

CORRELATION OF BUTTERFAT PRODUCTION PREDICTED FROM SINGLE TESTS  
WITH BUTTERFAT YIELDS CALCULATED FROM MONTHLY TESTS

by

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## TABLE OF CONTENTS

INTRODUCTION . . . . .	1
REVIEW OF LITERATURE . . . . .	4
EXPERIMENTAL PROCEDURE . . . . .	20
Preliminary Study of Day to Day Variations . . . . .	21
Factors and Methods Involved in Developing a Prediction Equation Using Data from an Ayrshire Herd . . . . .	22
Development of Prediction Equations from Dairy Herd Improvement Association Records of 23 Holstein Herds . . . . .	28
Simple and Multiple Correlations among the Variables, 270-day Production, Production on Testing Day, Month in Lactation, and Season of Calving . . . . .	33
Records from all Senior Two-year-old Cows Separated on the Basis of First and Second Lactations . . . . .	33
All Records Separated on the Basis of First and Subsequent Lactations . . . . .	33
Deletion of Variable for Season of Calving from Multiple Regression Equation . . . . .	34
Correlation between 270- and 305-day Records . . . . .	34
RESULTS . . . . .	35
Preliminary Study of Day to Day Variations . . . . .	35
Factors and Methods Involved in Developing a Prediction Equation Using Data from an Ayrshire Herd . . . . .	36
Development of Prediction Equations from Dairy Herd Improvement Association Records of 23 Holstein Herds . . . . .	40
Simple and Multiple Correlations among the Variables, 270-day Production, Production on Testing Day, Month in Lactation, and Season of Calving . . . . .	40
Records from all Senior Two-year-old Cows Separated on the Basis of First and Second Lactations . . . . .	42

All Records Separated on the Basis of First and Subsequent Lactations . . . . . 43

Deletion of Variable for Season of Calving from Multiple Regression Equation . . . . . 43

Correlation between 270- and 305-day Records . . . . . 44

DISCUSSION . . . . . 46

    General Discussion . . . . . 46

    Practical Applications . . . . . 49

    Unsolved Problems . . . . . 52

    Limitations . . . . . 55

SUMMARY . . . . . 56

ACKNOWLEDGMENT . . . . . 58

REFERENCES . . . . . 59

APPENDIX . . . . . 73

## INTRODUCTION

Testing of dairy cows for milk and butterfat production has evolved into a program based on records of the milk and butterfat produced during one day of each month. Since the tester must visit each farm once during each calendar month to secure samples for calculating complete 305-day lactation records on each cow, it is a time-consuming and often costly method. It is especially costly per cow when the herd is small. It would be desirable if some form of testing could be developed which would reduce the number of visits to a farm for each lactation, yet closely approximate the accuracy of estimation which is now accomplished by monthly testing.

The need for obtaining more and more production records is growing constantly both for indicating production of individual cows and for compiling sire proofs of bulls. Widespread use of artificial insemination of dairy cattle has made it desirable that more attention be given to the selection of sires for artificial breeding units. Under farm conditions, where the number of daughters sired by a bull has been relatively small, one bull may have raised or lowered the level of production of the herd in which he was used. This possibility is multiplied under artificial breeding conditions because one bull may have hundreds or thousands of daughters. To increase the potential production of the daughters resulting from artificial insemination, sires capable of transmitting high levels of production must be used extensively.

The inheritance of the level of milk production is usually attributed to multiple factors in contrast to color patterns and some of the external characteristics of cattle which are simply inherited. Total milk and butterfat yield of any cow during any production period is the expression of the

combination of inheritance and environment. A cow which inherits a potentially high level of milk and butterfat production will never attain her maximum possibilities if she is insufficiently fed. Conversely, if a cow inherits a low level of production, excess feeding will not increase her productivity above these limits. Other environmental factors such as sickness or injury may limit the maximum production during any one lactation.

Present methods of selecting bulls in many artificial breeding units are based upon the use of "sire proofs". These proofs involve comparisons of records from five or more daughters of a sire with the records of their respective dams. Records are computed from milk weights and butterfat tests obtained by a Dairy Herd Improvement Association (D.H.I.A.) supervisor at the time of his monthly visits to the herd owner's farm. All completed production records for each cow are used to obtain an average for that particular cow. An average of the production for all daughters is compared with the average production of the dams.

In selecting bulls by sire proofs, the average production of one bull's daughters is compared with the average production of a second bull's daughters. Some artificial breeding units use an indirect comparison whereby many sires are ranked according to the average production of their respective daughters. Only those bulls whose daughters' average falls within the upper levels of production are considered for use by many artificial breeding units.

Two sires with different inherited rates for transmitting production may have appeared to have the same transmitting ability. This could be true if the daughters' records from the sire with the higher inherited transmitting ability were restricted by environmental factors while the daughters

from the sire with the lower transmitting ability were milked under environmental condition which allowed them to approach their maximum potential production. It remains a question of human judgment to determine whether a sire's apparent ability to transmit high milk and butterfat production is due mainly to extra-ordinary inheritance, to favorable environmental conditions, or to a combination of the two factors.

Frequently a sire proof is compiled from data accumulated in only one herd. The degree to which the management and environmental conditions in that herd are comparable to the management and environmental conditions of herds using artificial insemination is not known. The hereditary factors for milk and butterfat production in a particular herd may differ from the hereditary factors found in the majority of herds in which the cows are bred artificially. The most desirable method of selecting a bull for use in artificial breeding would be to mate him to a random sample of cows in herds where the cows are bred artificially and to compare the production from the resulting daughters with both the production of their dams and the production of daughters from other sires. Records could be readily obtained from cows in herds which are members of dairy herd improvement associations. However, most of the daughters from sires used in artificial breeding are in non-testing herds. Many of these non-testing herds are too small for economical Dairy Herd Improvement Association testing. It would be desirable for a system of modified testing to be developed so that estimates of production from cows in these normally non-testing herds could be included in the proof of any sire used for artificial breeding purposes. Sire proofs which are calculated from records of daughters milked under varied environmental conditions should give the most reliable estimates of the production of future daughters managed under similar circumstances.

## REVIEW OF LITERATURE

Official testing of dairy cows for production arose from the purebred dairy cattle breeders' desire for a method of recording the highest production of their best cows. Early records were usually seven-day tests. Later, official 365-day lactation records were made. Both types of records were supervised by impartial testers. Seven-day records were usually made at the peak of production, which Haecker (1903) found to be about the second or third week of the lactation. Eckles (1912) showed that butterfat tests taken within the first month post-parturition could be influenced by fatness of the cow at calving. Tests taken early in the lactation could not be depended upon to indicate the normal percentage of butterfat. Yapp (1919) compared estimated butterfat yield computed from seven-day tests with actual production. Seven-day tests generally showed abnormal fat percentages and often yielded estimates of yearly production which were considerably larger than actual production. Gowen (1922) studied official seven-day tests on Holsteins and reached a similar conclusion.

Gaines (1927) found that the fourth month of the record gave the most reliable data for estimating the lactation records of cows freshening annually and the production during the fifth month gave the best indication of 365-day records. However, some of the records were not started immediately after freshening; therefore, the fourth month of the record actually might be the fourth, fifth, or an even later month of the lactation. Cannon, et al (1942) found the fifth month of the lactation to be the most reliable time for estimating 305-day records when only one test or one month's production was used. The sixth month was the next most reliable. Months

near the end of the lactation were found to be the least reliable.

Body conformation may be the only criterion available for estimating the producing capacity of cows which do not have production records. Swett, et al (1928) found a general similarity in the skeletal structures of a highly specialized dairy cow and a highly specialized beef cow. Gowen (1921) showed that less than half of nineteen official judges who had classified twenty-five or more cows could select by the score card the cows with the best 365-day records. The correlation coefficient between amount of milk produced and type ranged from  $\neq 0.61$  to  $-0.10$  and averaged  $\neq 0.25$ . Tyler et al (1928) found the correlation of type with production to be statistically significant but not of practical significance. Lush (1947) stated that when records are missing, type may indicate production. Production records were more reliable than type for indicating producing ability, but a single record was not an accurate indication of lifetime productivity.

DeGraff (1917) explained the method he used to record the production of individual cows on his farm. Although his method was rather crude, it reflected the average dairyman's need of a workable plan for measuring production. Apparently organized testing of farm herds progressed slowly because eight years earlier Rabild (1909) had recorded the history of dairy herd improvement associations and had explained their operations, laws, and by-laws. McDowell (1928) also reported on the general organization, constitution, and by-laws of the dairy herd improvement associations. The present rules governing testing and reporting procedures for herds testing in dairy herd improvement associations are found in the Dairy Herd Improvement Association Supervisor's Manual by Kendrick and Bain (1949).

The need for a method of testing smaller herds which was cheaper than the standard Dairy Herd Improvement Association method yet relatively reliable resulted in the owner-sampler method of testing as reported by Cline (1923) and by Hughes (1946). Under this system the farmer did his own weighing and sampling. A supervisor took the samples to a central laboratory where they were tested for butterfat percentages and records were calculated. This method was used either alone or in combination with regular testing.

Several investigators discussed the merits of bimonthly testing. McDowell (1927, 1927), Winter (1930), and McKellip (1941) considered it to be only a supplement to regular testing. Gifford (1930) thought that bimonthly testing was as satisfactory as monthly testing when made with the same degree of accuracy and honesty.

Loveland (1941) sent a questionnaire to the dairy department of the state colleges which were in charge of dairy herd improvement testing in each of the forty-eight states. Reports from twenty-nine states revealed that seven states used the owner-sampler plan, five used bimonthly testing, seven reported no modifications, and the rest showed only slight modifications from the standard dairy herd improvement plan.

Variations in length of time between testing periods have been reported by several authors. McCandlish (1920) reported on test periods of 10-, 20-, and 30-day intervals; Taussig (1934) listed studies of weekly, biweekly, monthly, bimonthly, and 10-day and 30-day intervals. Taussig (1934) also referred to a paper by LSaiz in which tests were taken during the sixth week, the fifth month, and the eighth month of the lactation. Apparently LSaiz's method did not give satisfactory results since it was soon abandoned

in the few cases in which it was tried. Houston and Hale (1932) compared records computed from tests taken at intervals of one, two, three, four, six, and eight weeks. These computed records were compared with actual production calculated from daily milk weights and weekly butterfat tests. Maximum errors in estimation of total yearly butterfat for individual records by this method ranged from 3.13 per cent on weekly samples to 12.79 per cent on tests taken at eight-week intervals. However, total estimated yearly butterfat production for the entire herd produced an error of only 3.8 per cent difference from the actual yield when it was based on composite samples of one day's milk yields taken at eight-week intervals.

Alexander and Yapp (1949) studied the relative accuracy of monthly, bimonthly and quarterly testing. They multiplied the production during a single day by the number of days in a testing period to estimate an individual segment of a lactation record. Under this plan a test taken in the fourth month might be used to calculate the first 153 days of production; the last 152 days of a 305-day record would be estimated from a test taken during the eighth month. The records were considered 85.52 per cent as dependable as records compiled from monthly tests. Production from tests taken during the second and tenth months were 87.59 per cent as dependable as records computed from monthly tests. In general, their work showed a high degree of dependability for tests taken less frequently than monthly intervals. However, herds would have to be visited monthly to secure the right combination of testing months for each cow.

Cannon, et al (1942) correlated milk and butterfat production for each month with the 305-day record. Using data from the Iowa herds they developed a separate prediction equation for tests taken during each of the ten months.

The correlation between estimates of production computed from a single monthly test and college herd records ranged from 0.91 in the fifth and sixth months to 0.67 in the tenth month. The prediction equations developed from Dairy Herd Improvement Association records produced a correlation coefficient range between 0.72 in the sixth month and 0.40 in the first month. Standard errors of estimates were 45.6 pounds of butterfat in the fifth month and 74.7 pounds of butterfat in the tenth month for Dairy Herd Improvement Association records. Using these equations, estimates of 305-day production could be obtained for each lactating cow which had been fresh for ten months or less during each visit to a farm.

Length of lactation records varies with different countries. Taussig (1935) reviewed the literature and found that records usually last 273 days in Australia; 280 days in Italy; 300 days in Belgium, Switzerland, France, and South Africa; 305 days in Canada, the United States and New Zealand; and 315 days in the Irish Free State. In the United States the various breed associations allow selected records to continue for the 365-day calendar year. Other systems often allow for lengthening of the record to a calendar year at the option of the owner. Gaines (1946) suggested using only the first eight months of the lactation in order to avoid the effects of gestation upon lactation.

