USEFULNESS OF PART RECORDS IN ESTIMATING THE BREEDING VALUES OF DAIRY CATTLE

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This is to certify that the

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USEFULNESS OF PART RECORDS IN ESTIMATING THE BREEDING VALUES OF DAIRY CATTLE

By

Robert C. Lamb

AN ABSTRACT OF A THESIS

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ABSTRACT

USEFULNESS OF PART RECORDS IN ESTIMATING THE BREEDING VALUES OF DAIRY CATTLE

by Robert C. Lamb

Complete lactation records for 24,602 Holsteins, 4,309 Guernseys, 1,878 Jerseys, and 892 Brown Swiss compiled in Michigan DHIA-IBM from June 1954 through December 1957 were analyzed to ascertain the effects of breed, age, and season of freshening on the relationship of total to part production and to develop factors which adequately take into account the effects of these variables in extending records to 305 days. The same data were used to measure heritabilities and repeatabilities of monthly, cumulative, and total production, to obtain genetic and phenotypic correlations between part and whole records, and to measure the relative genetic gain in whole records from selecting for genetic gain in part records.

Breed, age, and season of freshening influence the ratios between total and part production sufficiently to require adjustment in extending part records to completion. Separate factors should be used in extending milk and butterfat records.

Repeatabilities of single months increase gradually up to the seventh month and then decline rapidly. Repeatability of cumulative production shows an upward trend until the eighth or ninth month of the lactation where it is as high as for total yield. The repeatabilities for milk are slightly larger than

those for butterfat and repeatability is larger for adjacent than for non-adjacent records.

Heritabilities of monthly production range between zero and .29. Heritabilities of cumulative production generally increase with each additional month. Heritabilities of total production range between zero and .29 for milk and between zero and .19 for butterfat. Heritability of butterfat production is lower and more erratic than for milk production. Lactations differ in heritability of monthly, cumulative, and total production of milk and butterfat.

Phenotypic correlations between monthly and total production are largest for the fifth month and smallest for the first and last months of the lactation. Phenotypic correlations between cumulative and total production increase rapidly for the first six months and then more slowly to .99 by the ninth month. The correlations are higher for milk than for butterfat, for first lactations than later lactations, and between a part and a total of the same record than between a part of one record and the total of a succeeding record.

Genetic correlations between monthly and total production tend to be higher for the center months of the lactation, while between cumulative and total production they tend to increase as the lactation progresses.

Except for one or two months during the lactation, selection based on a single monthly record will provide only 50 to 90 percent as much genetic progress per generation in the complete record as selecting on the complete record. The relative efficiency of selecting for a complete record using a cumulative part record as the basis for selection increases as each succeeding month is added to the cumulative total.

The phenotypic correlations between part and whole records indicate that partial records can be extended with considerable accuracy, but the genetic parameters indicate that in general the genetic progress in complete records will not be as rapid if part records are used as the criterion for selection. However, genetic progress can still be made under this system and if the generation interval can be reduced markedly, if the selection pressure can be increased considerably, or if the economic conditions justify, it may be advantageous to use a part record as an aid in selection.

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INTRODUCTION

A large portion of the current selection in dairy cattle utilizes lactation records still in progress at the time of selection. This is true for selection of both sires and individual females. An even more intensive use of part records may be a valuable tool for earlier evaluation of the genetic worth of dairy cows and bulls. This preliminary information could provide a basis for making decisions on culling cows after only a few months of their first or second lactations. Earlier evaluation of the daughters of bulls would shorten the time required to test bulls, thus reducing the cost of maintaining young sires until proven. Artificial insemination units could profit from this by increasing the number of sires which could be tested in a young sire program without materially increasing the cost of maintaining young unproven sires. Sires destined for potentially heavy service could be selected sooner to lengthen their productive life.

The use of part records should provide additional information in evaluating the probable merit of a sire by including information from a larger number of daughters more quickly. The use of all records, complete and incomplete, should eliminate some biases in evaluating bulls caused by the differential culling among progeny of sires resulting from the removal of disproportionate numbers of potentially low producing daughters on the basis of early parts of the first lactation.

Total yield estimated from production during an early portion of the lactation could provide a way to use individual cows as their own controls in physiology, nutrition, or management experiments. Deviations from the extended lactation curve or from estimated total yield might serve to estimate more precisely the treatment effects than the difference between paired individuals.

Another use for part records may be to measure complete records with fewer tests. If a cow can be tested less frequently and each test weighted properly to estimate with sufficient accuracy actual production for 305 days, more herds could be tested without greatly increasing the cost or the labor involved.

Before using part records to the extent indicated, more should be known concerning their use. Part records may be either incomplete records still in progress or incomplete terminal records, the latter being lactations prematurely terminated by death or sale of the animal. What, if any, distinction must be made between them in actual use has not been determined. However, work along this line is currently in progress (51). Incomplete terminal records and records still in progress need to be extended to be comparable to complete records. Factors used to extend part records to a 305-day basis need to compensate for the influence of environmental variables which affect the relationship of total to part production.

Early parts of records are valuable for making wise decisions of selection only if the early months of lactation provide a reliable estimate of a cow's ability to produce for a complete lactation of 305 days. A partial first record may be less valuable for estimating a cow's ability to produce during a lactation, or for predicting a bull's probable transmitting ability than is an average of several completed records. The part record does become available earlier and by shortening the generation interval and by providing information from a larger number of daughters may more than compensate in genetic gain for errors which may be introduced in selection based on early parts of a first record. Estimates of genetic parameters are necessary to evaluate whether part records are reliable enough to be used to evaluate the genetic worth of dairy cattle. These parameters can be used to determine the genetic progress in 305-day production from selection based on part records as compared to genetic progress from selection based on complete records.

The objectives of this study are: (a) to ascertain more clearly whether age, breed, and season of freshening should be adjusted for in extending milk and butterfat records and whether the age and season groupings used in earlier studies adequately remove the effects of these variables; (b) to measure the repeatability (correlations between the same period of different lactations) of monthly, cumulative, and total production; (c) to obtain the correlations between individual and cumulative months of one lactation and complete yield of a succeeding lactation; (d) to measure the heritability of monthly, cumulative, and total lactation production; (e) to estimate the genetic correlations between monthly production and total yield and between cumulative and total lactation periods; and (f) to use the estimates of genetic parameters to measure the relative efficiency of selection for a 305-day record using a part record as the criterion for selection.

REVIEW OF LITERATURE

Predicting Complete Yield from Part Records

Phenotypic relationship between total and part production

The desirability of estimating a cow's complete lactation yield from only a few tests has led to several investigations of this possibility. Yapp (77) found in 1915 that a 7-day test early in lactation was not highly correlated with total yield for the lactation and concluded that this was not a satisfactory test. Gowen and Gowen (20) later reported a correlation of .58 between 7-day and 365-day yield of milk. Gaines (14) concluded that the 7-day test was of most value when made during the fifth month of the lactation. Kartha (31) found that a short-time test most accurately estimated 305-day production when the test was taken during the fourth month after calving.

Estimation of lactation yield from one test during a lactation was reported by Cannon _et al_. (5) to be most accurate when the test was made during the fifth or sixth month of the lactation. The correlations between production for these months and 305-day yield were .91 for the Iowa State College herd and .72 for Iowa DHIA herds. The work of Madden _et al_. (46) also showed the fifth month to be the most accurate if only one test is to be made. A single test in the sixth, fourth, or seventh month was almost as accurate as one in the fifth month for estimating total yield for the lactation. Working with New Zealand dairy records, Searle (62) found a test in the fifth month to be the most closely correlated (r = .76) with 305-day yield of butterfat, followed in turn by a single test in the fourth and sixth months. VanVleck and Henderson (70) reported a correlation of .85 between production on test day for each of the fourth, fifth, and sixth months and total production of milk for the lactation.

Kennedy and Seath (36) found that cumulative production for the first four months was at least as valuable as any single month for predicting total production for the lactation. Rendel et al. (59) found a correlation of .80 between 70-day and 305-day yield and concluded that 70-day yield could be used as a guide to early selection. PerTuff (56) reported that the correlation between 180-day yield and complete yield was .90. More recently O'Connor and Stewart (54) reported a correlation within herds of .92 between 180-day and 305-day yield of milk.

