance in the actual proof indexes of the bulls that can be accounted for by consideration of the variation among the estimates of the ancestors production from the regression formula. The square of the multiple correlation coefficient can be obtained directly by the formula $\frac{S_{\hat{Y}}^2}{S_Y^2}$ in which $S_{\hat{Y}}^2$ is the sum of the squares of deviations from the mean that are attributable to regression and S_Y^2 is the sum of the squares of the deviations from the mean of the observed averages of the index of each bull.

The standard error of estimate, Snedecor (1947), p. 368, was 97.00. This is a measure of the deviation of the observed values from the plane described by the regression equation. It can be compared with the standard deviation of observed values around the mean of its group.

The regression equation outlined above does not take into consideration the average of the mates in the herd in which the bull will be used. It allows for grouping bulls according to estimates based entirely on the average production of the ancestors of the bulls. This equation has value in discriminating between bulls on the basis of their inherited potentialities, since it is not influenced by the average production of the herd in which the bull is to be used. Therefore, when it is desired to determine the relative butterfat transmitting values of the individuals in a group of young bulls, the equation may be used. Approximately 12 percent of the variance in the bull's actual proof index will be accounted for. This appears to be a rather small percentage, but it would have been very surprising if it were much larger since past experience indicates only about 50 percent of the sires selected actually increase the production of their daughters.

Simplified Methods of Sire Prediction

The multiple regression equation may be used for determining which bulls have the highest inherent potential for a high equal-parent actual proof index. While it will account for approximately 12% of the variance encountered, many breeders would prefer to have a prediction method that is shorter and more easily understood at their disposal.

Table 12 shows three different possibilities for predicting the future proof index of a bull in question. Each of these three methods is relatively

TABLE 12--PREDICTION INDEXES - 138 PROVED SIRES

Prediction Used	Predicted Level Butter-fat Lbs.	Actual Av. Index of Proved Sires Butter-fat Lbs.	Correlation	Standard Error of Estimate
$\frac{\text{Sire Index + Dam}}{2}$	458.1	425.0	+0.306*	93.5 Lbs. Fat
$\frac{\text{Sire + Dam + Maternal Grandsire}}{3}$	445.8	425.0	+0.266*	93.5 Lbs. Fat
$\frac{\text{Sire + Maternal Grandsire}}{2}$	430.8	425.0	+0.145	94.0 Lbs. Fat

*Significant at the 1% level.

quick, easy and simple to handle. Each of the methods correlates the bull's actual proof equal-parent index with the average production with some certain two or three ancestors. All of the bulls used in these short methods had to meet the qualifications of being sired by a proved sire and from a tested dam who was sired by a proved sire. There were 138 proved bulls that met this set of specifications.

The most striking fact brought forth by the data in Table 12 is that two of the methods used have correlations that were significant at the 5% level. This is of particular importance since the more complicated multiple regression equation produced a correlation that was not significant at the 5% level. The greater degree of freedom, however, lowers the size of correlation needed for significance in the case of the more short, simplified methods of sire prediction.

The very simple method of adding the sire's equal-parent index plus the average of the dam's records and dividing by two resulted in the highest and most significant correlation of all. This correlation was + 0.306. One-half sire index + ½ maternal grandsire index correlated with the bull's actual proof index resulted in a correlation of + 0.145.

The dam's record when added to the indexes of the sire and maternal grandsire with equal weight for the three ancestors raised the correlation coefficient to + 0.266.

These three short methods of sire prediction are more or less arbitrary but these three ancestors (sire, dam, and maternal grandsire) are given a great deal of weight by breeders when purchasing future herd sires. With this in mind, a multiple regression equation was worked out with these ancestors and the proved sires actual equal-parent proof indexes. This was done to determine the optimum weighting for the sire, the dam and the maternal grandsire.

The multiple regression equation derived is as follows:

$$\hat{Y} = 174.5 + 0.083X_1 + 0.256X_2 + 0.216X_3$$

The variables were assigned symbols as follows:

X_1 = Equal-parent index of the proved bull's sire.
X_2 = Average production of the dam of the proved bull.
X_3 = Equal-parent index of the proved bull's maternal grandsire.
Y = Equal-parent index of the proved bull.

The actual numerical mean values of the variables used are as follows:

X_1 = 433.3 pounds of butterfat.
X_2 = 482.4 pounds of butterfat.
X_3 = 426.4 pounds of butterfat.
Y = 426.1 pounds of butterfat.