Variations in accuracy of records caused by differences of testing dates within a month have been studied. Sutton (1924) compared the accuracy of records computed from tests taken during the first, middle, and last parts of the calendar month. He favored taking tests near the end of the month because days of production and feeding rate were usually known and fewer corrections were needed in the following month's calculations. Morrison and

Erb (1948) compared the accuracy of the calendar month with the centering date as a basis for computing the monthly production but no statistics were available to this author. McKellip and Seath (1941) found that systematic irregularities of testing date aided rather than hindered accuracy. Tyler and Chapman (1944) suggested multiplying the sum of ten monthly tests by 30.5 to arrive at a 305-day production. They found a high correlation and no significant difference between the simplified and centered records. At present, the Dairy Herd Improvement Association Supervisor's Manual (1949) recognizes the centering date as the official method. Harris, et al (1934) considered the feasibility of calculating production on a calendar year basis, which usually included portions of two lactations. This production was compared to the complete lactation records started in the same calendar year. By analysis of variance, they found no significant difference between the two methods.

Gaines and Palfrey (1931) stated that the natural need for milk develops with birth of young and that this requirement increases with growth of the young as long as milk is the only food. As other food is taken, the milk requirement decreases and finally ceases. In animals kept for milk production, where adequate information is known, the amount of milk secreted day by day parallels roughly the rising and declining needs of the young. Turner, et al (1923) showed that the maximum milk production is reached on the fifteenth or sixteenth, eighteenth, and twenty-eighth day for cows milked two, three, and four times per day, respectively. Month to month decline in milk and butterfat production after the second month was shown to follow a definite trend.

Turner, et al (1923) found that monthly butterfat yields of non-pregnant Guernsey cows was 94 per cent of the butterfat production for the previous

month. Gaines and Davidson (1926) reported succeeding monthly milk yields to be 91 per cent of the preceeding month's production; Woodward (1945) calculated it to be 92.6 per cent. Studies by Carneiro and Lush (1948) of data from Brazil gave a somewhat similar trend for amount of morning's milk. The evening milk was not accounted for as the calves ran with their mothers during the day under the Brazilian system of management. Eckles (1919) charted each month's production as a per cent of the total production. Sanders (1923) used a "shape figure" which was obtained by dividing the average total yield by the average maximum yield per day for all cows calving in any particular month. Brody, et al (1923) used an exponential equation and Gaines (1927) used an equation based upon rate of yield, theoretical initial rate of yield, rate of change per month in rate of yield, time in months from calving and one constant to arrive at a formula for estimating a month's rate of production when the rate of production for the preceeding or succeeding month is known.

Turner (1926) considered persistency of production to be an average of one month's production divided by the previous month's production and that persistency of milk production and persistency of butterfat production were two separate things. Gilmore (1933) demonstrated that cows milked two times a day generally were more persistent than cows milked three and four times per day. Sikka (1949) studied lactation records of cows in the British Isles. He found that cows calving in August were the most persistent and cows calving in May were least persistent. He considered this a tendency for best and poorest producers to calve at different times of the year.

Many individual lactation records show considerable variation from normal, Turner (1924) listed possible causes of variations as: age, length of interval between milkings, breed, individuals, different quarters of

same udder, differences in night and morning milk, incomplete milking, condition at calving, feeds, underfeeding, pasture, amount of exercise, drugs, season of year, temperature, period of heat, and advanced stages of lactation.

Binney (1948) also considered health of cow and weather effects. Graham (1946) added excitement to the list. Hooper (1923) gave a similar summary. These variations affect milk yield, percent butterfat, and total butterfat in varying degrees.

One of the earliest attempts to determine age correction factors was by Gowen (1920), (1920). Clark (1924) found that the age correction factors recommended by Gowen, Ragsdale, and Pearl were very similar. Maximum mature production was reached around the eighth year. The requirements for the various breed association advanced registry programs considered that mature production was reached at five years and that this level of production was retained for several years. At the present time the United States Department of Agriculture, Bureau of Dairy Industry, Manual 925 by Kendrick lists tables of factors for the correction for age, times milked daily, and length of lactation. These factors are used by the Bureau of Dairy Industry in standardizing lactation records used in proving sires in dairy herd improvement associations. Lush and Shrode (1950) compared the factors devised from their study of Herd Improvement Registry records with Kendrick's factors. While there was a general agreement between the two sets of factors, Lush and Shrode believed Kendrick's factors were slightly low for cows calving at 45 to 66 months and somewhat high for older cows. They also believed that a distinction should be made between early second and late first-calving cows. Chapman and Dickerson (1936) found an irregular tendency for production to increase as age at first calving increased. In another study these same

workers, Dickerson and Chapman (1940), found that size at first calving also influenced butterfat production to some extent during the first two lactations. There was no apparent effect upon subsequent lactations. Hammond and Sanders (1923) used age and other correction factors to reduce variation of estimated records by twenty percent. These correction factors also increased by 27.3 per cent the number of records having less than 5 per cent error. Houston and Hale (1932) were convinced by a study of tests taken at one, two, three, four, six, and eight-week intervals that butterfat tests should be taken at least every four weeks to hold accuracy of computed records within 10 per cent of the actual butterfat production.

Under New Zealand conditions, Ward and Campbell (1938) were dissatisfied with all age correction factors which used a straight percentage basis; they favored a straight regression formula of the  $X = aY + b$  type, where  $X$  equals mature production and  $Y$  equals immature production. Gaines (1940), (1946) worked on substitution of weight for age as a correction term. In one of his later reports Gaines (1946) admitted that in order to effectively predict lactation yield the weight of the cow had to be recorded in the first month and preferably on the third or fourth day post partum. The Report of the Agricultural Experiment Stations (1950) cited work by an Illinois dairy specialist (presumably Gaines) which presented correction formulas for length of lactation, time calf was carried, and age of cows. The report stated that age and live weight affect yields about equally if all factors except food supply remain constant.

Percentage of butterfat in milk is apparently affected by many factors. Houston and Hale (1932) found a very high negative correlation between milk yields and butterfat test. They also found differences in day to day pro-

duction which they attributed to climatic variations. Davis, et al (1947) also found an inverse ratio between milk production and butterfat percentage. Ragsdale and Turner (1922) studied monthly tests of 3763 Guernsey, 299 Jersey, and 95 Holstein records. They found an inverse ratio between milk production and butterfat percentage. The records were averaged by breed and showed a downward trend in butterfat percentage from the first to the second month; this trend was extended into the third month on the Holstein records. After the drop, there was a gradual monthly increase in butterfat percentage which became more pronounced during the latter part of the lactation. Eckles (1912) found that the percentage of fat in the milk can be influenced greatly the first twenty or thirty days by the fatness of the animal at parturition and that tests taken early in the lactation period cannot be depended upon to indicate the normal percentage of fat produced by the individuals. Graham (1946) and Turner (1924) agreed that fatness of the cow at parturition affected the butterfat percentage for an indefinite period after parturition. Roberts (1918) found a general negative correlation between percent fat and milk yield among breeds with the percent fat remaining fairly constant for different ages. White (1918) stated that butterfat tests rose with the second and third lactations after which there was a small general decline in fat percentage until maturity. White and Judkins (1918) also found that other factors affected the test more than age after maturity was reached. Graham (1946) recorded a lower butterfat test for morning milk than for evening milk, whereas Turner (1924) stated that morning milk is the richest. Under climatic conditions at the Nigeria Government Farm at Samaru, Zaria, Hartley and Baker (1935) found that the butterfat content was highest at night during the dry season but higher in the morning during the rainy season. Normal temperature

range is 55° to 100° F and relative humidity ranges from 14 to 68.

The reasons for the variation in production from one milking to the next have been the basis for several studies. Turner (1924) found a difference in yield but no definite relation between yields from different quarters of the udder. Ward and Smith (1948) reported slightly less milk when the udder was milked over ten minutes after initial stimulation. Blosser and Smith (1947) found that extending the testing day to 26 hours gave more milk and a lower butterfat test; however, there was no significant difference in total butterfat between 24-hour and 26-hour days. Turner (1924) and Wylie (1923) reported that the leaving of strippings raised the test the following milking and Wylie (1923) further stated that the effect of leaving strippings lasts over several milkings and that a single preliminary milking does not prevent the effects of previous incomplete milkings.

Feed is often considered an important factor in milk production. Graham (1946) believed that feed had a marked influence upon the color of milk but that the fat test of milk could not be consistently increased by the use of specific feed. In a study of milk composition, Eckles (1939) found that feed consumed exerted an effect equal to that of any other factor influencing butterfat test. Turner reported (1924) no permanent change in milk due to a difference in feed; however, he stated that underfeeding lowers milk yield. In another study Turner (1924) found that feed consumption followed the lactation curve with only a slight lag. Woodward (1923) found that extra water, bone meal or limestone did not increase the butterfat percentage but that cottonseed and linseed oil meal did. He questioned whether the increase was due to the oil content or to the protein. Davis and Kemmerer (1948) found that under Arizona conditions the addition of grapefruit peel to an all

alfalfa ration increased production whereas the addition of an equal amount of grain had no effect. By adding oats pasture to the grain ration, they were able to maintain production.

Hazelwood (1948) studied four successive records of sixteen cows. Two records, usually the first two, were made under normal conditions; the other two were made without grain. The records made without grain were only about 76 per cent as large as those made with grain and the cows were not as persistent in production. Loosli et al (1948) found that differences in the hay fed were reflected by actual differences in production.

Drugs have been developed which will influence production. Thomas and Moore (1948) fed twelve cows thyroprotein from fifty days postpartum in their first lactation to ninety days previous to the expected calving date. These cows calved normally and during the first fifty days of their second lactations produced 32 per cent more than during the corresponding period of their first lactations. A control group showed an increase of only 17 per cent. Gullickson, et al (1948) failed to detect a difference in the production of a control group and cows who had tocopherols added to their rations. Whiting and Loosli (1948) reported a slight increase in butterfat test when tocopherol was included in the winter ration at the rate of one gram per cow per day over a four-week period. These same workers found, however, that feeding tocopherol failed to overcome an 11 per cent decrease in butterfat test caused by the addition of five ounces of cod liver oil to each cow's daily ration. Total milk yield was not affected. Adams and Allen (1948) found that the administering of oxytocin increased milk and total fat yield but did not change the butterfat test.

Variations in milk production due to season of year, climate, tempera-

ture and general weather conditions have been the basis of many studies. Campbell (1931) considered temperature to be one, if not the chief cause of fluctuations of milk yield and fat percentage. Wylie (1923), Oxley (1935), Becker and Arnold (1935), Ragsdale and Turner (1922), Overman (1945) and Turner (1924) found that the summer percentage of butterfat tended to be lower than the winter percentage. Woodward (1923) not only agreed with them but also found that the naturally high-testing breeds showed the most differences. Graham (1946) stated that under normal conditions of spring calving, the period of lowest test and highest milk yields coincide with the summer season. Edwards (1950) thought seasonal variations were indirect results of differences in feeding habits and metabolic processes.

The optimum season of the year for dairy cows to freshen is a question of much concern. Turner (1923) found that the cows which calved in the fall and winter months equalled or excelled the average production. Total yields of cows calving in the summer months was generally below average. The spring flush was a holding period, not a raising one for milk production. In another paper, he associated the rise in butterfat test, which is often noticed when cows are first turned onto pasture in the spring, with a type of underfeeding. Frick, et al (1947) found that, in their study done in Connecticut, cows which calved in February had the highest lactation records. This production was about 13.7 per cent above the yield of those calving in July, which were the lowest yielding group. No appreciable difference was found between Guernsey, Jersey, Ayrshire, or Holstein records. Wylie (1925) studied 2916 Registry of Merit records from Jersey cows. He found yearly fat production to be highest for cows calving in July, October, November, and December, and lowest for those calving in April, May, and August. Milk yields

were lowest for April, May, June, August, and September calves. Cannon (1933) studied 67,992 Dairy Herd Improvement Association records of Iowa cows for 1925-1930, inclusive. All dairy breeds were included but over fifty percent of the records were made by Holstein-Friesian or grade Holsteins. He averaged the butterfat yield for all cows calving in each calendar month and found that cows calving in May, June, and July produced the least butterfat. Cows calving in November produced the largest records. He calculated the average production for cows calving in each calendar month into terms of average yearly yield, thereby deriving factors which he expected to use in comparing records started in different calendar months.