In a study of Ayrshire records by Harvey (23), the correlations between cumulative production and total production for both milk and butterfat increased rapidly to .88 by the fourth month and .94 by the sixth month and then increased more slowly until the correlation at the end of 9 months was 1.00. The correlations found by Voelker (73) for two-year-old Holsteins were slightly lower, but followed the same pattern. Madden et al. (46) reported correlations for cumulative production with 305-day yield that reached .90 by the fourth month for cows over 3 years and .93 for cows under 3 years of age, and reached .95 and .97 by the sixth month for cows over and under 3 years of age, respectively. Using Michigan DHIA records for four breeds, Fritz et al. (13) obtained correlations between cumulative production and total production for both milk and butterfat. The correlations for Holsteins and Brown Swiss compared very closely and were at least .91 by the fourth month and .95 by the sixth month. The correlations for Guernseys and Jerseys were similar to each other and, although being lower in the initial stage of lactation, were .91 by the fifth month and .94 by the sixth month. Reece (58) correlated the average butterfat test for cumulative periods with the average butterfat test for the lactation and found a correlation of .93 by the sixth cumulative month.

Factors for extending part records

Ratio and regression factors for estimating complete lactation yield from various portions of the lactation have been reported by several investigators. The question of which type of factors, ratio or regression, is most appropriate for extending part records has been reviewed by Harvey (24), Lamb (37), and Madden *et al.* (46).

Among the earliest reports of extrapolation factors for extending milk production were those of Pearl and Patterson (55), Gowen and Gowen (20), Gowen (19), Turner and Ragsdale (68), Kartha (31), and Kendrick and Bain (35). Later Cannon *et al.* (5) and Eldridge and Atkeson (8) developed factors for extending butterfat records.

Some authors have presented multiple sets of factors. Harvey (23) and Kendrick (34) reported factors for three different age groups. Kendrick (34) also presented factors based on season of freshening and level of production. An extensive set of tables for each of three age groups for estimating total milk and butterfat production from any single test day during the lactation was developed by Erb *et al.* (9) from DHIA data. Madden *et al.* (44, 45, 46) presented both ratio and regression factors for extending monthly and cumulative production of milk and butterfat to 305 days. Separate factors were given for each of the two age groups, and in the latter two papers factors were presented which would adjust for age and frequency of milking. Extension factors which would adjust for season of freshening for Jersey and Sindhi-Jersey crossbreds were presented by Fletcher et al. (11).

Lamb and McGilliard (38, 39) developed ratio factors that would adjust for age and season of freshening in extending cumulative production of milk and butterfat for four breeds. Regression factors for extending cumulative test-day production of milk and butterfat to a 305-day basis for four breeds were developed by Fritz et al. (13). VanVleck and Henderson (70, 71, 72) used Holstein records from New York DHIA to develop factors for predicting 305-day production of milk from a single monthly test, from sequential test-day data, from cumulative monthly tests, and from sequential bimonthly and trimonthly test-day information.

Variables Affecting Relationship of Total to Part Production

Production records of dairy cows are influenced by many environmental factors. The effects of these same variables on the relationship of total production during a lactation to production during various portions of the lactation are of primary concern in developing factors for estimating total yield for the lactation from short-time records.

Age and parity

Eldridge and Atkeson (8) developed regression factors for estimating total yield of butterfat from one day's test for 12 different age groups. Separate factors appeared necessary, especially for younger cows. By regrouping the early ages into first and second lactations, they found that factors based on parity more accurately extended the part record to a complete lactation. Erb et al. (9) found a very marked difference between young and old cows with respect to the shape of the lactation curve. They divided records into three age groups (≤30 mo., 31-42 mo., and ≥ 43 mo.) to develop factors for predicting 305-day production of milk and butterfat from a single test. Madden and co-workers (44, 45, 46) also showed a difference in the shape of the lactation curve for first-calf heifers as compared to older cows. They concluded that separate factors are needed for records initiated at less than 3 years and for those started at 3 years and older.

Kendrick (34) and Harvey (23) separated records into three age groups, roughly corresponding to first, second, and all later lactations, respectively. Differences between factors for different age groups indicated a need for separate factors for each age group. Fritz et al. (13) studied the influence of age and parity, but failed to show any influence on regression factors attributable to either of them. Lamb and McGilliard (38, 39) studied simultaneously the influence of age and parity on the ratio of total production in 305 days to monthly production of milk and butterfat. Both were found to be important. Analysis of components of variance indicated that parity had a larger influence on the total to part relationship than did age at freshening. However, the ratio factors themselves indicated no practical differences between the factors for age and parity. The conclusion of these workers was that in actual practice extension factors based on age are more desirable.

Working with New Zealand records, Searle (61) found that monthly butterfat records needed to be corrected for age. Separate factors were developed for two-, three-, and four-year-old cows. VanVleck and Henderson (71) divided New York Holstein data into 60 age groups and found a significant effect of age on ratio factors for extending individual and cumulative monthly tests to a complete lactation basis.

Season of freshening

Eldridge and Atkeson (8) and Fritz et al. (13), using methods of regression, considered the effect of season of freshening on the relationship of total to part production, but found it insignificant. On the other hand, Kendrick (34) concluded that season of freshening should be considered for at least the first six months in extending cumulative short-time Ayrshire records. Fletcher et al. (10, 11) reported a need for adjustment for season of calving in extending part lactations for Jersey and Sindhi-Jersey cows. Lamb and McGilliard (38, 39) found that differences due to season of freshening contributed only slightly less to the variance than did parity or age. Searle (61) and VanVleck and Henderson (71) concluded that age and season of freshening should be adjusted for simultaneously in extending part-time milk and butterfat records.

Breed

Cannon *et al*. (5), using data from five breeds, concluded that the shapes of the lactation curves were so similar that breeds do not need to be considered separately in calculating factors for extending incomplete records. Erb *et al*. (9) reported that analysis of records from Jerseys, Guernseys, and Holsteins showed that breed had little effect on the shape of the lactation curve; therefore, they did not consider breeds separately in the extension factors which they developed. Fletcher *et al*. (11) found only a slight difference between extension factors for Jerseys and those for Sindhi-Jersey crossbreds. Although Fritz *et al*. (13) studied breeds separately, no conclusions were drawn as to possible breed differences. However, a visual comparison of the extension factors which they present for four breeds indicates definite breed differences in the relationship of total to part production. In studies by Lamb and McGilliard (38, 39) the ratio factors for cumulative production differed between breeds. Holstein and Brown Swiss factors tended to be alike for milk but differed widely for butterfat. Guernsey and Jersey factors were very similar to each other but differed from the Holstein and Brown Swiss factors for both milk and butterfat.

Herd

Michigan data (13, 38) indicated that herd differences were not important in the relationship of total to part production; therefore, separate factors are not needed for each herd for extending records.

Level of production

Kendrick (34) found a significant difference between extension factors for low-producing and high-producing cows freshening between 31 and 44 months of age, while for more mature cows there was only a slight difference due to level of production. Harvey (23) found a slight tendency for higher producing cows to decline more rapidly in production than did the lower producing cows, while Madden et al. (46) concluded that the relationship between total and part production was similar for low-producing and high-producing cows.

Frequency of milking

The study by Madden et al. (46) indicated that milking frequency is not important in extending part-time records.

Genetic Parameters

Repeatability

Early reports (16, 17, 18, 19, 20, 64) on the repeatability of complete milk and butterfat records were of the order of .55 to .80. Estimates of repeatability were high in these studies because herd differences were not removed. Gifford (16) estimated intra-herd repeatability of cumulative monthly production from correlations between two- and three-year-old records, three- and four-year-old records, and four- and five-year-old records. The magnitude of the correlations increased up to eight months where they were .57, .51, and .61, respectively, for milk and .54, .45, and .59, respectively, for butterfat. Berry (3) reported an intra-herd repeatability of

.29 for butterfat yield for cows with at least six records. The correlation between records by the same cow decreased as the number of intervening records increased. Sikka (64), Rendel *et al.* (59), Gowen (18), and Mahadevan (50) have also reported that the repeatability of adjacent records was higher than that of non-adjacent records.