When the appropriate values are substiuted for the X's in the formula, the value of Y is solved and is as follows:

$$\hat{Y} = 174.5 + (.083)\ (433.3) + (.256)\ (482.4) + (.216)\ (426.4)$$
$$\hat{Y} = 426.1 \text{ pounds of butterfat}$$
$$R^2 = 0.102$$
$$R = +\ 0.320$$

According to Fisher (1946) the multiple correlation would have to be as high as 0.255 to be highly significant (1% level). Since the coefficient obtained is + 0.320, it is highly significant. This multiple regression equation does give optimum weight to each of these three ancestors when predicting the future transmitting ability of young Brown Swiss bulls.

Families

The development and promotion of certain families have played a tremendously important role in the advancement of the Brown Swiss breed in this country. The following pages are devoted to a study of families. By definition, a family, as used in this study, is any bull that has five or more proved sons.

Information available made it possible to summarize and correlate the predictability of eleven such families. These included bulls proved through 1950. The size of the families ranged from 5 proved bulls up to 21.

The average prediction index and the average actual proof index are given as a summary of each family along with the correlation of predictability and standard error of estimate.

The correlation coefficient of predictability of only one family was high enough to be significant at the 5% level. This was the family headed by Pheifer Boy V. B. 22nd 35122.

Beautys Buster of Vernon 31073

Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. Jesse of Judds Bridge	519	430
2. Goldie's Buster J.B.	470	305
3. Myrtle's Buster J.B.	461	413
4. Eliza's Buster J.B.	473	611
5. S. Gertrude's Buster J.B.	453	615
6. Dame's Buster J.B.	439	368
Average	469	457
Correlation of actual indexes with predicted indexes		+ 0.123
Standard error of estimate		115.5 lbs. Fat

Bubbling Over of Walhalla 33458

Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. Violet's Tarzen of Vernon	436	377
2. Sherry's Prince Edward	436	361
3. Royal Jane's Max of Vernon	493	555
4. Royal Jane's Ambassador of Vernon	493	576
5. Vernon's Brown Bomber	517	450
Average	475	464
Correlation of actual indexes with predicted indexes		+ 0.598
Standard error of estimate		71.5 lbs. Fat

Judd's Bridge Swiss Betty Baron 34504

Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. Lauretta's Barbette J.H.	474	698
2. Barbette's Keeper of J.H.	492	463
3. Janette's Baron J.B.	454	449
4. Maggie's Baron J.B.	495	365
5. Annie's Betty Baron J.B.	472	467
6. Colonel Harry of J.B.	535	550
7. Lassie's Barbette J.B.	499	470
Average	485	495
Correlation of actual indexes with predicted indexes		+ 0.366
Standard error of estimate		85.5 lbs. Fat

Inkwyl 32960

Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. Onward	462	463
2. Baron Inkwyl	453	411
3. Prince Inkwyl	452	461
4. Bonnie's Inkwyl	435	414
5. Gertrude's Inkwyl	446	446
6. Sarah's Inkwyl	412	495
7. Betty's Inkwyl Boy	493	464
Average	450	451

Correlation of actual indexes with predicted indexes + 0.418
Standard error of estimate 22.0 lbs. Fat

Swiss Betty Boy 27137

Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. Admiral of Spring Valley	501	611
2. Laura's Betty Boy of J.B.	511	393
3. Francis of Spring Valley	507	574
4. Judds Bridge Swiss Betty Baron	533	480
5. Mardell Baron Duke	503	511
6. Byron of Spring Valley	507	354
7. Carlo of Spring Valley	504	470
8. Maiden's Betty Boy J.B.	475	506
9. Swiss Vincent	442	351
10. Terry of Spring Valley	480	447
11. Swiss Marcel	487	377
12. Gurthau's Boy of J.B.	538	343
13. Swiss Lad Marcel	491	449
14. Yodler of Spring Valley	506	373
15. Inkwyl	506	373
16. Kermit of Spring Valley	513	473
Average	500	455

Correlation of actual indexes with predicted indexes + 0.287
Standard error of estimate 81.5 lbs. Fat

Nevard of Bowerhome 23652

Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. Forest Farm's Conrad	472	516
2. Campo of Forest Farms	460	336
3. Pride's Nevard of Swissdale	433	379
4. Nevard Son of Hilltop	461	330
5. Santa Claus of Lee's Hill	497	318
Average	465	376

Correlation of actual indexes with predicted indexes 0.000
Standard error of estimate 77.5 lbs. Fat

Pheifer Boy V.B. 22nd 35122		
Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. V. B. Jack	429	241
2. Ben R. of Redwing	394	261
3. V.B. Pheifer Boy's Luck	455	425
4. Kofel V.B.	457	414
5. Pheifer Boy V.B. 22nd B.	436	347
6. Master Schoni V.B.	410	352
7. Royal V.B.	455	526
Average	434	367
Correlation of actual indexes with predicted indexes		+ 0.790*
Standard error of estimate		57.5 lbs. Fat

*Significant at the 5% level.