The possibility that seasonal variation in production is caused by temperature changes has been studied by several authors. Houston and Hale (1932) found day to day variation in production which they associated with weather changes. Weaver and Mathews (1928) considered temperature changes to be a major factor in causing day to day variations in butterfat production. Hills (1892) found an inverse change in butterfat test with temperature change. Ragsdale and Brody (1922) stated that the butterfat percentage increased about 0.2 per cent for each  $10^{\circ}$  F decrease in temperature. Turner (1924) quoted the same figure. Hays' (1926) study of two cows found a 0.189 per cent increase in fat for each  $10^{\circ}$  F drop in temperature between  $30^{\circ}$  F and  $70^{\circ}$  F. He considered this decrease to be associated with metabolic rate. Ragsdale and Brody (1922), Turner (1924), and Hays (1926) reported on work done in Missouri. Davis, et al (1947) found only about 0.1 per cent increase in butterfat test with a  $10^{\circ}$  F drop in temperature between  $65^{\circ}$  F and  $105^{\circ}$  F under Arizona conditions. Oloufa and Jones (1948) found no appreciable difference between records started in different calendar months in the Willa-

nette Valley of Oregon. Arnold and Becker (1935) found only a relatively narrow seasonal range of butterfat tests under Florida conditions. In another study, Becker and Arnold (1935) showed this to amount to about 0.3 per cent increase in butterfat test for each 10° F drop in temperature for the narrow temperature range of 57° F to 81° F with Jerseys, a high-testing breed.

Normal reproduction and its effects upon lactation has been the object of other studies. Turner (1924) reported that heat period showed little or no definite effect upon day to day production. Matson (1929) stated that the optimum calving interval varied directly with milking capacity and inversely with age up to maturity. He suggested that many European farmers purchased and discarded cows as disappointing when the sole reason was a short calving interval between that lactation and the preceding lactation. Ragsdale, et al (1924) found that the Jersey calf at birth was equivalent in total nutrients to between 110 and 170 pounds of Jersey milk and the large Holstein calf was equivalent to between 200 and 274 pounds of Holstein milk. Apparently this did not account for the total decrease in production since the reduction was between 400 and 800 pounds of milk if the cow was bred during the early part of lactation. These reductions became apparent about the fifth month of gestation. Brody, et al (1923) reported about the same findings. Turner, et al (1923) showed the same thing in a different way by comparing the lactation records of non-pregnant Guernseys with those of cows carrying calves. Gowen (1924) agreed that advanced pregnancy decreased production. Gaines and Davidson (1926) developed a chart with correction factors for the length of time which a calf was carried during the lactation. Their correction values range from 1.0015 at 200 days to 1.0278 at 280 days.

Hammond and Sanders (1923) and Dickerson and Chapman (1939) studied the

effects of length of dry period and its effect upon the succeeding lactation. The latter found that length of dry period tended to increase with age and that the two are often confused. The tendency for an increase in production with longer dry periods was greater for lower producing herds than for herds with high production. Possibly the importance of a rest period became greater as the plane of nutrition became lower. One of the reasons for herds with low production was that they were fed less adequately than the high producing herds. Best results were obtained with four to five, eight to nine, and twelve to thirteen weeks rest periods for cows on high, medium, and low planes of nutrition, respectively.

From this review of literature, the major factors which affect total milk and butterfat production for any lactation appear to be length of lactation, age of cow at calving, season of calving, condition of cow at calving, nutritional intake, maximum daily production, rate of decline in production as the lactation advances, and number of times the cow is milked daily.

In comparing records from two or more cows, the length of the record can be selected arbitrarily. Correction factors for age at parturition, length of record, and for number of times a cow is milked daily have been established to adjust records to a 305-day, twice a day milking, mature equivalent basis. It has been established that maximum daily butterfat production is reached sometime during the first month and that daily butterfat production follows a general pattern of decline until the cow ceases to produce. However, it is not clearly established whether this pattern of day by day production is the same for all age groups. It appears impossible to measure factors such as condition of cow at calving and nutritional intake at this time; however,

these factors are reflected in daily milk and butterfat production over prolonged periods of time.

Cannon (1933) developed factors from Iowa data for converting to a comparable basis records which were started in different months of the year. Since these factors were developed in a neighboring state on a large number of records, it was believed that these factors should fit Kansas conditions.

Other factors such as temperature, sickness, drugs, length of interval between milkings, incomplete milking, amount of exercise, period of heat, and excitement may affect one or more milkings. While these factors probably have very little effect upon the total production, they can have a pronounced effect upon estimated production if they happen to coincide with a testing day. This influence is magnified as the number of tests per lactation is reduced. However, no satisfactory method of accounting for these variables is available at the present time.

#### EXPERIMENTAL PROCEDURE

The work of Cannon, et al (1942) showed that formulas developed from Iowa State College herd records were slightly different from the formulas developed from Dairy Herd Improvement Association records. Since it was desired to develop a method of predicting production for cows in non-testing farm and commercial herds, it seemed imperative to develop equations from data which were collected from herds under similar management and environmental conditions. Of all records available, Dairy Herd Improvement Association records seemed most likely to have been made under parallel circumstances.

To obtain prediction equations which were relatively accurate, it

appeared necessary to use data from a large number of records which were made under varied environmental conditions. It was believed, however, that data from a smaller number of records were sufficient to indicate the best methods of solving the problem. Consequently, the method used for the main study was developed by pilot studies which involved a relatively small amount of data.

### Preliminary Study of Day to Day Variations

One of the initial problems in developing a modified method of testing dairy cattle for milk production at infrequent intervals was to determine how accurately one month's milk production could be estimated from any one day's production during the testing month. Although estimates calculated from Dairy Herd Improvement Association testing were highly correlated with actual 305-day production, it was not known how accurately production for any one month could be predicted from a random day's production within that month. Unless monthly milk production could be estimated reliably from a random day's production, it seemed illogical to expect that a complete lactation record could be satisfactorily predicted from only one or two tests. Since no literature was found, it seemed advisable to study this aspect of the problem.

Milk weights recorded at each milking for individual cows from the Kansas State College dairy herd (Ayrshire, Guernsey, Holstein, and Jersey) were used for this phase of the study. Daily production was recorded as the total night's and morning's milk production to the nearest tenth of a pound. An effort was made to obtain as much variation as possible by using all four breeds, selecting daughters from different sires, and using cows of different

ages. The latest completed record from the oldest cow, from the youngest cow with a record, and from three other cows in each breed were used.

In order to simplify the procedure, only the production during the odd months of the lactation was used. The first month started on the fourth day, counting freshening as the first day and continued until the corresponding day in the next calendar month. The standard deviation of daily milk weights and the coefficient of variation within each of these months was calculated separately for each cow.

#### Factors and Methods Involved in Developing a Prediction Equation Using Data from an Ayrshire Herd

Dairy Herd Improvement Association records from a local herd of registered Ayrshires were studied in designing the experimental procedure for the main problem. This herd had been on continuous Dairy Herd Improvement Association testing from 1925 through 1942 except for two short periods. The herd size varied from year to year, ranging from six to around twenty-five females of milking age. The herd appeared to be under average farm conditions; however, some attention seemed to have been given to making high production records during the later years of the study.

All available Dairy Herd Improvement Association record books were collected and all records of 180 days' duration or over which started before 1942 were recorded. Records started during the war years were not used because it was believed that the artificial environmental conditions such as shortage of labor, make-shift systems of management, and certain temporary types of concentrate shortages might have undue effect upon actual production. The drouth and depression years were included since the environmental changes

were considered to be due more to natural than to artificial causes.

Milk weights and butterfat tests taken during the tester's visit each month of each lactation were recorded on forms designed for this study. Space was provided for recording daily butterfat production for the testing day in each month, 270-day, and 305-day production. The forms also provided space for identification of the cow by name, registration or ear-tag number, entry number, breed, freshening date, age at freshening (in months), lactation number, dry date or end of lactation, and length of lactation. There was sufficient marginal space to write down the next freshening date, date sold or otherwise disposed of, or any other information which was considered desirable.

Age was recorded to the nearest month, sixteen days or over adding another month to the age of the cow. The first test for each cow was considered as falling in the first month of production, although sometimes it actually occurred in the second calendar month of the lactation. Counting the freshening date as day number one, records were started on the fourth day. No tests were taken before the seventh day of the lactation. Production was calculated on the calendar basis instead of on the centering date plan which is now used in calculating Dairy Herd Improvement Association records. A cow freshening on September twelfth would receive credit for production on the fifteenth and all subsequent days in September at the rate of the September test if the testing day was the nineteenth of the month or later. If, however, the testing day occurred before the nineteenth, the cow would receive credit for sixteen days in September and thirty-one days in October, a total of forty-seven days of production, on the basis of the October test. Records lacking one or more monthly tests or those with

insufficient information were discarded.

One hundred eighty-nine usable records were sorted and tallied by age and month of calving. These totals were plotted on a 12 x 12 table. The twelve age groups were: yearlings, junior two's, senior two's, junior three's, senior three's, junior four's, senior four's, junior five's, senior five's, six's, seven's, and over seven (Appendix, Table 1).

Since the number of records in any one group was small and some spaces were blank, the data were then regrouped into five seasonal groups: January and September; March and April; May, June and July; February and August; and October, November, and December (Appendix, Table 2). These seasonal groups were composed of months of similar production according to Cannon (Appendix, Table 4). It was believed that his factors should fit Kansas conditions because they were developed in a neighboring Midwest state which should have similar climatic conditions. The records were further regrouped into seven age groups by combining the junior and senior ages for each year and putting seven-year-old and over together (Table 3, Appendix). January and February data were regrouped into one season and August and September data into another season because average monthly production appeared to follow a regular cycle and the variables contributing to a rising production may have been different from those variables which contributed to a falling production.

In order for any modified system of testing for production to be of value, several factors must be considered. In the opinion of the writer, the most important factors included (a) production level at time of test, (b) normal decline in daily production associated with progress of lactation, (c) age of cow at parturition, and (d) season of calving. The records had

been grouped so that all records within a group were made at the same age and same season of calving. Multiple regression equations could then be developed for any group or combination of groups. Pounds of butterfat produced on the testing day was designated as  $X_1$ . Since the normal monthly decline in production was assumed to follow a linear trend, month in the lactation was designated as  $X_2$ .

Butterfat production for the first 270 days of the lactation was used instead of the standard 305-day lactation because it was suspected that some farmers and commercial herd owners would have bred their cows to calve in less than twelve months. Shortening the length of the record removed some of the effects caused by the accelerated rate of decline of daily milk production during the latter months of the succeeding pregnancy. It also tended to remove the variation between records which may have been caused by variation in the number of days that different cows carried their calves. Butterfat production calculated from the Dairy Herd Improvement Association monthly tests for 270 days was designated  $Y_1$ . These symbols of  $X_1$ ,  $X_2$ , and  $Y_1$ , remained throughout the study.

The amount of variation caused by differences between ages at parturition and season of calving was unknown. These variations were temporarily accounted for by grouping the records from cows of approximately the same age and which had calved in the same season of the year. Records from sixteen two-year-old cows which calved in October, November, and December were selected for the initial study.

A multiple regression equation was developed from the records on this group of cows. For each record three months were selected using a table of random numbers. Thus, 48 different estimates, each based on one day's test

out of a month, three estimates per record, were obtained for the 16 cows. Where duplication occurred, the duplicate number was discarded and another month was selected. Any month in which the cow failed to have a test was indicated by a zero and was included as one of the random samples.

Since no test is taken on a dry cow and estimates of production cannot be obtained when a cow is not in production and it was not considered logical to include estimates of zero for any cow, a second multiple regression equation was developed with the months of zero production eliminated.

Whether variations existed due to differences of age at parturition or season of calving was the next point of consideration. It was believed that a comparison of the multiple correlation coefficient and the regression equation from two groups of sub-data was sufficient information to show these differences if they existed. Eleven records from cows seven years old and over which calved in August and September were studied. Multiple regression equations were calculated based on three estimates per record with months of zero production discarded.

Since differences due to season of calving and/or age at parturition had been indicated, it was desirable to hold one of these variables constant and obtain a measure of the importance of the other source of variation. Records from all two-year-old cows were used because this age group had the most uniform distribution of seasonal freshening. Butterfat production from two different months in each of 52 lactations was selected by use of a table of random numbers. When the first and the second selections were the same, the duplicate selection was discarded and a different month was selected. All months of zero production were discarded. Single digit numbers, based on Cannon's factors, were used in the equation to indicate season of calving.

This variable was designated  $X_3$ .

As the coefficient for  $X_3$  was found to be small, new prediction equations were developed with the variable for season of calving deleted.

How much would semi-annual testing of herds increase the accuracy of the predictions? Semi-annual tests spaced six months apart would include not only many cows missed on the first visit but would also provide a second test for some cows which were tested previously. Under conditions of continuous semi-annual testing, with tests spaced six months apart, each cow should be tested sometime within the first six months of her lactation. If she were tested in one of the first four months, she would have another test during a 305-day lactation. If she were tested in the fifth or sixth month, she would have only one test in the lactation.

The first testing months were obtained by using the numbers one to six from a table of random numbers. Second testing months for each record were obtained by adding six to the first randomly selected number. Of the 52 two-year-olds, 19 were tested in the fifth or sixth month of the lactation, 7 were dry at time of second test, and only 26 cows had two tests. Estimates of 270-day production were made using the prediction equation with  $X_3$  deleted. An arithmetic average of the two estimates was used when two tests had been made. When only one test was obtained for a lactation, the estimate was based on the single test. These estimates were correlated with the actual production of the 270-day records.