During recent years repeatability has been calculated on an intra-herd basis, resulting in estimates ranging from approximately .3 to .5. Hartmann (21) estimated repeatabilities of .34 and .37 for milk and butterfat yield, respectively. Working with Swedish cattle, Johansson (26, 27) reported repeatabilities of .38 to .42 for milk yield and .32 to .45 for butterfat yield. Plum *et al.* (57) reported a repeatability of .32, while Carneiro (6), Berousek *et al.* (2), and Thompson *et al.* (66) found repeatabilities of approximately .40 for milk and butterfat yield. Slightly higher estimates were found by Specht and McGilliard (65) (r = .40 for butterfat, .46 for milk), Madden *et al.* (44) (r = .43 for butterfat, .51 for milk), Johnson and Corley (30) (r = .45 for butterfat, .47 for milk), Wadell *et al.* (74) (r = .47 for butterfat, .50 for milk), Rendel *et al.* (59) (r = .55 for butterfat, .48 for milk), VanVleck and Henderson (69) (r = .50 for butterfat, .53 for milk), and Mahadevan (48, 50) who found repeatabilities for milk yield of .46 and .53 with two different groups of cattle. When year effects were neglected, Castle and Searle (7) obtained a repeatability of .49, but when a correction was made for year effects the estimate was .61. In a separate study, Searle (62) obtained a repeatability estimate of .60 for lactation yield of butterfat.

Several investigators have reported correlations between a part of one lactation and the same part of a succeeding lactation. Gaines (15) measured the correlations between cumulative months in a current and the subsequent lactation. The resulting correlations for milk and butterfat increased from approximately .50 for the first month to .65 by the tenth month. In studies by Gifford (16, 17), gross and intra-herd correlations between cumulative months of succeeding lactations increased rapidly during the first four months and then increased more slowly with each additional month of production.

Estimates of repeatability for monthly and cumulative production of milk and butterfat were computed from intra-class correlations by Madden et al. (44) who found that repeatability increased to the second month for monthly records and the third month for cumulative records and then decreased with each succeeding month in the lactation. Searle (62) found that repeatability of monthly records increased as lactation progressed, leveling off at the fourth or fifth month. A still different trend was found by VanVleck and Henderson (69). Repeatability of single test-day records increased with stage of lactation until the sixth month and then declined rapidly. First, sixth, and tenth month repeatability estimates were .38, .50, .25 for milk and .30, .44, and .26 for butterfat, respectively. Repeatability estimates for cumulative production showed an upward trend until the eighth or ninth month of the lactation. Correlations between 180-day production (.52 for milk, .48 for butterfat) were almost as high as between 305-day yield (.53 for milk, .50 for butterfat). Mahadevan (49) found a slightly higher repeatability for 180-day records ($r = .52$) than for 305-day records ($r = .49$). Rendel et al. (59)

reported repeatability of 70-day records (r = .40) to be lower than repeatability of 305-day records (r = .50).

The only reported work dealing with correlations between a part of one lactation and a complete succeeding lactation is that of Gowen and Gowen (20) who reported that correlations between a 7-day test in one lactation and a 365-day record for a later lactation were .48 for milk yield and .42 for butterfat percentage.

Heritability

Early workers reported heritability estimates from daughter-dam correlations of .36 to .50 for milk and .24 to .40 for butterfat. These estimates were not made on an intra-herd or intra-sire basis and, therefore, appear high because of the inclusion of environmental correlations between relatives within a herd or sire line. Shrode and Lush (63) reviewed earlier studies and reported that estimates of heritability of intra-herd differences in milk and butterfat production were of the order of .20 to .30. Reports since then have substantiated these figures. These reports include: Beardsley *et al.* (1), Berousek *et al.* (2), Harvey and Lush (25), Johnson (29), Kempthorne and Tandon (32), Legates (41), Legates and Lush (42), Mitchell *et al.* (53), Touchberry (67), VanVleck and Henderson (69), and Yao *et al.* (75, 76). Heritability estimates from other countries by Carneiro (6) in Brazil, Hartmann (21) in Germany, Mahadevan (50) in Great Britain, and Searle (62) in New Zealand have been in close agreement with American estimates. On the other hand, estimates of heritability by Hartmann (22), Johansson (27), and Sikka (64) have been somewhat higher.

Estimates of heritability of individual lactations (12, 21, 28, 30, 40, 48, 59) have indicated a higher value for first records than for later records, suggesting that first lactations are influenced less by environment and more by heredity. In a study by Freeman (12), heritability estimates for first, second, and third lactations were .36, .24, and .26 for milk, and .43, .35, and .26 for butterfat, respectively.

Several reports of heritability of part records are available. Mahadevan (48) obtained a heritability of .31 for first 180-day production of milk. Rendel et al. (59) reported a heritability for the first lactation of .36 for 70-day yield of milk as compared to .43 for 305-day yield of milk. Heritability for the second lactation was .09 and .24 for 70-day and 305-day yield of milk, respectively. Heritability estimates were of the order of .30 for 100-day milk and butterfat records and .34 for 200-day milk and butterfat production in a study by Johnson (30). The differences between the 100-, 200-, and 305-day regressions were not significant. Madden et al. (44) estimated heritability of monthly and cumulative records and found the later months of the lactation influenced less by genetic effects than the earlier months. Estimates for the first eight months ranged between .31 and .41 for milk and .14 and .32 for butterfat. Estimates for cumulative records were relatively higher, ranging from .35 to .63 for milk and .30 to .47 for butterfat. Searle (62) estimated the heritability of monthly yield of butterfat from New Zealand data using both the regression of daughter-on-dam and the half-sib analysis of variance components. The dam-daughter estimates were lower than those obtained by Madden et al. (44), but they appeared to follow the same downward trend toward the end of the lactation. The estimates from the analysis of paternal half-sibs were larger than those from the dam-daughter analysis, particularly in the later months of the lactation. A paternal half-sib analysis was used by VanVleck and Henderson (69) to estimate heritability of monthly and cumulative monthly records for milk and butterfat production. The heritability estimates for monthly production were low in the first and last months of the lactation, but reached approximately .20 in the third through the fifth months. The heritability estimates for cumulative production of milk followed an upward trend for the first four months and then leveled off at .22, while the estimates for cumulative production of butterfat remained fairly constant around .17.

Genetic correlations

Freeman (12) reported that genetic correlations between first and second records were .68 for milk and .80 for butterfat; the values for first with third lactation and second with third were of the order of .40 for both milk and butterfat. He concluded that, to some extent, different sets of genes influence milk and butterfat production in different lactations.

Madden et al. (44) estimated genetic correlations between cumulative and total production and found them near unity for all months, suggesting that genes affecting production early in lactation also affect other parts of the same lactation. Robertson (60) obtained a genetic correlation of .74 between 70-day and 305-day yield.

Searle (62) estimated genetic correlations between monthly records and between monthly and total production of butterfat for the lactation. Estimates of genetic correlations between monthly and total production from a daughter-dam analysis, although lower than those of Madden et al. (44), showed an increase up to the third month and then a general decline. The estimates from correlations between paternal half-sibs approached unity for the middle months correlated with total yield. The genetic correlations between monthly records tended to be higher among the early months than among later months and also higher than the correlations between early and later months. VanVleck and Henderson (69) found the middle months of the lactation highly correlated genetically with total yield. The correlation estimates ranged from a high of 1.01 in the fifth month down to .79 in the second month and .71 in the tenth month. The genetic correlations between cumulative records and total yield increased with an advance in the stage of lactation, reaching .94 by the fifth month and 1.00 by the ninth month. The genetic correlations among monthly records were near unity for adjacent months and decreased with an increase in the time between tests.

Lerner and Cruden (43) found that the genetic correlation between cumulative and annual production of eggs increased steadily with each succeeding month of production, reaching .93 by the seventh month and unity by the tenth month. Blow et al. (4) found a genetic correlation of .89 between part and complete egg records in turkeys. Maddison (47) obtained genetic correlations of .69 and .72, respectively, between cumulative 4 and 5 month egg production and annual yield of eggs.

Relative Efficiency of Selection Based on Part Records

Few investigators have studied the relative efficiency of selection for a whole record using a part record as the criterion for selection. Madden *et al.* (44) found that "selection on the basis of first 60-day production best approaches the gain expected in the whole record until the part record is six months or more in length." In a study by VanVleck and Henderson (69) it was found that a single third or fifth month would provide 92 percent as much progress as selection on total yield. Cumulative production for 6 months was 95 percent as effective as 10-month yield, and 9 months production was 100 percent as efficient as production for 10 months. Lerner and Cruden (43) found genetic progress was 95 percent as efficient with selection based on cumulative production for 9 months as with selection based on egg records 12 months in length.