Pheifer Boy V.B. 27385		
Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. Pheifer Boy V.B. 5th	417	316
2. Pheifer Boy V.B. 32nd	379	454
3. Pheifer Boy V.B. 27th	387	547
4. Pheifer Boy V.B. 22nd	435	428
5. Susanna's College Boy V.B.	404	458
6. V.B. Pheifer Vogel	421	360
7. Pheifer Boy V.B. 14th	353	410
Average	399	425
Correlation of actual indexes with predicted indexes		—0.571
Standard error of estimate		52.0 lbs. Fat

Baron of Spring Valley 17460		
Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. Walhalla Scattergood Baron	517	506
2. Walhalla Sparkler Baron	485	223
3. Walhalla Crusader Baron	517	307
4. Walhalla Gallant Baron	459	376
5. Walhalla Jester Baron	479	290
Average	491	340
Correlation of actual indexes with predicted indexes		—0.744
Standard error of estimate		57.5 lbs. Fat

Jane's Royal of Vernon 28494		
Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. Michelangelo of Lee's Hill	566	564
2. Royal's Victor of Vernon	536	381
3. Inez's Swiss Lady's Captain	445	497
4. Royal MacArthur of Lee's Hill	492	496
5. Royal Nomad of Lee's Hill	458	285
6. Privet's Royal Junior of Lee's Hill	544	601
7. Royal's Gendarme of Lee's Hill	501	409
8. Royal's Friday of Lee's Hill	544	386
9. Alva's Royal Lad of Lee's Hill	539	347
10. Melanie's Royal of Lee's Hill	516	524
11. Royal's Squire of Lee's Hill	535	508
12. Natalie's Royal Boy of Lee's Hill	528	499
13. Privet's Columbus of Lee's Hill	544	576
14. Fifty Grand of Lee's Hill	520	604
15. Royal's Ranger of Lee's Hill	533	354
16. Mistletoe's Royal of Lee's Hill	488	399
17. Royal's Best Man of Lee's Hill	475	321
18. Camilla's Royal of Lee's Hill	508	719
19. Sandra's Royal of Lee's Hill	523	587
20. Privet's Royal of Lee's Hill	544	349
21. Royal's Robin of Lee's Hill	551	470
Average	519	470
Correlation of actual indexes with predicted indexes		+ 0.318
Standard error of estimate		111.5 lbs. Fat

The Keeper of Walhalla 31653		
Sons	Predicted Index Lbs. Fat	Actual Index Lbs. Fat
1. Dame Melroy Keeper's J.B.	444	500
2. Sallie's Keeper J.B.	398	344
3. Judd's Bridge Royal Keeper	418	523
4. Lee's Hill Whirlaway	448	513
5. Marlene's Keeper J.B.	415	346
6. The Keeper of Lee's Hill	532	458
7. Louise Baron's Keeper J.B.	475	449
8. Annie's Keeper J.B.	478	457
9. Judd's Bridge Baron	470	377
Average	453	441
Correlation of actual indexes with predicted indexes		+ 0.228
Standard error of estimate		75.5 lbs. Fat

Type and Production

Seventy-seven of the 864 proved bulls have been officially classified for type. No attempt is being made here to show a correlation between type and production. This phase of the study has been conducted merely as a point of interest. Of the 77 classified bulls, 7 were "Excellent", 43 were "Very Good", 25 were "Good Plus" and 2 were "Good".

The bulls were grouped according to their classification ratings. The prediction indexes for butterfat were then correlated with the actual proof indexes for the group of bulls in each classification rating. The results are shown in Table 13. As will be noted from the table, the prediction indexes of the 25 "Good Plus" bulls showed a correlation of + 0. 428 when correlated with their actual proof indexes. This is significant at the 5% level. None of the correlations for the predictability of the bulls in the other type classes were significant. It will be noted from Table 13 that bulls of all four type classifications were mated with cows of almost identical levels of butterfat production. This again emphasizes the lack of assortative mating in the Brown Swiss breed.