Since accuracy of production estimates was increased by semi-annual testing, possibly three tests a year could be justified. Using the random numbers one to four and taking tests at four-month intervals throughout the lactation, the groups of tested months were: 1st, 5th, and 9th; 2nd, 6th, and 10th; 3rd

and 7th; 4th and 8th. An arithmetic average of all 270-day estimates for each record was calculated and this average was correlated to the actual production.

From a statistical standpoint, each cow's record should have been used only once. Since the total production,  $Y_1$ , was the same for all samples from any single lactation, two or more estimates from the same lactation would not have been independent in the  $Y_1$  term. Therefore calculations were reduced to one test for each lactation. Records terminated by sale, end of testing, or other non-inherited causes before the end of 270 days were discarded.

#### Development of Prediction Equations from Dairy Herd Improvement Association Records of 23 Holstein Herds

Originally the main study was designed to use Dairy Herd Improvement Association records from all herds which had been on continuous Dairy Herd Improvement Association testing for ten years or longer and which had a minimum of ten cows throughout the testing period. Cows of all dairy breeds were to be used if at least ten percent of the total number of records came from that breed. Breeds having less than ten percent of the total population were to be discarded. A study of available annual reports from two testing associations disclosed only one herd which met the prescribed qualifications. Although some other associations may have had larger numbers of qualified herds, this did not appear to be the most efficient method of locating them. Moreover, the inclusion of all breeds appeared to be impractical since each breed might entail a separate analysis and the numbers in some breeds might be too limited for statistical significance. Records of the Kansas Artificial Breeding Service Unit showed that about half of the services were from Holstein sires, indicating that Holsteins were the predominant dairy breed in

Kansas. The study was therefore restricted to Holsteins.

Mr. J.W. Linn, state extension dairyman, provided a list of Holstein breeders who were testing their herds for production in 1951, and who also had been testing in 1941. He also furnished a list of herds for which the old records were probably available. Forty-two herd owners were sent a form letter asking for the use of their books previous to and including 1942 (Appendix, Form 1). A self-addressed postal card for the reply was enclosed. On this card information concerning the availability of the records was mimeographed in question form so that the desired information could be returned with minimum effort (Appendix, Form 2).

Twenty-four herd owners furnished books (Appendix, Figure 1). One herd owner replied too late to be included in the study. The remaining seventeen owners either failed to reply or did not have their books for the desired period. Herd books were collected personally by the author at the owner's premises. At the completion of the study the herd books were returned either through the county agent, by registered mail, or in some cases personally.

Records were transcribed from the original book to mimeographed forms which were only slightly modified from those used in the pilot studies (Appendix, Form 3). Space was added for identification of the sire. Identification of the dam, when known, was recorded on a herd summary sheet. Numbering of the entries changed from the single record basis which was used in the pilot studies to a cow numbering system. The first lactation recorded on each cow was designated by the letter A, the second by B, et cetera. The letter H was used as a prefix for the Holstein breed since some cows in these Holstein herds were classified as some other breed. Thus H0015B designated the second record from the fifteenth Holstein cow. Not all of the numbered

cows had useable records.

All completed records started before January 1, 1942, were retained. A complete record was construed to be the first 270 days of any lactation or the complete record of any cow which milked over 180 days whose record was terminated by natural causes. Lactation records were calculated for both 270- and 305-day production. All calculations were on a calendar basis. Three tables were developed to expedite the calculation of the number of days of production for each record (Appendix, Tables 5, 6, 7). The 270-day lactation record was used because it was desirable to partially eliminate the effects of gestation upon the last months of the lactation. Dairy Herd Improvement Association records often show an increased rate of daily decline in milk production during the last months of the record when there is less than a year's interval before the succeeding calf. Records of less than 180 days were discarded even though they may have been terminated by lack of persistency. Records of between 180 and 270 days in which the cow remained in the herd were considered complete. Records of 180 to 305 days terminated by sale of cow, end of herd testing, or other removal of the cow for reasons other than natural causes were discarded. Records lacking in vital information such as freshening date, age of cow, or one or more tests were also discarded.

The symbols  $X_1$ ,  $X_2$ , and  $Y_1$  were retained and represented butterfat production in pounds on the testing day, month of lactation, and total pounds of butterfat production for 270 days, respectively. Although  $X_3$  still designated season of calving, new values were assigned using the reciprocal of Cannon's factors (Appendix, Table 4). Cows calving in October, November, and December produced lactation records whose average exceeded the yearly average for all

records. These months had been assigned the lowest number. Conversely, records started in May, June and July had been assigned the largest numbers, but the average of all lactation records from cows calving in those months was below the yearly average for all records. This had produced a negative partial regression coefficient for  $X_3$  in the pilot study. Assigning new single digit numbers produced a positive  $X_3$  value in the prediction equation. A high correlation between assigned numbers and average monthly production was retained. The numbers assigned to the various months were: May, June, and July, 1; March and April, 2; August, 4; February, 5; January and September, 6; and October, November, and December, 9 (Appendix, Table 4).

The following procedure was used for selecting the data which would be used to present that lactation in the subsequent calculations. Separate sheets were used to record the data for each of twelve age groups within a herd. These age groups were: senior yearlings, junior two's, senior two's, junior three's, senior three's, junior four's, senior four's, junior five's, senior five's, junior six's, senior six's, and seven-year-olds and over (Table 1). Each sheet had a labeled column for recording identification of cow, butterfat production on the testing day, month in the lactation, code number for season of calving, and 270-day butterfat production. The numbers one to nine were obtained from a table of random numbers and recorded in the column marked  $X_2$  (month in the lactation). The tenth month of the lactation was not used because production during the tenth month occurred after the 270 days and had no influence upon the shortened record. The lactation records within a herd were taken in whatever order they happened to be after the calculations had been completed. The age group determined the sheet on which a record was copied, and the previously selected number determined the month in

the lactation. For any record, selection of the month of the lactation determined the testing day and thereby established the value which was used for daily production for that record. Season of calving and 270-day production was constant for any record. Clerical help was obtained for this phase of the study.

Table 1. Distribution of records by herds and age groups.

Herd	Senior Yearling's	Junior Two's	Senior Two's	Junior Three's	Senior Three's	Junior Four's	Senior Four's	Junior Five's	Senior Five's	Junior Six's	Senior Six's	Seven's and over	Total
1	6	14	9	13	9	12	11	4	3	6	1	24	112
2	2	4	5	4	2	2	3	1	1	5		9	38
3		13	8	8	8	2	8	2	2	4	2	18	75
4	15	33	28	27	23	23	11	17	4	9	6	29	225
5	6	9	12	10	6	11	4	7	3	6	6	10	90
6	3	20	9	16	13	9	10	9	4	6	4	20	123
7	1	13	9	5	8	3	6	5	4	6	2	20	82
8	4	2	5	3	3	5	1	1		1		2	27
9	7	13	8	12	11	9	12	3	2	6	5	23	109
10	1	9	10	6	5	4	3	4	2	3	1	11	59
11	5	9	10	12	12	10	8	9	8	4	3	22	112
12	10	43	21	24	12	14	9	8	10	1	7	27	186
13	2	12	24	20	24	14	18	14	8	10	4	23	173
14		8	4	4	3	3	2	1	1	2	2	4	34
15	1	3	1	3		2		2			3	1	16
16	4	4	1	1	1	1	1	2		2		2	19
17	20	17	18	18	13	14	5	7	4	6	2	11	135
18	4	3	3	4	1	5	1	3	1	4	4	4	37
19	11	46	20	31	21	18	17	11	12	9	13	43	252
20	11	63	43	32	29	29	23	18	10	9	12	32	311
21	2	4	3	5		2	2	4	3	4	4	23	56
22	12	21	11	17	5	10	5	3	4	3	2	1	94
23	1	1		1		3	1	3			1	3	14
Total	128	364	262	276	209	205	161	138	86	106	82	362	2379

Totals, sums of equares, and sums of products were calculated for the variables within six month age groups of each of the 23 herds. All data for each age group were then added. The use of a loose-leaf type booklet for each herd allowed the data to be recombined easily into age groups or other combinations if it later seemed desirable.

Simple and Multiple Correlations among the Variables, 270-day Production, Production on Testing Day, Month in Lactation, and Season of Calving. Simple correlations and multiple regression equations were calculated by age groups. No linear trends were detected by visual inspection. However, the partial regression coefficients for butterfat yield on the testing day showed noticeable increase in value between the senior two-year-old data and the junior three-year-old data. Although some of the multiple regression equations were calculated by the author, most of these and all subsequent equations were calculated by the Kansas State College statistical laboratory.

Records from all Senior Two-year-old Cows Separated on the Basis of First and Second Lactations. The senior two-year-old data were divided into two groups on the basis of first and second calving, since differences in  $X_2$  values might have been due to differences between the first and second lactations.

All Records Separated on the Basis of First and Subsequent Lactations. Since actual differences were found between first and second lactation records of senior two-year-old cows, all the data were separated into the first lactation and subsequent lactation groups. Data from senior two-year-old cows were divided according to first and second lactations. Nine junior two-year-old cows appeared to be starting their second lactations and 59 junior three-year-old cows appeared to be on their first lactations. These two sets of

records were not subdivided because it was known that some cows in older age groups had calved several times previous to the first herd test yet were credited as calving for the first time because previous lactations were not recorded. Also, when a non-testing herd first starts on Dairy Herd Improvement testing, the tester often must guess the age of individual cows because authentic records of age are not always available. Seventeen of the 59 three-year-old cows credited with their first lactation were in one commercial grade herd which bought some of their replacements and probably many of these cows had a previous unrecorded lactation. It was believed that the remaining second lactation junior-two-year-old and first lactation junior three-year-old records would have relatively small effect upon the prediction formulas after known corrections were made and questionable records were eliminated. The time involved in rechecking the herd books and recalculating the data did not seem to justify the slight gain in accuracy. All junior two-year-olds were considered to be starting their first lactation and all junior three-year-olds were assumed to be starting their second record. Multiple regression equations and partial regression equations were calculated on the two lactation groups.

Deletion of Variable for Season of Calving from Multiple Regression Equation. Since the partial regression coefficients for season of calving were so small, it was thought that the equations probably could be simplified without reducing the multiple regression coefficient appreciably by deleting the factor for season of calving. Using the simple regression coefficients found for the first and second lactation data, new equations were developed with the factors for season of calving deleted.

Correlation between 270- and 305-day Records. Since Dairy Herd Improve-

ment Association records are of 305 days' duration and data used in this study considered only the first 270 days of recorded production, simple correlations were calculated between the two sets of data. It was expected that the correlation should be high because yields for the first nine months of production, which is usually 274 or 275 days, represents approximately 92 percent of the 305-day production. Therefore, about 90 percent of the record was being correlated with the total record.

## RESULTS

### Preliminary Study of Day to Day Variations

An analysis of day to day variation among records of 20 cows in the college herd gave a simple arithmetic average of 9.4 per cent for the coefficient of variation for all data studied. This coefficient of variation included (a) variations due to the increase in production during the first few days of the lactation, (b) the expected normal decline found as the lactation advances, (c) two months of large coefficients of variation due to sickness, and (d) the day to day variation which is due to unmeasurable factors. It was realized that if the variations due to the first few days' production in the lactation, the expected normal decline associated with the advance in the lactation, and those caused by sick cows were eliminated, the coefficient of variation would be reduced. However, such variations were considered normal under field conditions of modified testing and no attempt was made to remove them. The writer concluded that monthly milk production could be estimated satisfactorily from any randomly selected day within that month since two-

thirds of the daily milk weights for any cow vary less than 10 percent from the average daily milk weights for any cow for that respective month.

Factors and Methods Involved in Developing a Prediction Equation  
Using Data from an Ayrshire Herd

A local herd of Ayrshires was used to establish the methods for the main study. Records from 71 cows sired by 23 different bulls were recorded. Only 3 bulls had more than four daughters. Of the original 312 records, only 189 were useable; the other 24 were discarded because of insufficient data.