SOURCE OF DATA

The data were 31,681 complete lactation records initiated during the period June 1954 through December 1957. These records were obtained from the Michigan DHIA-IBM program and represented four dairy breeds. Included were 24,602 Holstein, 4,309 Guernsey, 1,878 Jersey, and 892 Brown Swiss lactations. Each of these records conformed to the following specifications: (a) 2X milking, (b) production for less than 50 days calculated from a single test day, (c) first test day within 34 days of freshening, and (d) 10 consecutive monthly tests. Only the first 10 months of each record were used.

Each record identified the cow, the herd in which the record was made, and contained information on the month and year of freshening, breed, age at freshening (in months), lactation number, identification of sire and dam, and production of milk and butterfat on test day. Milk production was recorded to nearest one-tenth pound, and butterfat production was recorded to the nearest one-hundredth pound.

METHODS

Variables Affecting Relationship of Total to Part Production

Previous investigations by Lamb (37) and Lamb and McGilliard (38, 39) used components of variance to study the effects of breed, herd, age, parity, and season of freshening on the relationship between monthly and total production. The results indicated that breed and age or parity should be considered in extending incomplete records of both milk and butterfat. The effect of season of freshening appeared important for milk, but not as important for butterfat. Differences among herds were not important.

The present study combined new data with the earlier data to increase the volume and reduce sampling errors. The availability of additional records made possible the verification of earlier results and allowed a more complete evaluation of the influence of season of freshening by providing a larger number of groupings.

Factors for extending milk and butterfat records from each of 10 monthly tests were computed separately for sub-groups of various combinations of breeds, ages, parities, and seasons of freshening. Ratios of total production from ten test days to production on each test day were averaged for all records in each sub-group. Ratio factors for cumulative test days were obtained from factors for individual test days in the following manner. The reciprocals of the factors for monthly production for the first 2 months were added and the reciprocal of the sum was the factor for extending production for the first 2 cumulative months. The reciprocal of the factor for the third month was added to the sum of the reciprocals for the first 2 months and then reciprocated to obtain the factor for 3 cumulative months. Factors for succeeding months were obtained in a similar manner.

Ratio factors for ages of freshening were computed for each of these 42 age groups: less than 20 months, 1 month intervals from 20 months through 59 months, and 60 months and over. Factors were obtained for the first, second, and a combination of all later lactations.

Sets of ratio factors for each of the 12 calendar months were used to study the influence of season of freshening. The factors were grouped together in all possible combinations of 3, 4, and 6 adjacent months to find the seasons of freshening with the largest difference between their respective ratio factors. Adjustment for season on the basis of this grouping should remove more of the variance due to season of freshening than adjustment for any other choice of grouping.

Ratio factors were computed from 16,272 lactation records used in earlier studies (37, 38, 39), and a separate set of factors was computed from an additional 15,409 records. The ratio factors from the two sets of data were almost identical for Holsteins and agreed very closely for the other three breeds. Any differences between the two sets of factors for Guernseys, Jerseys, and Brown Swiss could be attributed largely to sampling due to the relatively small numbers of observations. Since the conclusions concerning the environmental influences were similar for the two sets of data and since

there were no practical differences between the ratio factors derived from each set, the two sets were combined in the final analysis.

Genetic Parameters and Phenotypic Correlations

The parameters needed to study the genetic relationships between total and part production are: (a) the repeatability and heritability of production for individual months, for cumulative months, and for the complete lactation; and (b) the genetic correlations between total and part records. Actual production of milk and butterfat on test day was used as the measure of production for this part of the analysis.

In order to study the genetic relationship between total and part production, the influence of environment must be removed as completely as possible. One way to do this is to standardize the environment in which all cows are placed so that any differences between animals are caused entirely by genetic differences. A second approach is to remove statistically the environmental differences. Statistical control is less expensive than physical control, but its effectiveness is limited by an incomplete knowledge of just what environment prevailed or in estimating how much effect the particular environment had on each phenotype. Unfortunately, the first approach is practically impossible, both physically and economically; therefore, statistical control is the only practical method available for use in studying large populations of dairy cattle.

Failure to remove differences between herds generally causes estimates of genetic parameters for complete records to be too large. Presumably the same is true for part lactations. Since breed, age, and season of freshening influence the amount of milk and butterfat produced, it becomes desirable to determine whether the influence of these three variables should also be removed when estimating genetic parameters of part records.

Differences in part records due to age or season of freshening can be removed either by the use of appropriate correction factors or by performing the analysis within herds, ages, and seasons. Madden et al. (46) adjusted part records for age by using age correction factors which had been derived from 305-day lactation totals. They found that these factors were fairly suitable for correcting the center months of the lactation, but were less applicable for the first and last months of the lactation. At the time the study being reported here was undertaken, factors were not available for adjusting either individual or cumulative months of a lactation for age or season of freshening. Since then, Searle (61) in New Zealand has reported multiplicative factors to correct monthly butterfat yields for age and first month on test. However, since dairying is seasonal in New Zealand, only three months were considered for first month on test, and ages were recorded to the nearest year only. This restricts the application of these factors almost entirely to data from New Zealand.

With no appropriate correction factors for age or season of freshening available, two alternatives were possible: (a) derive correction factors for age and season of freshening from all the available data and then reapply them to the same data in order to make the correction as exact as possible, or (b) perform the analysis on a within-herd-age-season basis. The analysis within classifications sets aside the variation due to differences between units, such as ages or herds, by including in the analysis only those differences that exist within the unit. This method should be even more exact in removing differences since it sets them aside rather than trying to correct for them. The use of correction factors does have the advantage that all of the data are usable, whereas with the within-classification method there must be a minimum of two observations within each classification in order to measure differences. Thus, some of the data may be lost in this method. Considerable extra time, effort, and cost are involved in developing and applying correction factors in addition to their providing a less exact removal of differences; therefore, the within-classification method was used in this study. The variation due to differences between herds, between ages, between seasons, and possible interactions between them was eliminated by analyzing only the differences which occur within an age-season-herd group.

Because of the relatively small number of records for Guernseys, Jerseys, and Brown Swiss, only the Holstein records were used to estimate the genetic parameters and the phenotypic correlations.

Repeatability and phenotypic correlations

Repeatability is herein defined as the coefficient of correlation between the same part of different lactations by the same cow. The coefficient of correlation between different parts of the same lactation or between a part of one lactation and the total of a succeeding lactation is designated simply as a phenotypic correlation to distinguish this from repeatability and from a genetic correlation which will be defined later. The same data were used to calculate both repeatability and phenotypic correlations; hence, the methods used are included in the same section.

Estimates of repeatability for parts of first and second lactations separate from later lactations are needed because so relatively little is known about the producing ability of the cow at these early ages. Several workers (3, 18, 50, 59, 64) have reported that the repeatability of adjacent records was higher than that of non-adjacent records. For these reasons estimates of repeatability were obtained from correlations between first and second lactations, between second and third lactations, between all later adjacent records; and separate estimates were obtained by correlating first and third or later lactations, second and fourth or later lactations, and all non-adjacent third or later records.

Repeatabilities were computed as product-moment correlations between total production for a first recorded lactation and the succeeding adjacent record, between total production for a first recorded lactation and a succeeding non-adjacent record, between individual months of a first recorded lactation and the succeeding adjacent record, between individual months of a first recorded lactation and a succeeding non-adjacent lactation, between cumulative months for an early record and the succeeding adjacent record, and between cumulative months for a first recorded lactation and a succeeding non-adjacent lactation. Phenotypic correlations were computed as product-moment correlations between monthly and total production for the same lactation, between cumulative and total production for the same lactation, between monthly production for an early record and total production for the succeeding adjacent record, between monthly production for a first recorded lactation and total production for a succeeding non-adjacent record, between cumulative production for a first recorded lactation and total production for the succeeding adjacent record, and between cumulative production for an early record and total production for a succeeding non-adjacent record.

When a cow had three or more complete records during the period studied, all combinations of pairing a given record with a later record were used. Repeating records is not entirely correct, particularly when a record is used more than once in the same estimate. On the other hand, using each record only once eliminates part of the data when an odd number of records is involved and, in any case, requires setting up a system for selecting the pairs of records to be used. Some procedure between these two alternatives is optimum; however, since it is much easier mechanically to handle all combinations of pairs of records, records were repeated when more than two records for the same cow were available.