DISCUSSION

The chief objective of this study has been the determination of a prediction method that will quickly and with reasonable accuracy estimate the expected transmitting ability of unproved Brown Swiss bulls. The 864 Brown Swiss bulls reported proved in D.H.I.A. and H.I.R. test-

TABLE 13--TYPE AND PRODUCTION

Classification Rating	Number of Bulls	Av. of Mates' Fat Production Pounds	Av. of Daughters' Fat Production Pounds	Av. of Equal-Parent Index Pounds Fat	Av. of Predicted Index Pounds Fat	Correlation of Indexes Actual and Predicted	Standard Error of Estimate
Excellent	7	423	446	469	473	+0.372	109.5
Very Good	43	416	433	450	473	+0.216	97.0
Good Plus	25	417	429	441	467	+0.428*	82.5
Good	2	420	450	480	406	-1.000	0.0

*Significant at the 5% level.

ing by the Bureau of Dairy Industry, U.S.D.A., from 1941 through 1950, were used to provide the data for this study.

A breed average to serve as a working basis was determined by use of the proved sire data. The 864 proved sires had an average of 9.4 dam and daughter pairs. Thus a total of 16,243 tested cows was involved. Their records averaged 9,755 pounds milk and 388 pounds fat with an average butterfat test of 4.0 percent.

An equal-parent index following the plan of Hanson (1916) was calculated for each of the proved bulls as well as for their sires dams and paternal and maternal grandsires and grandams if they also had provings. All records were studied on the basis of 2x milking, 305 day lactation, mature equivalent. A predicted equal-parent index was calculated for each of the proved sires by giving equal weight to the average production of each of the tested ancestors of the proved bull that appeared in the first two generations of his pedigree. The total of the ancestors average production was then divided by the number of tested ancestors. This gave an equal-parent predicted value for each of the bulls. A regressed predicted value was also calculated for each bull. The regressed value was ½ equal-parent predicted index plus ½ the breed average.

The general trend of butterfat production for daughters of sires used in this study, is for the average equal-parent index of the proved sires to increase with a higher level of production with each succeeding year for the period involved. The average equal-parent index of 133 bulls proved in 1942 was 363 pounds of butterfat. In contrast to this level of production, the 168 bulls proved in 1950 had an average index of 428 pounds of fat (Table 2). This upward trend in production is doubtlessly due to two things: (a) the genetic inheritance for higher production has probably been increasing slightly during this time and (b) the environmental conditions governing the feeding and management of the cattle have been more favorable since 1942 than in earlier years. The price of dairy products has encouraged better feeding. The price of beef has been favorable to a rigid culling program. These factors have some influence on the caliber of cows sires are mated to and likewise encourage the more strict culling of the lower producing progeny of a sire. It will be noted that the level of production for the dams was 375 pounds of fat in 1942 and 396 pounds in 1950, with an average of 385 pounds during the period studied.

There is little evidence of assortative mating in the Brown Swiss breed. The data indicate little relation between the predicted index of the bull and the level of production of his mates. The correlation was only + 0.074. This is much lower than the correlations for assortative mating reported by Benson (1950) for Ayrshires and by Eldridge (1949) for Holsteins. In general, both the highest and the lowest producing Brown Swiss cows were mated with bulls whose prediction indexes were about equal; however, the better producing cows are mated to sires with the greatest potential transmitting ability because we usually find the breeder with outstanding cows using the best bull he can obtain.

The breeder with a lower producing herd often secures a sire in the general production range of his herd. Even if he does obtain a sire of superior production from an inheritance standpoint, the feeding and management may be such as to level the genetic gains in the offspring so far as performance is concerned. It is also possible that the intensity of selection varied from one sire to another in daughters tested, and that similar variation occurred in the selection of dams of these daughters. These factors are responsible for biased errors and do not correct themselves as the number of daughters of a bull increases. The environmental factors would tend to be equalized if the daughters of a given sire were scattered in many herds, but such is seldom the situation particularly in the case of sires with their first proving. It would seem from the data herein studied, however, that sires of the Brown Swiss breed are fairly uniform for transmitting production in the 380 to 430 pounds of butterfat range so far as a general breed average is concerned.