Records from sixteen two-year-old cows which calved in October, November and December were selected for the initial study. According to Cannon's work (Appendix, Table 4), cows calving in these months should have had the largest average production records. Moreover, two-year-old cows furnished the largest age group and cows calving in the fall months furnished one of the largest seasonal groups. Furthermore, it was reasoned that the study of this subgroup of two-year-old cows calving in these months might be a step completed if it later seemed advisable to compare all records from cows which calved at a definite age or during a specific season of the year. Multiple regression equations were developed and the following values were found:

Multiple regression equation	$\hat{Y} = 82.9 + 118.1 X_1 + 12.9 X_2$
Sample size	$n = 48$
Multiple correlation coefficient	$R = 0.64$
Standard error of estimate	$= 37.8$ pounds

The elimination of the months of zero production reduced the number of estimates but raised the multiple correlation coefficient to  $\neq 0.70$ . Other data were:

$$\hat{Y} = 56.0 \neq 145.8 X_1 \neq 12.5 X_2$$

$$n = 43$$

Multiple regression equations were calculated on records from 11 seven-year-old cows which calved in August and September. Using three estimates per records with the months of zero production discarded the results were as follows:

$$\hat{Y} = 161.0 \neq 90.7 X_1 \neq 17.0 X_2$$

$$n = 31$$

$$R = \neq 0.68$$

Visual examination revealed the multiple correlation coefficient to be approximately the same for both groups. The prediction equation, however, was considerably different. The coefficient of  $X_1$  for the older cows was only about two-thirds as large while the coefficient of  $X_2$  was one and one-half times as large and the constant three times as large as for the two-year-old group. No statistical tests of significance were obtained because the small samples probably were not random samples of the general cattle population and such tests would have had limited meaning. However, the differences obtained in the equations indicated the desirability of giving further consideration to the effects of age and/or season of calving.

Cannon (Appendix, Table 4) had devised factors for correcting records which were started in different calendar months so that effects of season of freshening were eliminated and the records were placed on a comparable basis. For ease of calculation it was desirable to replace Cannon's factors with

single digit numbers. When October, November, and December were assigned 1; January and February were assigned 3; August and September were assigned 4; March and April assigned 6; and May, June, and July assigned 8 and these numbers were correlated with Cannon's factors a correlation coefficient approaching 1.0 was obtained.

Multiple regression equations were calculated on data from all 52 two-year-old cows. The multiple correlation coefficient became larger,  $X_1$  was larger, the constant was smaller, and  $X_2$  remained about the same value as for the two-year-olds calving in October, November, and December. The values obtained were:

$$\hat{Y} = 10.8 + 168.9 X_1 + 12.2 X_2 + 3.6 X_3$$

$$n = 98$$

$$R = + 0.76$$

The multiple correlation coefficient of  $+ 76$  indicates that this formula accounts for about 58 percent of the variation among all Dairy Herd Improvement Association records from two-year-old cows in this herd.

Recalculation of data for all two-year-olds with the variable for season of calving deleted gave a larger multiple correlation coefficient and slightly larger partial regression coefficients in the prediction equation:

$$\hat{Y} = 18.0 + 174.8 X_1 + 12.3 X_2$$

$$n = 98$$

$$R = + 0.77$$

Thus it was found that consideration of season of calving contributed nothing to the accuracy of the estimate in this case.

When estimates of production were based on a random test in one of the first six months and a second test six months later, if the test occurred

during the first ten months of the lactation, the correlation coefficient was  $\neq 0.83$ . This could not be compared directly to the multiple correlation coefficient obtained for the two-year-old cows on a single test basis. Testing in a randomly selected calendar month would have excluded part of the records used in the study of single tests because some cows would have been dry at the time of the tester's annual visit to the farm. One test could not be compared to two tests because cows tested in the fifth or sixth month had only one test. However, the correlation coefficient between the actual records and the records estimated from two visits per year apparently was enough larger than the multiple correlation coefficient obtained as a result of developing the equation on the basis of annual testing to warrant further study.

When estimates of production were based on an average of tests taken at four-month intervals, the correlation coefficient was  $\neq 0.83$ . This was almost identical to the correlation coefficient for semi-annual testing. Based on these limited data, three tests a year apparently produced no increase in accuracy over semi-annual testing.

Theoretically, fifty percent of the cows should have had three tests and the remaining cows should have had two tests. However, the distribution of tests was as follows: four cows had only one test, they were dry in the 7th or 8th month when the second test should have occurred; twenty-three more had one test in the 3rd or 4th month and another in the 7th or 8th month; nine cows were tested in the 1st or 2nd and again in the 5th or 6th month, they were dry at the time of the third test in the 9th or 10th month. Only 16 cows out of the 52 had three tests evenly spaced throughout their lactations.

When records terminated by sale, end of testing or other non-inherited

causes before the end of 270 days were discarded, only 45 two-year-old cows had complete records. The multiple correlation coefficient based on one test per record was  $\hat{r} = .86$ . This explained 0.74 of the variance among completed records. The prediction equation was:

$$\hat{Y} = 33.2 + 187.9 X_1 + 7.9 X_2 - 2.5 X_3$$

Since this method was considered accurate enough for use in the major problem, no other studies were completed on records from this herd.

Development of Prediction Equations from Dairy Herd Improvement  
Association Records of 23 Holstein Herds

Simple and Multiple Correlations among the variables, 270-day Production, Production on Testing Day, Month in Lactation, and Season of Calving. Data from 2379 records of 1042 herds were used in developing the prediction equations (Appendix, Table 6). Simple correlations among the  $X_1$ 's,  $X_2$ 's,  $X_3$ 's, and  $Y_1$ 's were calculated by age groups (Table 2). Differences between the correlations were found to exist, but no trends associated with age were detected.

Partial regression coefficients for the  $X_1$ ,  $X_2$ , and  $X_3$  were compiled by age groups (Table 3). For the younger age groups the values for  $X_2$  were: senior yearling,  $\hat{r} = 7.75$ ; junior two's  $\hat{r} = 9.43$ ; senior two's,  $\hat{r} = 11.83$ . The values of the partial regression coefficients for groups which were junior three's and over ranged between  $\hat{r} = 18.25$  for junior six's and  $\hat{r} = 25.67$  for senior five's; however, most of the values were between  $\hat{r} = 20.45$  and  $\hat{r} = 23.62$ . This was markedly different from the values found for the younger age groups. This seemed to indicate that something affected the variable for month in the lactation which was not directly accounted for by an increase in age of the

cow, because any influence due to age should follow a gradual trend instead of exhibiting such a pronounced increase.

The partial regression coefficient for the butterfat yield on the testing day showed a wide range of values. Except for the fact that it tended to reflect the findings of the partial regression coefficients for the  $X_2$  variable, no noticeable difference would have been observed by visual inspection. Neither the multiple regression coefficient nor the partial regression coefficient for season of calving showed any trends which were detectable by visual inspection.

Table 2. Simple correlation coefficients among production on the testing day ( $X_1$ ), month in the lactation ( $X_2$ ), season of calving ( $X_3$ ) and 270-day production ( $Y_1$ ) for data used in the main study.

Age group	$X_1$ and $X_2$	$X_1$ and $X_3$	$X_1$ and $Y_1$	$X_2$ and $X_3$	$X_2$ and $Y_1$	$X_3$ and $Y_1$
Senior yearlings	-0.3452	+0.1301	+0.7552	+0.0483	+0.0604	+0.2096
Junior two's	-0.6079	-0.0407	+0.6556	+0.0671	-0.1377	-0.1232
Senior two's	-0.5011	+0.0723	+0.6569	-0.0494	-0.0002	+0.0936
Junior three's	-0.6126	+0.0871	+0.5992	+0.0721	+0.0200	+0.0942
Senior three's	-0.6142	+0.1052	+0.5844	+0.0528	+0.0447	+0.1975
Junior four's	-0.6488	-0.0198	+0.4962	+0.0198	+0.0910	+0.0941
Senior four's	-0.6957	+0.0991	+0.5940	-0.1137	+0.0587	+0.0786
Junior five's	-0.6762	+0.2282	+0.6786	-0.1021	-0.1365	+0.3209
Senior five's	-0.4865	+0.0330	+0.7414	+0.0544	+0.0712	+0.0447
Junior six's	-0.5562	+0.0812	+0.6484	+0.1229	-0.0204	+0.2419
Senior six's	-0.5036	+0.1634	+0.5686	+0.1548	+0.2116	+0.0794
Seven's and over	-0.6737	+0.0847	+0.5766	+0.0140	-0.0767	+0.2003

Table 3. The statistical elements which compose the multiple regression equations for predicting 270-day butterfat production by six month age groups with the multiple correlation coefficients and error of estimate for each equation.

Age group	Number of Entries	Partial regression coefficients			Constant	Multiple Correlation Coefficient	Error of Estimate in Pounds Butterfat
		(1) by1.23	(2) by2.13	(3) by3.12			
Senior yearlings	128	164.20	7.75	1.33	58.34	0.80	32.0
Junior two's	364	150.36	9.43	-2.27	97.07	0.74	40.3
Senior two's	262	150.45	11.83	1.11	64.00	0.76	43.0
Junior three's	276	162.52	18.76	9.11	-17.91	0.80	46.9
Senior three's	209	164.24	20.45	3.42	10.22	0.79	50.4
Junior four's	205	165.31	23.62	5.00	-10.68	0.75	56.5
Senior four's	161	145.38	22.02	1.47	41.06	0.72	57.8
Junior five's	138	161.82	20.99	4.59	12.72	0.77	60.6
Senior five's	86	221.43	25.67	-0.76	-53.83	0.89	52.0
Junior six's	106	158.72	18.25	3.89	46.52	0.77	67.6
Senior six's	82	172.57	21.58	1.06	16.31	0.82	52.0
Seven's and over	362	171.96	21.64	3.74	0.75	0.77	57.5

(1) by1.23 should be read "the regression of estimated production on daily butterfat production independent of month tested in the lactation and season of calving".

(2) by2.13 should be read "the regression of estimated production on month tested in the lactation independent of daily butterfat production and season of calving".

(3) by3.12 should be read "the regression of estimated production on season of calving independent of daily butterfat production and month tested in the lactation".

Records from all Senior Two-year-old Cows Separated on the Basis of First and Second Lactations. A recalculation of senior two-year-old records separated on the basis of first and second lactations gave the following results:

$$\text{First-lactation data} \quad \hat{Y} = 156.76 X_1 + 9.66 X_2 + 0.66 X_3 + 69.4$$

$$R = 0.73$$

$$n = 173$$

$$\text{Standard error of estimate} = 42.9$$

Second-lactation data  $\hat{Y} = 159.61 X_1 + 18.11 X_2 + 0.31 X_3 + 28.7$   
 $R = 0.82$   
 $n = 89$   
 Standard error of estimate = 42.1

The regression of estimated production on month tested in the lactation independent of daily butterfat production and season of calving was twice as large for the second-lactation records as for the first-lactation data. These results verified the supposition that the differences in the variable for month of the lactation were due to the number of the lactation instead of directly to age differences.

All Records Separated on the Basis of First and Subsequent Lactations.

Calculation of all data on the basis of first and second lactations gave the following results:

First-lactation data  $\hat{Y} = 155.44 X_1 + 9.34 X_2 + 0.58 X_3 + 72.50$   
 $R = 0.75$   
 $n = 665$   
 Standard error of estimate = 40.0

Subsequent-lactation data  $\hat{Y} = 167.12 X_1 + 21.00 X_2 + 2.04 X_3 + 16.18$   
 $R = 0.78$   
 $n = 1714$   
 Standard error of estimate = 55.9

Deletion of Variable for Season of Calving from Multiple Regression Equation. The elimination of the factors for season of calving produced the following prediction equations:

First lactations  $\hat{Y} = 75.5 + 155.55 X_1 + 9.36 X_2$   
 $R = 0.75$

	$n = 665$
	Standard error of estimate = 40.1
Second and Subsequent lactations	$\hat{Y} = 25.3 + 168.62 X_1 + 21.12 X_2$
	$R = + 0.78$
	$n = 1714$
	Standard error of estimate = 55.4

Although the partial regression coefficients for butterfat production on the testing day and for month tested in the lactation were increased slightly in both equations, the accuracy of the prediction equations remained the same through the second decimal. The two formulas with the season of calving deleted were considered sufficiently accurate for practical purposes and were accepted as final formulas.

Correlation between 270- and 305-day Records. Since Dairy Herd Improvement records are based on 305-day production and records used in this study were based on the first 270 days of recorded production, it was decided to calculate a simple correlation between the two records. Using the data from the 2379 records of the main study on a herd basis and rounding off to the second digit, 270-day butterfat yields were highly correlated with 305-day butterfat production. Of the 23 herds, a correlation of  $+ 0.99$  was found in 19 herds, a correlation of  $+ 0.98$  was found in 3 herds, and a correlation of  $+ 0.97$  was found in the remaining herd. (Table 4)

Combining all data into a single correlation, the correlation coefficient was  $+ 0.99$ . The equation for converting 270-day production to 305 days was:

$$\hat{Y} = 1.07 Y_1 - 3.9$$

The equation for reducing 305-day production to a 270-day basis was:

$$\hat{Y}_1 = 9.7 + 0.92 Y$$

Table 4. Coefficients of correlation between 270-day and 305-day production records by herds.