Repeatabilities and phenotypic correlations were estimated from 10,898 records from 4,962 Holstein cows having two or more complete records in 2,115 herds. Of this number, 4,032 cows had two records, 886 had three records, and 44 cows had four complete records.

Let x and y represent the two variables being correlated and x_{jklm} and y_{jklm} denote the production for the m^{th} record made during the l^{th} season in the k^{th} age group of the j^{th} herd. Then:

$$\sum_j \sum_k \sum_l \sum_m \left(x_{jklm}\right)^2 = \text{uncorrected total sum of squares,}$$

$$\sum_j \sum_k \sum_l \sum_m \left(x_{jklm}\right)\left(y_{jklm}\right) = \text{uncorrected total sum of products,}$$

$$\sum_j \sum_k \sum_l \frac{\left(x_{jkl.}\right)^2}{n_{jkl.}} = \text{uncorrected sum of squares among age-herd-season groups,}$$

$$\sum_j \sum_k \frac{\left(x_{jk..}\right)^2}{n_{jk..}} = \text{uncorrected sum of squares among age-herd groups,}$$

$$\sum_j \frac{\left(x_{j...}\right)^2}{n_{j...}} = \text{uncorrected sum of squares among herds.}$$

The same notation applies for calculating the sum of squares for y and for the within-classification sum of products. The dot notation signifies summation over a subscript, and $n_{jkl.}$ is the number of observations in the l^{th} season for the k^{th} age group in the j^{th} herd.

The effects of herd, herd and age, and herd, age and season of freshening were removed separately by subtracting first the uncorrected sum of squares and products among herds from the uncorrected total sums of squares and products, and then in each of two completely separate operations subtracting from the uncorrected total sums of squares and products the uncorrected sums of squares and products among age-herd groups and among age-herd-season groups. In each case the remaining sums of squares and products were used to calculate the product-moment correlations. Thus,

$$r = \frac{E_{xy}}{\left(E_{xx} E_{yy}\right)^{1/2}}$$ = product-moment correlation, where

E_{xy} = residual sum of products = uncorrected total sum of products minus uncorrected sum of products within classifications,

E_{xx} and E_{yy} = residual sum of squares = uncorrected total sum of squares minus uncorrected sum of squares within classifications.

Separate removal of the effects of herd, herd and age, and herd, age and season allows a comparison of the variation removed by each. Removing only the effects of herds will leave the largest number of degrees of freedom for the correlations; however, if age and season differences do influence repeatability, removal of variation of herds, ages, and seasons should be more useful wherever this leaves enough degrees of freedom to give a stable estimate.

In an analysis within classifications, multiple groupings may rapidly deplete the number of degrees of freedom. On the other hand, broad groupings may not adequately remove the effects of the important environmental variables. A balance is sought between stability with larger numbers and adequate removal of environmental correlations.

The following reasoning was used to decide upon the age grouping to use. Conversion factors commonly used to adjust complete records for the effect of age at calving differ for monthly groups up to about 50 months of age, after which the groupings include more months per group. From a standpoint of adequate adjustment for age of freshening, monthly groupings would seem to be desirable, especially at younger ages. However, a preliminary survey of the data showed that the many groups would use up more degrees of freedom than were available. Therefore, first lactations were grouped according to age at freshening as less than 24 months, 24 to 29 months, 30 to 35 months, and 36 months and more. Second lactations were grouped as less than 42 months and 42 months and more. Third and later lactations were not differentiated by age. Such grouping for ages, which narrows the limits for younger ages but leaves a broad limit for older ages, should facilitate removal of the effects due to age from the younger ages where the effects are apt to be larger and where interest in obtaining estimates of repeatability is greatest. Such a system of grouping should not seriously deplete the degrees of freedom.

To facilitate removal of the effects of season of freshening, the records were grouped into the seasons defined in the section on environmental variables (April to July and August to March for milk, March to June and July to February for butterfat).

Heritability

Heritability is the fraction of the observed phenotypic variance caused by differences between the genotypes of the individuals. It is used in both a narrow and a broad sense. Used in the broad sense it refers to the whole genotype functioning as a unit and contrasts heredity with environment. But the genotype is not transmitted as a unit, instead its constituent genes segregate and recombine in new combinations. The genes may interact with each other in nonadditive ways, resulting in deviations due to dominance or to epistasis. Heritability in the narrow sense includes only the average effects of the genes, i. e., only the genic or additively genetic variance. The narrow definition is used to describe the fraction of differences between parents which are recovered in their offspring. Because of the methods used to estimate heritability, the values obtained are generally somewhere between the broad and narrow definitions. In statistical terms the definition of heritability in the broad sense is:

$$h^2 = \frac{\sigma_H^2}{\sigma_P^2} \bullet \frac{\sigma_g^2 + \sigma_d^2 + \sigma_i^2}{\sigma_g^2 + \sigma_d^2 + \sigma_i^2 + \sigma_e^2 + \sigma_{eh}^2},$$

and in the narrow sense is:

$$h^2 = \frac{\sigma_G^2}{\sigma_P^2} = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_d^2 + \sigma_i^2 + \sigma_e^2 + \sigma_{eh}^2},$$

where

σ_g^2 = additively genetic or genic variance,

σ_d^2 = variance due to dominance,

σ_i^2 = epistatic variance,

σ_e^2 = environmental variance,

σ_{eh}^2 = variance due to heredity-environment interaction.

Estimates of heritability apply to a particular characteristic and to a particular population in a specific environment. Methods for estimating heritability are based on resemblances between relatives and depend upon being able to measure the extent to which related individuals are more like each other than unrelated ones. The two methods which are most frequently used on dairy cattle populations are the intra-sire regression of daughter on dam and the correlation between paternal half-sibs.

The resemblance between dams and their daughters is generally more useful because (a) sampling errors are less important in correlations between closely related individuals than between more distantly related ones. Heritability is equal to twice the daughter-dam regression but four times the correlation between paternal half-sibs; therefore, sampling errors are multiplied by two in the first case and by four in the second case. (b) Less environmental correlation is likely to be included in daughter-dam regressions than in correlations between contemporaries. (c) In most non-experimental data the daughter-dam regression dodges correction for system of mating since the differences being investigated are only between females mated to the same sire.

The half-sib correlation method is useful in that (a) half-sib populations are more likely to be unselected than are parents. (b) In data limited to only a few years there may be more data available for a half-sib analysis than for a daughter-dam regression.

The regression of daughter on dam was used in this study. A total of 3,555 Holstein daughter-dam pairs was used for this analysis. The same data were also used to estimate genetic correlations.

Heritability (h^2) can be expressed as:

$$h^2 = 2b, \text{ where}$$

$$b = \frac{E_{xy}}{E_{xx}} = \text{intra-herd-sire regression of daughter on dam.}$$

Let x represent production for dams and y represent production for the daughters. Then x_{jkl} denotes production for the l^{th} record made by the dam of a daughter of the k^{th} sire in the j^{th} herd and y_{jkl} denotes production for the l^{th} record made by a daughter of the k^{th} sire in the j^{th} herd. Then,

$$\sum_j \sum_k \sum_l \left(x_{jkl}\right)^2 = \text{uncorrected total sum of squares for production of dams,}$$

$$\sum_j \sum_k \sum_l \left(x_{jkl}\right)\left(y_{jkl}\right) = \text{uncorrected total sum of products,}$$

$$\sum_j \sum_k \frac{\left(x_{jk.}\right)^2}{n_{jkl.}} = \text{uncorrected sum of squares for production of dams among herd-sire groups,}$$

$$\sum_j \sum_k \frac{\left(x_{jk.}\right)\left(y_{jk.}\right)}{n_{jk.}} = \text{uncorrected sum of products among herd-sire groups.}$$

The influence of sire and herd was removed by analyzing on a within-herd-sire basis. The uncorrected sums of squares and products among herd-sire groups were subtracted from the uncorrected total sums of squares and products to obtain the intra-herd-sire sums of squares and products. Hence,

E_{xy} = intra-herd-sire sum of products,

E_{xx} = intra-herd-sire sum of squares for production of dams.