There were 296 proved sires that had at least four or more tested ancestors. The equal-parent indexes of these bulls were correlated with the production record of each of the tested ancestors. **The most significant correlations were with the proved bull's sire, his dam and paternal grandam for total pounds of butterfat.** The correlation coefficients between the bulls' indexes and the records of their maternal grandsire and maternal grandam were also significant but at a lower level. (Table 5). A negative correlation was secured between the bulls indexes and the indexes of the paternal grandsires. The predicted sire indexes were correlated with the bull's actual proof. One hundred one of the bulls had no tested ancestors in the first two generations of their pedigrees. These were omitted when the prediction indexes were correlated with the actual indexes. For the most part the bulls with less than five tested ancestors had a higher predictability than the bulls with five or six tested ancestors. The bulls with fewer tested ancestors showed significant correlations since their numbers were larger. Hence, not so large a coefficient was required for significance by them as compared to the smaller number of bulls that had five or six tested ancestors. The variability of the bull's transmitting ability was materially lessened when the prediction indexes were regressed to the breed average.

In case of sires with at least four tested ancestors (296 such sires) it was found that when the prediction indexes of these bulls were correlated with their actual proof indexes, with their daughters production, and with their mates production, that a correlation of + 0.244 between the bulls' prediction indexes and their actual sire proof indexes resulted.

Correlating the prediction with actual indexes gives the same results as correlating the prediction indexes with the bull's daughters' production. The latter produced a correlation coefficient of + 0.237. The correlation produced with the bulls' mates though was much lower as it was only + 0.100. This again demonstrates the lack of assortative mating in the Brown Swiss breed and in the case of this study a fairly uniform population so far as average butterfat production is concerned.

There were 46 proved bulls that had all six ancestors tested. A multiple regression equation was derived from this group. When the multiple regression equation was correlated with the proved bulls' actual proof indexes it gave a multiple correlation of + 0.351. This correlation is not significant but it does account for approximately 12 percent of the variance in the indexes of the proved sires. In view of the many factors such as intensity of selection and environmental condition existing from herd to herd, as well as between sires' progeny, it would hardly be possible to account for a large percentage of the variance in sire indexes.

Three methods of predicting a bull's transmitting ability were tested. It was found (Table 12) that the simple addition of ½ the sire's index plus ½ the dam's record gives the highest rate of predictability of any of the three methods tested. It resulted in a correlation of + 0.306 between the sire's prediction and his actual proof. The prediction method that resulted in the next highest correlation was ⅓ sire index plus ⅓ dam's record plus ⅓ maternal grandsire's index. The correlation coefficient from this method was + 0.266. A multiple regression equation was derived from these three ancestors and the proved sires. It gives optimum weight to each ancestor for prediction purposes. The simple method of ½ the sire's index plus ½ the dam's record is purely an empirical method, but it's close agreement with the actual production of the sire's progeny indicates it may be useful in predicting transmitting ability of young sires. The multiple regression equation is too cumbersome and complicated for use by practical breeders.

The large negative correlations between the maternal grandsire's index (x5) and the sire's index (—.81), the paternal grandsire's index (—.77) and the paternal grandam's record (—.97) may probably best be explained as follows: When the maternal grandsire's index is low it means that he has a large number of low producing daughters. This situation usually stimulates a breeder to obtain a sire whose pedigree indicates high production to use on these daughters. Bulls used in such instances, and there are many, are able to rather easily show a high index (X_1) because of the low level of the cows to which they are mated.

Where a bull had five or more proved sons, his sons were considered as a sire family and analyzed as such. Only one family out of the eleven tested had a predictability coefficient high enough to be significant. The low predictability of the families was undoubtedly due, in part at least, to the small number of bulls in each of the families. Furthermore, the proved sons of the sires studied were for most part used in herds other than the one in which their sire was used and the results are influenced by different levels of feeding and management as well as production levels of cows to which they were mated.

No attempt was made to correlate type and production because only 77 of the 864 sires studied had been officially classified. The sires were grouped according to their classification ratings and the prediction indexes for butterfat correlated with the actual proof indexes. There was no significant correlation (Table 13) except in the case of the 25 "Good Plus" bulls which gave a correlation of + 0.428 which is significant at the 5% level. The lack of a pronounced correlation in this instance is probably due to the fact that all sires were mated to cows of about equal production. The dams of daughters of the classified sires ranged from 416 to 423 pounds of butterfat. This again demonstrates the fact that there was very little assortative mating practiced.

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