Herd number	Usuable records	Correlation	Herd number	Usuable records	Correlation
1	112	$\neq 0.99$	13	173	$\neq 0.99$
2	38	$\neq 0.99$	14	34	$\neq 0.99$
3	75	$\neq 0.99$	15	16	$\neq 0.97$
4	225	$\neq 0.99$	16	19	$\neq 0.99$
5	90	$\neq 0.99$	17	135	$\neq 0.99$
6	123	$\neq 0.99$	18	37	$\neq 0.99$
7	82	$\neq 0.99$	19	252	$\neq 0.99$
8	27	$\neq 0.99$	20	311	$\neq 0.99$
9	109	$\neq 0.98$	21	56	$\neq 0.98$
10	59	$\neq 0.98$	22	94	$\neq 0.99$
11	112	$\neq 0.99$	23	14	$\neq 0.99$
12	186	$\neq 0.99$			
Total				2379	$\neq 0.99(1)$

(1) The coefficient of correlation of all data considered as one population.

## DISCUSSION

### General Discussion

Sire proofs based upon a comparison of the milk and butterfat production records from a minimum of five daughters of a sire with the production records from their five dams are used in comparing the transmitting ability of dairy sires. All of the records in any one proof may be made in the same herd.

Logically, it appears that the sires with the best sire proofs should have the highest milk and butterfat transmitting ability; however, milk and butterfat production is the combined effect of inheritance, environment, and management. It is possible for a sire of average transmitting ability to be considered outstanding if his daughters' records are made under better than average environmental conditions or under superior management. Conversely, an outstanding sire might be judged to be only average because his daughters were limited by poor management or environmental circumstances. The relative value of the effect of heredity and the effects of environment are a matter of human judgment. The degree to which a bull will repeat his performance in one herd when bred to many cows in many herds is even more dependent upon the ability of human judgment to compare the circumstances of the original proof with the general environmental and genetic composition of the herds using artificial breeding.

Sires available for artificial breeding often have daughters with records in only one or two herds. In order to be unbiased, a sire proof must include production records from all daughters or be based on a representative sample from the entire population of daughters. In herds which are on dairy herd

improvement test or breed association herd test, records are available for computing a sire's proof. However, many herds which use artificial insemination do not test for production. Thus, records on daughters in these herds are not available. It is desirable that some form of testing be employed to represent this segment of the dairy cattle population. Since testing on a monthly basis is an involved and costly procedure, a simpler method would be valuable. Bi-monthly testing is the only modified testing plan generally accepted at the present time.

A summary of previous literature indicated that daily milk and butterfat production during the lactation of a cow follows a general trend. The volume of daily milk and butterfat production increases from parturition until maximum daily production is reached sometime during the first month of the lactation, the exact time depending somewhat upon feeding and management. Normally a gradual decline in production starts after maximum daily production is reached and continues until the cow dries up, first-calf heifers and younger aged cows showing less decline than older age cows. Late stages of pregnancy accelerate the daily decrease in production.

Previous work has also indicated that the season of calving influenced total milk and butterfat production. Cannon's study (1933) of Iowa Dairy Herd Improvement association records indicated that cows which calved in October, November, and December tended to produce the largest 305-day records and that cows which calved in May, June, and July tended to produce less than the yearly average for all cows. (Appendix, Table 4).

Previous work on predicting lactation yields from a single test had been done on Dairy Herd Improvement Association data from Iowa which might differ from data in Kansas. Differences in production that might be due to differences

in seasons of calving were not considered in these formulas. Also no attention had been paid in previous work to the possibilities of age differences in developing prediction equations. For these reasons, it seemed desirable to develop one formula, if possible, which would estimate with an acceptable degree of accuracy the production for a lactation using the results from one day's test, the month in the lactation, and other measures if they were of sufficient value.

Milk and butterfat records calculated from one day's milk and butterfat yield in each month are highly correlated to actual yields calculated from daily milk weights and butterfat tests on composite milk samples. This might be attributed to one of two reasons. Either all the monthly tests were very near the average production for that month, or high estimates in some months offset low estimates in other months. A study of the daily milk weights taken during the first, third, fifth, seventh, and ninth months of the lactation from a stratified sample of production records in the Kansas State College herd showed the coefficient of variation to average about 10 per cent for all the days in any one month. The college herd may not fully represent all the chances for variation which are found in commercial herds throughout the state; however, the data included the first month's production with an initial increase and subsequent decline in daily production and two cases of abrupt drops in production due to sickness. The low coefficient of variation gave confidence that milk production on any randomly selected day could be used to indicate the average daily production in that period of the lactation with a reasonable degree of reliability.

Considering previously cited factors, it was decided to establish linear regression equations. The general form for the equation was:

$$\hat{Y}_1 = a + b X_1 + c X_2 + d X_3$$

The symbols were:  $\hat{Y}_1$ , 270-day production in total pounds of butterfat;  $X_1$ , butterfat production of the testing day in pounds butterfat;  $X_2$ , month in the lactation; and  $X_3$ , a single-digit coded number which represented the season of calving; b, c, and d were the calculated coefficients for the respective X's; a was the constant.

Reducing the length of the record to 270 days, which is approximately nine months, eliminated the possibility of the cow's freshening within the testing period under normal conditions. It also reduced the influence upon production caused by an early conception and thereby reduced the cow to cow variation caused by differences in calving intervals.

### Practical Applications

The formulas derived in this study were developed primarily as a tool for evaluating the transmitting ability of dairy sires, especially those bulls being used or being considered for use in artificial breeding. Many of the sires considered for use by pedigree methods based upon ancestry are relatively unknown or have been used largely on non-testing herds. Production records of their daughters are scarce or absent. Estimates of production based on random samples from more records and from a larger number of daughters may materially change the information about any one bull.

Even where production records exist in one or two herds, there is no guarantee that the environment and management factors in these herds are similar to the conditions under which the daughters resulting from artificial breeding will be expected to produce. It is conceivable that bulls which are being

stressed by some breeding units may actually be less satisfactory transmitters of milk and butterfat production than are other bulls in the same unit which are not promoted as vigorously.

Statistical analysis of milk and butterfat production calculated from numerous random samples should help explain whether or not apparent differences in transmitting ability of different sires are actually genetic differences or whether they are largely reflection of environmental conditions. Comparison of differences in milk and butterfat production between daughters of different bulls in several herds may show either that these variations are mostly genetic or that environment is the major factor. Experiments with identical twins at the Ruakura Animal Research Station, New Zealand (Edey, 1953) seem to indicate that cows with the best genetic inheritance for milk production will, on the average, out-produce cows of lesser ability when both cows are maintained on the same nutritional level. Very little information on the production of daughters resulting from bulls used in artificial breeding is available except the information gleaned from dairy herd improvement records. In addition, the feeding and management practices of herds testing in dairy herd improvement associations may not represent a true cross section of the dairy cattle population using artificial breeding.

High correlations were obtained between 270-day butterfat yields estimated from one test and 270-day butterfat production calculated from monthly tests. These correlations explain 56 per cent of the variance between first-lactation records and 60 per cent of the variance between subsequent lactation records. Since relatively reliable estimates of production can be obtained from one test in each lactation, production levels can be established for cows which are not on Dairy Herd Improvement Association or breed herd tests. Estimates of

production from many daughters which are not currently tested could be used in compiling sire proofs. Apparent differences in transmitting ability of two sires would be largely genetic differences if sire proofs were based upon paired samples from many herds and under varied environmental conditions. If differences in milk and butterfat production are found to be actual genetic differences, it would be possible to stress the use of superior sires and restrict the services or entirely eliminate the sires which are below average in transmitting ability.

Once the procedures were established for comparing sires, part of the risk encountered in introducing new sires could be eliminated and bulls could be tested at a younger age. This would be possible because young bulls which potentially appear to possess superior transmitting ability could be used sparingly at an early age. Normal dilution of semen allows for many cows to be served from one ejaculation; therefore, a large number of daughters could be produced and tested for butterfat production under a wider range of environmental conditions than is now practiced. The bull could be proved at a relatively young age. The testing of several promising bulls need not involve the breeding of any more cows than is now practiced under the policy of securing a bull on the basis of a few daughters and using this bull extensively before it is known how his daughters from the general population of dairy cattle will measure up to expectations. Young bulls could be withheld from general service during the time interval between initial services for checking transmitting ability and calculation of production from the resulting daughters. After being proved, the desirable bulls could be used extensively.

Due to age factors, older bulls probably could not be handled in the same way but would probably have to be used as at present with the hope that produc-

tion based on a few daughters in a relatively small number of herds is a good indication of what all daughters would produce. It would be possible to restrict or eliminate the services from these older bulls if they were found to be below average in transmitting ability, but the time lag between the breeding of a cow and the testing of her resulting daughters would, in many cases, mean that older sires would be discarded before their daughters were tested. However, the results from testing many artificially produced daughters could be compared with the original proofs and could thus be used to improve the method of selecting proved sires.

#### Unsolved Problems

The application of a new method often presents many new problems. The formulas for this study were calculated from data which were restricted to Kansas Holsteins on Dairy Herd Improvement Association testing between the years of 1917 and 1942; it may be biased because certain herds contributed more records than other herds. Any calculation of data from a different breed, a different geographical area, different years, or a different cross section of the dairy cattle population may produce prediction equations which differ from those in this study. New knowledge of feeds and feeding practices, vitamins, antibiotics, or better management practices might alter the results.

Verification of the formulas or modification based on other data still leaves several problems to be solved. The formulas were calculated on the basis of one-day production per record which was taken any time during the first nine months of the lactation. Considering the fact that daily production normally declines as the lactation progresses and that the average

daily production for each month occurs near the middle of that testing month, is it practical to add or subtract 0.1 of a month to the formula for each three days that the testing day occurs from the middle day in a month? Each month in the lactation adds 9.4 pounds to the estimate of production for first-calf heifers and 21.2 pounds to the estimation of production for cows in their second or succeeding lactations. Although a 9.4 or 21.2 pound increase in the estimation of production appears relatively small, decline in daily production is a continuous process; a cow should not be credited with 9.4 to 21.2 extra pounds of butterfat production merely because the tester arrived one day later. Further study is needed to indicate whether an increase in accuracy of estimating production would sufficiently justify the additional calculation required to reduce month in lactation to smaller units.

Estimates of production calculated from tests taken during the first month of the lactation are somewhat erratic. This raises the question of whether lactation yields estimated from tests taken during the first month of production should be used in compiling sire proofs. If estimates calculated from tests taken in the first month are used, possibly correction factors are needed.

Season of calving presents another unsolved problem. On the average, cows calving in the fall months outproduce cows calving in the other nine months of the calendar year; conversely, cows calving in the late spring and early summer months tend to produce the smallest yields. A linear regression does not fit this variation satisfactorily. The additive values of butterfat for cows calving in the supposedly optimum months was less than expected. First-lactation cows which calved in October, November, and December were credited with less than five pounds more butterfat than first-lactation cows

which calved in May, June, and July. The value was sixteen pounds for records of subsequent lactations. Two conflicting theories can be advanced concerning this situation. One theory assumes that the expected gain in production is distributed uniformly throughout the lactation and that expected increase in yield is partially absorbed by the factors for production on the testing day. The other theory considers the expected increase to be non-uniform through the lactation but that the inclusion of many random tests from lactations started in all calendar months tends to nullify the variance caused by irregular monthly decline in production of individual records. It may be necessary to use curvilinear equations or devise some other method to include this variable. From this study, however, there is no advantage gained by consideration of season of calving.

The practical application of the equation developed in this study brings up the question of how often to visit any one farm. Assuming annual non-seasonal freshening, a single visit to many farms should secure a test during one of the first nine months of the lactation for three-fourths of the cows. Two tests, spaced six months apart, should give either a single test near the middle of the lactation, which is the most reliable time to test, or two tests per cow. In the case of two tests per cow, one test should be obtained in an early month of the lactation and the other test should occur on one of the later months of the lactation. Semi-annual visits to each farm should also result in testing practically 100 per cent of the cows in each calendar year. However, variations of intervals between freshening would result in the occasional missing of a cow. From a practical viewpoint, semi-annual testing should prove very satisfactory. It would also give an opportunity to recheck the feeding and management conditions at opposite seasons of the year. A good

pasture program may not be balanced by a good winter feeding program or a herd on good winter rations may not have adequate summer pasture.

Data from the pilot study, while not conclusive, tends to indicate that testing three times a year does not increase the accuracy of the estimates of single records enough to justify the added expense of a third visit to any farm. Probably quarterly testing would give only slightly more accurate estimates than three tests a year; however a different combination of testing months might alter these facts. It seems illogical to consider taking five tests a year, as that is practically equivalent to semi-monthly testing. All of these assumptions are based upon the fact that an estimate of production will be calculated from each test and that an average of predictions will be used to furnish an estimate of the lactation record.

How many lactation records from different daughters based on single tests will be required to become as accurate a prediction of a sire's transmitting ability as the complete lactation records from five daughter-dam pairs? Sire proofs calculated from a second set of five or more daughter-dam pairs do not always duplicate the first proof. It should be merely a statistical process to determine how many estimates of production calculated from single tests are required to be as accurate as the standard method now in use.