The daughter-dam pairs were separated into the following six groups to remove the effect of age from the heritability of part records: first lactation for both daughter and dam; first lactation for daughter, second lactation for dam; first lactation for daughter, third or later lactation for dam; second lactation for both daughter and dam; second lactation for daughter, third or later lactation for dam; and third or later lactation for both daughter and dam. Within each of these groups heritability was estimated on the within-herd-sire basis for monthly production, cumulative production, and total production.

Inclusion of season of freshening as one of the variables in this portion of the study reduced the number of degrees of freedom to almost zero, necessitating omission of season of freshening from the analysis. The restrictions placed upon the data by analyzing on a within-herd-sire basis combined with dividing the dam-daughter pairs into groups according to the lactation number of both the daughter and the dam reduced the number of degrees of freedom to the point where sampling caused the resulting estimates to be quite erratic. To overcome this, the within-herd-sire sums of squares and products were pooled over parity groups to reduce the number of separate estimates and to accumulate more degrees of freedom to increase the stability of the results. Separate estimates were pooled by summing the sums of squares and products over the parity groups being pooled. Pooled estimates were obtained for first lactation for the daughter irrespective of the parity of the dam, for second lactation for the daughter and second or later lactation for the dam, for second or later lactations for both daughter and dam, and then all the data were pooled to give one over-all estimate.

The pooled estimate of heritability was:

$$2b_c = \frac{2\sum_{i=1}^{n} E_{xy_i}}{\sum_{i=1}^{n} E_{xx_i}}, \quad \text{where}$$

b_c = pooled estimate of regression of daughter on dam,

$\sum_{i=1}^{n} E_{xy_i}$ = pooled intra-herd-sire sum of products,

$\sum_{i=1}^{n} E_{xx_i}$ = pooled intra-herd-sire sum of squares for dam's production,

i denotes the parity groups over which the data were pooled,

n = number of intra-sire-herd regressions of daughter on dam.

In the above method of pooling, the regressions to be pooled are assumed to be independent, equal, and have homogeneous variances. Except for the situation to be described more fully later in which a dam's record may be repeated, the regressions to be pooled were independent. The slopes of the lines were similar and appeared to be from the same population of regressions.

The assumption of homogeneity of variances was checked by comparing the standard error of estimate for the regressions which were pooled. The standard error of estimate can be expressed mathematically as:

$$S_{y.x} = \left(\frac{E_{xx}\ E_{yy} - (E_{xy})^2}{(N-2)\ E_{xx}}\right)^{1/2}, \quad \text{where}$$

$S_{y \cdot x}$ = the standard error of estimate,

E_{xx} = intra-herd-sire sum of squares for production of dams,

E_{yy} = intra-herd-sire sum of squares for production of daughters,

E_{xy} = intra-herd-sire sum of products,

N = number of dam-daughter pairs.

The standard errors of estimate fell within narrow ranges for both milk and butterfat for all estimates of regression which were pooled. The narrow range of these standard errors indicate that the deviations of sample points from the regression lines are small for all regressions and that the variances, which are the squares of the standard errors, are essentially equal. Thus the regressions being combined appear to be homogeneous and the method of pooling should be valid.

Occasionally a dam had more than one daughter, and in many cases there was a different number of complete records available for the dam from that for the daughter (or daughters). When a dam had more than one record but only one daughter with a single lactation, the record made by the dam at the nearest age comparable to that of the daughter was used.

When a dam had only a single record but had one daughter with multiple records or more than one daughter with one or more records each, the dam's record was repeated with each record by a daughter. In most cases each repetition of the dam's record fell in a different parity grouping, making duplication of the records by the dam a valid procedure since it introduces no systematic bias into the resulting estimates. Even when the parity groups were combined the main effect of repeating records for the dam was that the actual number of degrees of freedom became smaller than it appeared.

Kempthorne and Tandon (32) considered three methods of weighting the records in a situation where some of the dams had more than one offspring. The three methods used to estimate heritability were: (a) repeat the dam's record with each daughter's record, (b) average the production for all of the daughters of the dam and regress each unweighted average on the dam's record, and (c) weight the average production for the daughters of a dam and regress each weighted average on the dam's record. The authors pointed out that (a) would be valid if the correlation among the offspring of a dam were zero, while (b) would be valid if the correlation among members of each progeny group were one. The real situation in most animal material is intermediate to these two extreme conditions, although usually nearer to the former. The weighted regression method (c) should fall somewhere between the other two estimates. From an actual sample of data the authors concluded that there was little difference between the three methods. They did note, however, that the estimate obtained from the weighted regression method was closest to the estimate resulting from repeating the record for a dam with each record by a daughter. The authors suggested that the smallness of the difference between the estimates arose because a large proportion (71 percent) of the dams had only one daughter. In the study reported here approximately 78 percent of the dams had only one daughter. If single daughters with multiple records are counted as multiple daughters then 66 percent of the dams had only one daughter.

When both the dam and daughter had multiple records, the records made at the nearest comparable ages were paired. Any excess records for a dam were discarded, while if the daughter had more records than the dam then the dam's record at the closest comparable age was repeated as above.

The 3,555 dam-daughter pairs included 1,429 pairs with single observations for dam and daughter, 468 dams with more than one daughter, each with one or more records for a total of 1,065 daughters with 1,526 records, and 259 dams with single daughters with multiple records for a total of 600 records. Thus 2,156 dams had 2,753 daughters with 3,555 completed lactations.

Genetic correlations

Observed phenotypic correlations between two characteristics x and y in the same individual may result from two kinds of causes: (a) the same or associated genes affect both traits (correlated genic effects), and/or (b) common environmental factors affect both traits. Genic values are the average effects of the genes. Thus a genetic correlation is the correlation between the genic values for two traits x and y measured in the same individual. In terms of the present study, the genetic correlations measure the extent to which the same genes affect production in the same individual during various parts of the lactation.

The formula used for estimating genetic correlations between part and whole records was:

$$r_{G_pG_w} = \left(\frac{E_{x_py_w} \quad E_{x_wy_p}}{E_{x_py_p} \quad E_{x_wy_w}}\right)^{1/2},$$

where x and y refer to production for dam and offspring, respectively, p and w refer to part and whole records, respectively, and E_{xy} denotes the sum of products within herd and sire.

The same data were used to estimate genetic correlations as were used to estimate heritabilities. Estimates of genetic correlations were made for the same six parity groups defined for estimating heritability. Genetic correlations were computed between monthly and total production and between cumulative and total production.

The small numbers of degrees of freedom associated with each parity group resulted in erratic estimates of the genetic correlations. The separate estimates were then pooled by summing the sums of products over the parity groups as described previously for heritabilities. The pooled estimate of a genetic correlation was:

$$r_{c_{G_pG_w}} = \left(\frac{\left[\sum_{i=1}^{n}\left(E_{x_py_w}\right)_i\right]\left[\sum_{i=1}^{n}\left(E_{x_wy_p}\right)_i\right]}{\left[\sum_{i=1}^{n}\left(E_{x_py_p}\right)_i\right]\left[\sum_{i=1}^{n}\left(E_{x_wy_w}\right)_i\right]}\right)^{1/2} \quad \text{(a)},$$

where $r_{c_{G_pG_w}}$ = pooled estimate of genetic correlation,

$\left(E_{xy}\right)_i$ = intra-herd-sire sum of products for the i^{th} group,

n = number of intra-herd-sire sum of products,

i denotes parity groups over which the data were pooled.

Pooled estimates of genetic correlations were obtained for first lactation for daughter irrespective of the parity of the dam, for second lactation for the daughter and second or later lactation for the dam, for second or later lactations for both daughter and dam, and then all the data were pooled to give one over-all estimate. The same assumptions of independence and homogeneity of the estimates were made for pooling of genetic correlations as for pooling heritabilities.