#### Limitations

As previously stated, this study is a search for a tool to use in estimating the transmitting ability of sires and very little confidence is warranted when predicting single records. The errors of estimate are too large

for precise work and individual females tend to vary both in day to day production and in the closeness with which they follow the normal lactation curve. Unless any single test comes as a complete surprise, the shrewd operator may be able to manipulate records by feeding and managing his cows so that they have a high production on the testing day. This is most likely to appear when an individual or an organization wants to merchandize a particular bull. In herds which use artificial insemination, any bias for daughters from one bull in any particular herd probably is neutralized by a bias for another bull in some other herd unless a particular bull has been stressed to such an extent that his daughters have had preferential feeding and/or management. Preferential treatment is often given to daughters of selected cows and it seems probable that such treatment might also be given to daughters of selected bulls.

#### SUMMARY

Linear regression equations were developed from 2379 lactation records of 1042 Holstein cows in 23 herds which were on Dairy Herd Improvement Association testing between 1917 and 1942. Most of the records were made in the latter part of the period.

The equations which were developed to estimate 270-day production were:  
for first-lactation heifers,

$$\hat{Y}_1 = 75.5 + 155.55 X_1 + 9.36 X_2$$

for all cows in subsequent lactations,

$$\hat{Y}_1 = 25.3 + 168.62 X_1 + 21.17 X_2$$

Butterfat production in pounds on the testing day was designated by  $X_1$ ;  $X_2$  indicated the month of the lactation;  $\hat{Y}_1$  was predicted 270-day butterfat yield.

The correlation between production calculated from monthly tests and production predicted from a single random test was  $\neq 0.75$  for first-lactation cows and  $\neq 0.78$  for the older group. Differences in persistency, as reflected by the coefficient for  $X_2$  in the above equations, between cows of different ages was found to be due more to lactation number than to age.

Although cows calving in the fall months tended to outproduce cows calving in the other months of the year, the inclusion of this variable within the equation did not significantly increase the accuracy of the prediction equation.

The lactation record was reduced from 305 to 270 days partially to eliminate the effect of the succeeding gestation upon production when calvings were closely spaced. The correlation between all 270- and 305-day records was large (0.99).

The formula  $\hat{Y} = 1.07 Y_1 - 3.9$  may be used to convert 270-day records to 305-day records. Predicted 305-day production recorded in pounds butterfat is  $\hat{Y}$ ;  $Y_1$  is the 270-day butterfat production; 3.9 is read as 3.9 pounds butterfat.

It is expected that relatively accurate prediction of milk and butterfat production for cows in non-testing herds will be useful in compiling unbiased sire proofs. Estimates from many daughters of each of several sires in many herds which are kept under varied environmental and management conditions should be helpful in evaluating bulls used in artificial breeding units and also should aid in the study of environmental effects upon production. It is not intended that this method should supplant standard Dairy Herd Improvement Association testing in calculating production of individual cows. These prediction equations are considered sufficiently accurate for calculating the butterfat transmitting ability of dairy sires when the herd owner has nothing to gain by favoring any cow or cows, and when random samples are obtained from many cows and under varied environmental conditions.

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**APPEND IX**

Table 1. Distribution of records used in pilot study by six month age groups and month of calving.

Age group	Calving month												Total
	:Jan:	Feb	:Mar:	Apr	:May:	June:	July:	Aug	:Sept:	Oct	:Nov:	Dec	
Yearlings		1		1		2		1					5
Junior two's	6	1	1	3				4	5	3	3	2	28
Senior two's		1	1	1	2	1	2	4	4	5	3		24
Junior three's	3	3	2	2					4	5		2	21
Senior three's		4		1	1	1		3	5	1	2		18
Junior four's	1	5	1					2		1		2	12
Senior four's		1	1	2	1	1		4	1	4	1		16
Junior five's	3	2	1					3			1		10
Senior five's	1	2		1	1		1	2	1	1			10
Six's	2	1	2		1		2	3	4	2	1		18
Seven's	1	1	2	1	1			4	4			1	15
Over seven's	1		3	1			1	2	1		1	2	12
Totals	18	22	14	13	7	5	6	32	29	22	12	9	189

Table 2. Distribution of records used in pilot study by six month age groups and season of calving.

Age group	Season of Calving					Total
	:May, June, July	:Mar, Apr	:Feb, Aug	:Jan, Sept	:Oct, Nov, Dec	
Yearling's	2		1	2		5
Junior two's			4	5	11	28
Senior two's	5		2	5	4	24
Junior three's			4	3	7	21
Senior three's	2		1	7	5	18
Junior four's			1	7	1	12
Senior four's	2		3	5	1	16
Junior five's			1	5	3	10
Senior five's	2		1	4	2	10
Six's	3		2	4	6	18
Seven's	1		3	5	5	15
Over seven's	1		4	2	3	12
Totals	18		27	54	48	189

Table 3. Distribution of records used in the pilot study by yearly age groups and season of calving.

Age group	Season of Calving					Total
	May, June, July	Mar, Apr	Aug, Sept	Jan, Feb	Oct, Nov, Dec	
Yearling's	2	1	1	1		5
Two's	5	6	17	8	16	52
Three's	2	5	12	10	10	39
Four's	2	4	7	7	8	28
Five's	2	2	6	8	2	20
Six's	3	2	7	3	3	18
Seven's and over	2	7	11	3	4	27
Totals	18	27	61	40	45	189

Table 4. Factors for month of calving.

Month of Calving	Number of Records (1)	Average yearly butterfat yield per cow (1)	Correction factor for fat yield (1)	Assigned number for pilot study	Reciprocal of Cannon's factors (2)	Assigned number for main study
January	7049	292	0.99	3	1.01	6
February	6181	285	1.01	3	0.99	5
March	6192	276	1.05	6	0.96	2
April	4563	273	1.06	6	0.94	2
May	3621	268	1.08	8	0.93	1
June	2753	268	1.08	8	0.93	1
July	2784	268	1.08	8	0.93	1
August	3400	284	1.02	4	0.98	4
September	7493	292	0.99	4	1.01	6
October	8094	304	0.95	1	1.05	9
November	8202	307	0.94	1	1.06	9
December	7660	303	0.95	1	1.05	9
Totals and Averages	67992	289(3)				

(1) Data from C. Y. Cannon. Seasonal effect on yield of dairy cows. Jour. Dairy Sci. 16:11-15. 1935.

(2) These factors were derived by dividing the average production of cows calving in each month by the means production of all cows.

(3) The weighted mean.

Table 5. Testing day-days left in calendar year. (1)

	: Jan :	Feb :	Mar :	Apr :	May :	June:	July:	Aug :	Sept:	Oct :	Nov :	Dec
1	364	333	305	274	244	213	183	152	121	91	60	30
2	363	332	304	273	243	212	182	151	120	90	59	29
3	362	331	303	272	242	211	181	150	119	89	58	28
4	361	330	302	271	241	210	180	149	118	88	57	27
5	360	329	301	270	240	209	179	148	117	87	56	26
6	359	328	300	269	239	208	178	147	116	86	55	25
7	358	327	299	268	238	207	177	146	115	85	54	24
8	357	326	298	267	237	206	176	145	114	84	53	23
9	356	325	297	266	236	205	175	144	113	83	52	22
10	355	324	296	265	235	204	174	143	112	82	51	21
11	354	323	295	264	234	203	173	142	111	81	50	20
12	353	322	294	263	233	202	172	141	110	80	49	19
13	352	321	293	262	232	201	171	140	109	79	48	18
14	351	320	292	261	231	200	170	139	108	78	47	17
15	350	319	291	260	230	199	169	138	107	77	46	16
16	349	318	290	259	229	198	168	137	106	76	45	15
17	348	317	289	258	228	197	167	136	105	75	44	14
18	347	316	288	257	227	196	166	135	104	74	43	13
19	346	315	287	256	226	195	165	134	103	73	42	12
20	345	314	286	255	225	194	164	133	102	72	41	11
21	344	313	285	254	224	193	163	132	101	71	40	10
22	343	312	284	253	223	192	162	131	100	70	39	9
23	342	311	283	252	222	191	161	130	99	69	38	8
24	341	310	282	251	221	190	160	129	98	68	37	7
25	340	309	281	250	220	189	159	128	97	67	36	6
26	339	308	280	249	219	188	158	127	96	66	35	5
27	338	307	279	248	218	187	157	126	95	65	34	4
28	337	306	278	247	217	186	156	125	94	64	33	3
29	336		277	246	216	185	155	124	93	63	32	2
30	335		276	245	215	184	154	123	92	62	31	1
31	334		275		214		153	122		61		0

(1) In leap years, add one day to above figures before March 1.

Table 6. Day of month-day of year. (1)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	68	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29		88	119	149	180	210	241	272	302	333	363
30	30		89	120	150	181	211	242	273	303	334	364
31	31		90		151		212	243		304		365

(1) In leap years, add one day to above figures after Feb. 28.

Table 7. Freshening date-testing days left in calendar year.(1)

	: Jan	: Feb	: Mar	: Apr	: May	: June	: July	: Aug	: Sept	: Oct	: Nov	: Dec
1	362	331	303	272	242	211	181	150	119	89	58	28
2	361	330	302	271	241	210	180	149	118	88	57	27
3	360	329	301	270	240	209	179	148	117	87	56	26
4	359	328	300	269	239	208	178	147	116	86	55	25
5	358	327	299	268	238	207	177	146	115	85	54	24
6	357	326	298	267	237	206	176	145	114	84	53	23
7	356	325	297	266	236	205	175	144	113	83	52	22
8	355	324	296	265	235	204	174	143	112	82	51	21
9	354	323	295	264	234	203	173	142	111	81	50	20
10	353	322	294	263	233	202	172	141	110	80	49	19
11	352	321	293	262	232	201	171	140	109	79	48	18
12	351	320	292	261	231	200	170	139	108	78	47	17
13	350	319	291	260	230	199	169	138	107	77	46	16
14	349	318	290	259	229	198	168	137	106	76	45	15
15	348	317	289	258	228	197	167	136	105	75	44	14
16	347	316	288	257	227	196	166	135	104	74	43	13
17	346	315	287	256	226	195	165	134	103	73	42	12
18	345	314	286	255	225	194	164	133	102	72	41	11
19	344	313	285	254	224	193	163	132	101	71	40	10
20	343	312	284	253	223	192	162	131	100	70	39	9
21	342	311	283	252	222	191	161	130	99	69	38	8
22	341	310	282	251	221	190	160	129	98	68	37	7
23	340	309	281	250	220	189	159	128	97	67	36	6
24	339	308	280	249	219	188	158	127	96	66	35	5
25	338	307	279	248	218	187	157	126	95	65	34	4
26	337	306	278	247	217	186	156	125	94	64	33	3
27	336	305	277	246	216	185	155	124	93	63	32	2
28	335	304	276	245	215	184	154	123	92	62	31	1
29	334		275	244	214	183	153	122	91	61	30	0
30	333		274	243	213	182	152	121	90	60	29	-1
31	332		273		212		151	120		59		-2

(1) In leap years, add one day to figures before March 1.

Table 8. Sources of data for main study.