Even after the data were pooled, part of the sums of products were negative. Both positive and negative sums of products can be expected in the numerator of (a) but are not normally expected in the denominator. Whenever the sums of products in the numerator were of opposite sign, the arithmetic mean of the numerator was used. The formula for calculating the pooled estimate of a genetic correlation then became:

$$r_{c_{G_pG_w}} = \frac{\sum_{i=1}^{n} \left(E_{x_py_w}\right)_i + \sum_{i=1}^{n} \left(E_{x_wy_p}\right)_i}{2\left(\left[\sum_{i=1}^{n} \left(E_{x_py_p}\right)_i\right] \left[\sum_{i=1}^{n} \left(E_{x_wy_w}\right)_i\right]\right)^{1/2}} \qquad \text{(b)},$$

In a few cases the sums of products were of opposite sign in both the numerator and denominator, in which case formula (a) was used. Whenever the sums of products were of opposite sign in the denominator but not in the numerator, the arithmetic mean was used for both. Then the formula for the pooled estimate of a genetic correlation became:

$$r_{e_{G_pG_w}} = \frac{\sum_{i=1}^{n}\left(E_{x_py_w}\right)_i + \sum_{i=1}^{n}\left(E_{x_wy_p}\right)_i}{\sum_{i=1}^{n}\left(E_{x_py_p}\right)_i + \sum_{i=1}^{n}\left(E_{x_wy_w}\right)_i} \qquad (c).$$

Relative Efficiency of Selection

According to Lerner and Cruden (43), the relative efficiency of selection for a whole record by using a part record as the selection criterion is indicated by the ratio: $\frac{\Delta G_{wp}}{\Delta G_w}$, where the numerator represents genetic progress per generation in the whole record when selection is based on a part record and the denominator represents genetic progress when selection is based on the whole record. This ratio can be expressed mathematically as:

$$\frac{\Delta G_{wp}}{\Delta G_w} = \frac{r_{G_wP_p} \; h_w \; \sigma P_w \; z/v}{h_w^2 \; \sigma P_w \; z/v} \qquad (a),$$

where G and P represent genotype and phenotype, respectively, w and p refer to whole and part records, respectively, h_w^2 is the heritability for whole records and $\sigma P_w \; z/v$ is the selection differential. The same selection differential is assumed for both methods of selection to compare their relative progress; hence, equation (a) becomes $\frac{r_{G_wP_p}}{h_w}$. Since the phenotypic expression of part records P_p is a function of the genotype G_p plus an environmental contribution E_p,

$$r_{G_wP_p} = \frac{\text{Cov } G_wP_p}{\sigma G_w \ \sigma P_p} = \frac{\text{Cov } G_wG_p + \text{Cov } G_wE_p}{\sigma G_w \ \sigma P_p} \qquad \text{(b).}$$

But the expected Cov G_wE_p is zero and drops out of the numerator. Since the phenotypic variance of part records (σP_p^2) times the heritability of part records (h_p^2) is equal to the genetic variance of part records (σG_p^2), (b) can be written as

$$\frac{\text{Cov } G_wG_p \ h_p}{\sigma G_w \ \sigma P_p \ h_p} = \frac{\text{Cov } G_wG_p \ h_p}{\sigma G_w \ \sigma G_p} = r_{G_wG_p} \ h_p.$$

The ratio (a) then becomes

$$r_{G_wG_p} \ \frac{h_p}{h_w} \qquad \text{(c).}$$

Formula (c) was used to compare progress in genetic merit for complete lactations when selection was on the basis of part records with progress when selection was based on complete records. When the estimated genetic correlations were greater than one, the value one rather than the actual estimated value was used in calculating the relative efficiencies of selection.

RESULTS AND DISCUSSION

Variables Affecting Relationship of Total to Part Production

Production records of dairy cows are influenced by many environmental factors. The effects of these same variables on the relationship between total production for the lactation and production during various portions of the lactation is of primary concern in developing factors for estimating total yield for the lactation from short-time records. This part of the study was undertaken to ascertain more clearly whether age, parity, breed, and season of freshening should be taken into account in extending both milk and butterfat records, and secondly, whether the age and season groupings used in earlier studies adequately remove the effects of these variables.

Tables 1-4 present factors for four breeds for extending individual monthly tests to 305 days. Separate factors are given for extending milk and butterfat records. Each table contains factors which will adjust for age and season of freshening simultaneously and factors which will adjust for age alone. Factors which will adjust only for season of freshening can be obtained from the tables by combining the factors for a season over all ages, each one weighted according to the proportion of records in that group. The last column in each table gives the factors to be used if adjustments are not made for either age or season of freshening.

Table 1. Ratio factors for extending monthly production for Holsteins according to age and season of freshening

Milk

Test day	< 36 April -July (1,409)[a]	< 36 Aug.- March (6,102)	≥ 36 April -July (3,764)	≥ 36 Aug.- March (13,327)	< 36 (7,511)	≥ 36 (17,091)	Over-all (24,602)
1	7.81	8.51	7.14	7.67	8.38	7.55	7.81
2	7.90	8.50	7.13	7.78	8.39	7.64	7.87
3	8.73	9.03	8.01	8.45	8.97	8.35	8.54
4	9.59	9.53	9.01	9.18	9.54	9.14	9.26
5	10.32	9.96	10.06	9.83	10.03	9.88	9.93
6	10.87	10.35	11.11	10.48	10.45	10.62	10.57
7	11.38	10.67	12.28	11.16	10.80	11.41	11.22
8	11.91	11.17	13.56	12.25	11.31	12.54	12.16
9	12.90	12.22	15.69	14.58	12.35	14.82	14.07
10	15.04	14.96	21.14	21.26	14.98	21.23	19.32

Butterfat

Test day	< 36 March -June (1,060)	< 36 July- Feb. (6,451)	36-47 March -June (913)	36-47 July- Feb. (4,400)	≥ 48 March -June (2,635)	≥ 48 July- Feb. (9,143)	< 36 (7,511)	36-47 (5,313)	≥ 48 (11,778)	Over-all (24,602)
1	7.78	8.22	6.94	7.32	6.77	7.02	8.16	7.25	6.97	7.39
2	8.38	8.79	7.80	8.18	7.52	7.84	8.73	8.12	7.77	8.14
3	9.04	9.35	8.68	8.94	8.37	8.70	9.31	8.90	8.63	8.90
4	9.80	9.83	9.55	9.58	9.23	9.42	9.82	9.57	9.38	9.57
5	10.43	10.19	10.33	10.11	10.09	10.13	10.22	10.15	10.12	10.16
6	10.80	10.51	10.93	10.64	10.97	10.80	10.55	10.69	10.84	10.72
7	11.14	10.74	11.73	11.17	12.12	11.48	10.80	11.27	11.62	11.30
8	11.60	11.08	12.90	11.95	13.59	12.48	11.15	12.11	12.73	12.11
9	12.43	11.89	14.25	13.54	15.74	14.64	11.96	13.66	14.87	13.74
10	14.38	14.05	18.30	17.78	21.40	20.56	14.09	17.87	20.75	18.09

[a]Numbers of records averaged to obtain the ratio factors.

Table 2. Ratio factors for extending monthly production for Guernseys according to age and season of freshening

Milk

Test day	<36 April -July (213)[a]	<36 Aug.- March (1,036)	≥ 36 April -July (640)	≥ 36 Aug.- March (2,420)	< 36 (1,249)	≥ 36 (3,060)	Over-all (4,309)
1	7.43	8.09	6.64	7.29	7.98	7.15	7.39
2	7.55	8.33	6.79	7.57	8.20	7.41	7.64
3	8.57	9.00	7.70	8.45	8.93	8.29	8.48
4	9.57	9.64	8.96	9.36	9.63	9.28	9.38
5	10.38	10.20	10.38	10.02	10.23	10.10	10.14
6	11.52	10.54	11.82	10.74	10.71	10.97	10.89
7	12.08	11.10	13.25	11.44	11.27	11.82	11.66
8	12.56	11.41	14.89	12.69	11.61	13.15	12.70
9	13.24	12.46	16.70	15.17	12.59	15.49	14.65
10	14.62	15.16	20.51	21.53	15.07	21.32	19.51

Butterfat

Test day	< 36 March -June (206)	< 36 July- Feb. (1,043)	36-47 March -June (169)	36-47 July- Feb. (708)	≥ 48 March -June (481)	≥ 48 July- Feb. (1,702)	< 36 (1,249)	36-47 (877)	≥ 48 (2,183)	Over-all (4,309)
1	8.39	8.88	7.19	7.67	7.02	7.41	8.80	7.57	7.32	7.80
2	8.32	9.06	8.13	8.21	7.33	7.93	8.94	8.20	7.80	8.21
3	9.00	9.51	8.32	9.22	8.15	8.73	9.43	9.05	8.60	8.93
4	9.57	9.87	9.20	9.70	8.93	9.48	9.82	9.60	9.36	9.54
5	10.07	10.19	10.21	10.16	9.89	10.08	10.17	10.17	10.04	10.10
6	11.11	10.38	11.41	10.68	11.10	10.72	10.50	10.97	10.80	10.71
7	11.13	10.72	12.27	11.15	12.44	11.29	10.79	11.37	11.54	11.29
8	12.03	10.76	13.28	11.86	14.40	12.31	10.97	12.13	12.77	12.12
9	12.41	11.49	14.71	13.32	16.26	14.49	11.64	13.59	14.88	13.68
10	14.01	13.44	18.05	17.07	20.68	19.93	13.54	17.26	20.10	17.62

[a]Numbers of records averaged to obtain the ratio factors.