Herd no.	Owner	Address	Dairy Herd Improvement Association Books obtained	Entries	Herd Classification						Usuable Records	Cows recorded	Average no. usable records per cow recorded	Cows with usable records	Average no. usable records per cow studied
					Start of testing			1941							
					Registered Holsteins	Grade Holsteins	Others	Registered Holsteins	Grade Holsteins	Others					
1	Phillips Brothers	Manhattan	'36-'42	H0001-H0065	22			38			112	65	1.72	57	1.96
2	Robert Bergsten	Green	'38-'42	H0066-H0092		16		4	15		38	27	1.41	22	1.73
3	Lambert Young	Haddam	'33-'26, '39-'42	H0093-H0133	12			22			75	41	1.83	41	1.83
4	Herbert Hatersohl	Greenleaf	'21-'42	H0134-H0211	6	10		17			225	78	2.88	75	3.00
5	Sedlacek Brothers	Greenleaf	'30-'42	H0212-H0259	1	10	1		15		90	48	1.88	29	3.10
6	Henry Topliff and Son	Formosa	'31-'34, '37-'42	H0260-H0319		18	3	12	20		123	60	2.05	47	2.62
7	St Mary's College	St Mary's	'36-'42	H0320-H0369		30			25		82	50	1.64	42	1.95
8	Art Jensen	Olathe	'40-'42	H0370-H0410	5	18	16	7	26	21	27	41	0.66	16	1.69
9	E. E. Strickler	Iola	'28, '38-'42	H0411-H0479	1	33	1	11	28		109	69	1.58	59	1.85
10	R. C. Beezley and Sons	Girard	'39-'42	H0480-H0518	20	12	5	28	4	4	59	39	1.51	35	1.68
11	McConnel Herd(1)	Edna	'17, '19-'24, '26, '28-'30, '32-'35, '37-'42	H0519-H0574	5	10		12			112	56	2.00	42	2.67
12	Raymond Bollman	Edna	'36-'42	H0575-H0679	17	19	7	25	26	1	186	105	1.77	93	2.00
13	Faulconer Brothers	Eldorado	'25-'42	H0680-H0894	6	34	4		55	2	173	215	0.80	74	2.34
14	Wilson Brothers	Lincoln	'39-'42	H0895-H0935	2	29		1	37		34	41	0.82	19	1.79
15	W. G. Bircher and Sons	Ellsworth	'31, '35, '41-'42	H0936-H0951	13			16			16	16	1.00	16	1.00
16	Wayne Blackhall	Sterling	'38-'42	H0952-H0966		9			9		19	15	1.27	11	1.73
17	R. L. Evans and Sons	Hutchinson	'22-'42	H0967-H1042	4	3	4	11			135	76	1.78	50	2.70
18	C. C. Kagarice	Hutchinson	'40-'42	H1043-H1064	16	2	2	19	2	2	37	22	1.68	21	1.76
19	M. A. Schultz and Son	Pretty Prairie	'27-'42	H1065-H1151	11	7	1	28			252	87	2.90	75	3.36
20	Leo Hostetler	Harper	'20, '24-'42	H1152-H1286	20	1		30	1		311	135	2.30	123	2.53
21	Luthar Shetler	Conway Springs	'38-'42	H1287-H1335	11	11	16	14	19	10	56	49	1.14	25	2.24
22	Jake Zarnowski	Newton	'39-'42	H1336-H1396	70			43			94	61	1.54	59	1.59
23	Ted Buhler	Assaria	'41-'42	H1397-H1408	12	9		12	9		14	12	1.17	11	1.27
24	Jake Carlin(2)	Salina	'41	H1409-H1410		9	3		9	3	2	2	1.00		
Totals and averages											2379	1408	1.70	1042	2.28

(1) The McConnell herd books were obtained from Raymond Bollman, Edna.

(2) The Carlin records were discarded because of the small number of records.

Form 1. Letter of inquiry.

February 4, 1952

Dear \_\_\_\_\_:

With the widespread use of artificial breeding in the state of Kansas, as well as nation-wide, it is becoming more and more desirable that the daughters from these services be tested. Many users of artificial breeding have not yet affiliated themselves with the services of the DHIA and consequently, records are not available on animals in their herds.

In order to get a rapid and complete picture of the production of the daughters from artificial breeding and the production of their dams, it will be advisable to get estimates of production from non-DHIA as well as DHIA herds.

As a preliminary step in trying to develop such a testing program, considerable study needs to be given to records which have been completed. The best source of this information is in the records accumulated by dairymen who have been testing for a long time such as you have in your herd. We would like to have the opportunity of using any records accumulated during the period of 1930 to 1942 for this study. If you have these books available and would be willing to let us use them for a short time, we will make arrangements to obtain them from you sometime in the near future.

Please fill out the enclosed card and return it to us so that we can proceed with this project.

Sincerely yours,

Franklin Eldridge, Assoc. Professor  
Department of Dairy Husbandry

FE:bls  
Enclosure

## Form 2. Postal card for herd owner's reply.

Name \_\_\_\_\_

Our records show that your herd was enrolled in Dairy Herd Improvement testing during the period prior to and including 1942. Do you have Herd Record books for any of this period?

Yes  No 

Can these books be obtained for study?

Yes  No 

Where are these records now located? (Please give directions from nearest town, major highway intersection or other landmark.)

\_\_\_\_\_  
\_\_\_\_\_

## Form 3. Form for recording data from individual cows.

Cow No.	Sire												No.		Entry No.
	JAN	Feb	MAR	Apl	MAY	June	JUL	AUG	Sept	OCT	Nov	DEC	305 dys.	270 dys.	Breed
Daily Milk #															Age (Mo.)
Test, BF%															Lac. No.
Daily BF #															Fresh
															Dry
															Length(dys)

Cow No.	Sire												No.		Entry No.
	JAN	Feb	MAR	Apl	MAY	June	JUL	AUG	Sept	OCT	Nov	DEC	305 dys.	270 dys.	Breed
Daily Milk #															Age (Mo.)
Test, BF %															Lac. No.
Daily BF #															Fresh
															Dry
															Length(dys)

Cow No.	Sire												No.		Entry No.
	JAN	Feb	MAR	Apl	MAY	June	JUL	AUG	Sept	OCT	Nov	DEC	305 dys.	270 dys.	Breed
Daily Milk #															Age (Mo.)
Test, BF %															Lac. No.
Daily BF #															Fresh
															Dry
															Length(dys)

Cow No.	Sire												No.		Entry No.
	JAN	Feb	MAR	Apl	MAY	June	JUL	AUG	Sept	OCT	Nov	DEC	305 dys.	270 dys.	Breed
Daily Milk #															Age (Mo.)
Test, BF %															Lac. No.
Daily BF #															Fresh
															Dry
															Length(dys)

Cow No.	Sire												No.		Entry No.
	JAN	Feb	MAR	Apl	MAY	June	JUL	AUG	Sept	OCT	Nov	DEC	305 dys.	270 dys.	Breed
Daily Milk #															Age (Mo.)
Test, BF %															Lac. No.
Daily BF #															Fresh
															Dry
															Length(dys)

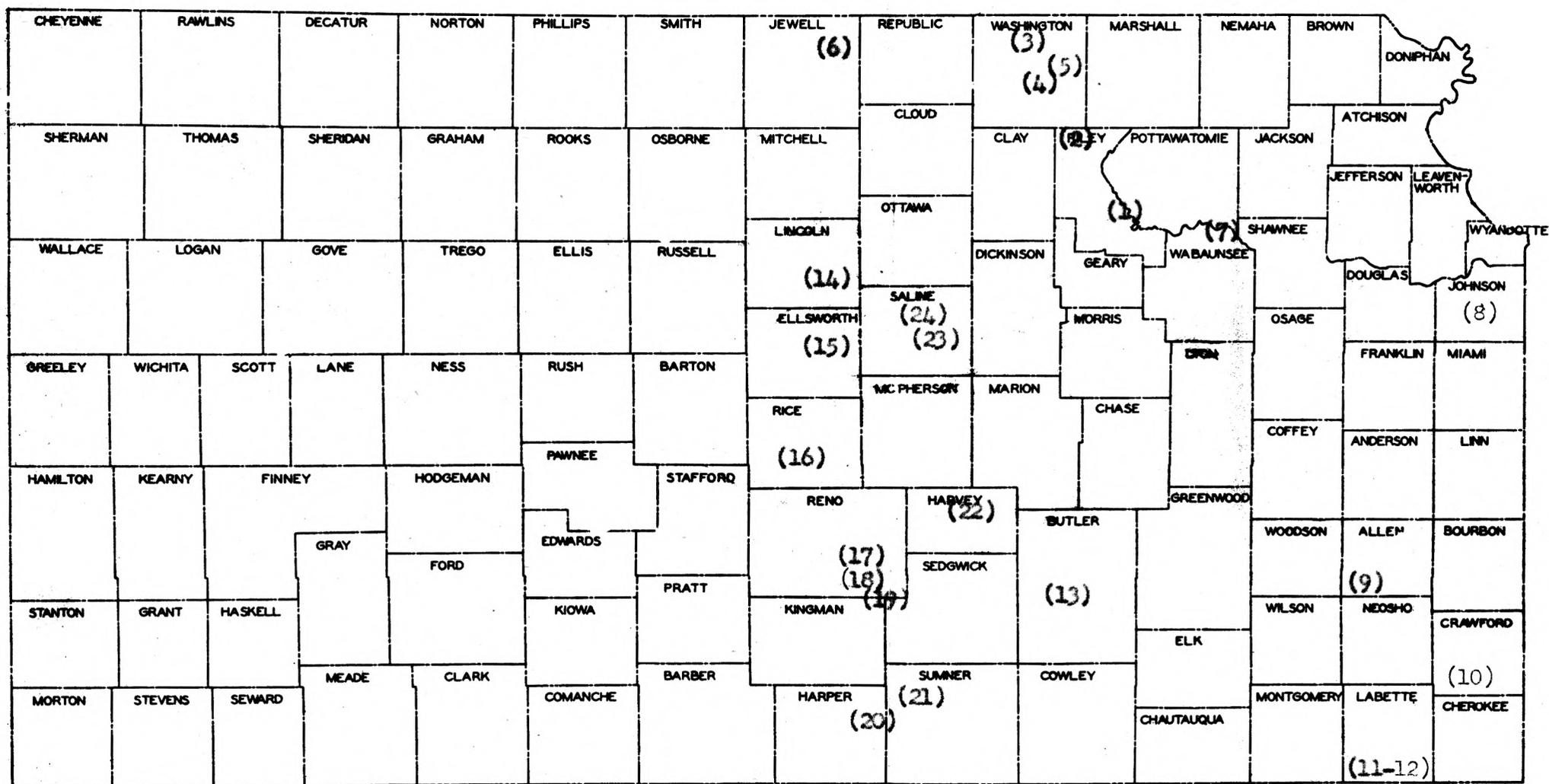


Fig. 1. Location of herds used in main study.

CORRELATION OF BUTTERFAT PRODUCTION PREDICTED FROM SINGLE TESTS  
WITH BUTTERFAT YIELDS CALCULATED FROM MONTHLY TESTS

by

HAROLD J. SEYMOUR

B.S., Kansas State College of Agriculture and Applied Science, 1948

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AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Dairy Husbandry

KANSAS STATE COLLEGE  
OF AGRICULTURE AND APPLIED SCIENCE

1953

## ABSTRACT

It has long been recognized that short term tests near the beginning of the lactation are inaccurate in estimating complete lactation records and that monthly tests of small herds are costly on a per capita basis. Consequently, a modified testing program is needed for estimating production of cows in these herds.

Dairy Herd Improvement Association records and breed herd test records indicate the apparent transmitting ability of dairy sires. In selecting bulls for artificial breeding units, additional estimates of production from cows which are not normally tested would be valuable because the management and environmental conditions in these herds may be different from those found in herds which test for production. Semi-monthly testing is the only method using less than one test per month which is currently accepted in computing sire proofs. It was desirable to devise a method of estimating lactation yields of butterfat from fewer tests.

A preliminary study of records from the Kansas State College herd seemed to indicate that the monthly production for any cow could be estimated relatively reliably from any day's production within that month. Records from a local Ayrshire herd were used in establishing a method for calculating lactation yields from single tests. Prediction equations for estimating butterfat production were computed from 2379 records of 1042 Holstein cows in 23 herds. These cows were on Dairy Herd Improvement testing in 1952 but only records started before 1942 were used in the study. This eliminated the effects of artificial environmental conditions produced during the war years, yet furnished records from consecutive years. Linear multiple regression equations

were developed. Factors considered were: production on the testing day, month tested in the lactation, season of year in which the cow freshened, and age of cow at parturition.

Records of 270 days instead of 305 days were used to partially eliminate the variance due to differences in length of time which cows carried their calves. The use of 270-day records also partially eliminated the possibility of including records which were terminated because of early re-breeding. Factors for season of calving did not increase the accuracy of the prediction equations and were therefore discarded. The prediction equations for the older age groups in the partial regression coefficient for month tested in the lactation. Further investigation revealed that this difference was more a reflection of differences between first and second lactations than it was a reflection of the effect of age. Therefore the first-lactation data were separated from the subsequent-lactation records and two equations were developed. The prediction equations were:

$$\begin{aligned} \text{First-lactation records, } \hat{Y}_1 &= 75.59 + 155.55 X_1 + 9.36 X_2 \\ n &= 665 \\ R &= .75 \end{aligned}$$

$$\begin{aligned} \text{Subsequent-lactation records, } \hat{Y}_1 &= 25.39 + 168.62 X_1 + 21.17 X_2 \\ n &= 1714 \\ R &= .78 \end{aligned}$$

In these formulas,  $\hat{Y}_1$  = 270-day production,  $X_1$  is butterfat production on the testing day and  $X_2$  is month in the lactation.

The use of these prediction equations to estimate production from daughters of bulls under varied environmental and management conditions should be helpful in evaluating bulls used in artificial breeding units. Estimates

from many daughters of each of several sires in many herds should aid in the study of environmental effects upon production. This method is not intended to supplant standard Dairy Herd Improvement Association testing in calculating production of individual cows. It is considered sufficiently accurate for calculating the butterfat transmitting ability of dairy sires when the herd owner has nothing to gain by favoring any cow or cows, and when random samples are obtained from many cows which are kept under varied environmental conditions.