Table 3. Ratio factors for extending monthly production for Jerseys according to age and season of freshening

Milk

Test day	< 36 April -July (100)[a]	< 36 Aug. - March (488)	≥ 36 April -July (276)	≥ 36 Aug. - March (1,014)	< 36 (588)	≥ 36 (1,290)	Over-all (1,878)
1	7.27	7.95	6.60	7.24	7.83	7.11	7.33
2	7.26	8.18	6.73	7.56	8.02	7.39	7.59
3	8.12	8.99	7.63	8.48	8.84	8.30	8.46
4	9.43	9.74	9.15	9.44	9.69	9.38	9.48
5	10.60	10.26	10.50	10.31	10.32	10.35	10.34
6	11.55	10.87	11.84	10.88	10.99	11.08	11.05
7	12.52	11.15	13.52	11.44	11.38	11.88	11.72
8	12.94	11.53	15.04	12.65	11.77	13.15	12.72
9	14.07	12.75	17.07	14.73	12.97	15.22	14.52
10	15.51	15.62	19.90	21.23	15.60	20.95	19.28

Butterfat

Test day	< 36 March -June (82)	< 36 July- Feb. (506)	36-47 March -June (67)	36-47 July- Feb. (306)	≥ 48 March -June (184)	≥ 48 July- Feb. (733)	< 36 (588)	36-47 (373)	≥ 48 (917)	Over-all (1,878)
1	8.29	8.74	7.00	7.60	7.30	7.50	8.68	7.49	7.46	7.85
2	8.21	8.77	7.53	8.02	7.66	7.80	8.69	7.93	7.77	8.09
3	8.72	9.22	8.12	8.76	8.26	8.58	9.15	8.64	8.51	8.74
4	9.61	9.75	9.77	9.55	8.96	9.41	9.73	9.59	9.32	9.50
5	10.06	10.02	10.45	10.18	9.86	10.23	10.03	10.23	10.16	10.13
6	10.52	10.51	10.95	10.73	11.05	10.83	10.51	10.77	10.88	10.74
7	11.39	10.78	12.42	11.19	11.94	11.44	10.87	11.41	11.54	11.31
8	12.14	11.10	13.43	12.35	13.63	12.45	11.24	12.55	12.69	12.21
9	12.71	12.03	15.16	13.55	16.06	14.44	12.13	13.84	14.77	13.75
10	14.29	14.48	18.69	19.44	19.32	19.64	14.45	19.30	19.57	17.92

[a]Numbers of records averaged to obtain the ratio factors.

Table 4. Ratio factors for extending monthly production for Brown Swiss according to age and season of freshening

Milk

Test day	< 36 April -July (49)[a]	< 36 Aug.- March (160)	≥ 36 April -July (233)	≥ 36 Aug.- March (450)	< 36 (209)	≥ 36 (683)	Over-all (892)
1	8.59	8.65	7.55	8.08	8.64	7.90	8.07
2	8.38	8.73	7.46	8.22	8.64	7.96	8.12
3	8.49	9.31	8.01	8.74	9.12	8.49	8.63
4	9.35	9.58	8.97	9.31	9.53	9.19	9.27
5	10.25	9.81	9.81	9.92	9.91	9.88	9.89
6	11.21	10.32	10.94	10.29	10.53	10.51	10.51
7	11.82	10.61	12.14	10.89	10.89	11.32	11.22
8	12.05	10.97	13.27	11.78	11.22	12.29	12.04
9	12.59	12.05	15.28	13.59	12.18	14.16	13.70
10	16.07	14.27	19.15	19.09	14.69	19.11	18.07

Butterfat

Test day	< 36 March -June (43)	< 36 July- Feb. (166)	36-47 March -June (44)	36-47 July- Feb. (110)	≥ 48 March -June (192)	≥ 48 July- Feb. (337)	< 36 (209)	36-47 (154)	≥ 48 (529)	Over-all (892)
1	9.19	8.82	8.05	7.97	7.55	7.77	8.90	8.00	7.69	8.02
2	9.11	9.16	8.62	8.76	7.70	8.37	9.15	8.72	8.13	8.47
3	8.92	9.62	8.66	9.25	8.33	8.96	9.48	9.08	8.73	8.97
4	9.72	9.79	9.61	9.58	9.30	9.46	9.78	9.59	9.40	9.52
5	10.19	9.85	10.21	10.28	9.94	9.97	9.92	10.26	9.96	10.00
6	10.72	10.32	10.55	10.38	10.72	10.62	10.40	10.43	10.65	10.56
7	10.89	10.58	11.21	10.95	11.76	10.99	10.64	11.03	11.27	11.08
8	11.44	10.66	11.96	11.36	13.09	11.70	10.82	11.53	12.20	11.76
9	12.18	11.47	13.05	12.53	14.84	13.31	11.62	12.68	13.86	13.13
10	15.18	12.74	17.04	14.97	18.80	17.96	13.24	15.56	18.26	16.62

[a]Numbers of records averaged to obtain the ratio factors.

Ratio factors for extending cumulative test-day production based on breed, age, and season of freshening are presented in tables 5-8. Separate factors are given for extending milk and butterfat records. The factors differ from those in earlier tables only in that they are calculated so as to extend cumulative test-day production rather than production from a single test day.

Age and parity

The factors for monthly production were larger for young cows than for older cows during the early months of the lactation but smaller during the later months of the lactation. This indicates that first-calf heifers do not produce as large a proportion of their total production for the lactation during the early months as do older cows, nor do they decline in production as rapidly during the last months of the lactation; i.e., the lactation curve is flatter for young cows than for older cows. This observation is in agreement with other reports (8, 9, 13, 23, 34, 37, 38, 44, 45, 46, 61, 71). Although the change in the shape of the lactation curve from younger to older ages was in general quite gradual, a distinct change in the factors for cumulative production occurred between 35 and 36 months of age for both milk and butterfat, and between 47 and 49 months for butterfat only. These are the ages roughly coinciding with the break between first and second lactations and between second and third lactations, respectively (13, 46).

The data were grouped into broader age classes and factors computed for ages less than 36 months, 36 to 47 months, 48 to 59 months, and 60 months and over. Factors for ages less than 36 months were distinctly

Table 5. Ratio factors for extending cumulative production for Holsteins according to age and season of freshening

Milk

Test day	< 36 April -July (1,409)[a]	< 36 Aug.-March (6,102)	≥ 36 April -July (3,764)	≥ 36 Aug.-March (13,327)	< 36 (7,511)	≥ 36 (17,091)	Over-all (24,602)
1	7.81	8.51	7.14	7.67	8.38	7.55	7.81
2	3.93	4.25	3.56	3.86	4.19	3.79	3.92
3	2.71	2.89	2.47	2.65	2.86	2.61	2.69
4	2.11	2.22	1.94	2.06	2.20	2.03	2.08
5	1.75	1.81	1.62	1.70	1.80	1.68	1.72
6	1.51	1.54	1.42	1.47	1.53	1.46	1.48
7	1.33	1.35	1.27	1.30	1.35	1.29	1.31
8	1.20	1.20	1.16	1.17	1.20	1.17	1.18
9	1.10	1.10	1.08	1.08	1.10	1.08	1.09

Butterfat

Test day	< 36 March -June (1,060)	< 36 July-Feb. (6,451)	36-47 March -June (913)	36-47 July-Feb. (4,400)	≥ 48 March -June (2,635)	≥ 48 July-Feb. (9,143)	< 36 (7,511)	36-47 (5,313)	≥48 (11,778)	Over-all (24,602)
1	7.78	8.22	6.94	7.32	6.77	7.02	8.16	7.26	6.97	7.39
2	4.04	4.25	3.67	3.86	3.56	3.70	4.22	3.83	3.67	3.87
3	2.79	2.92	2.58	2.70	2.50	2.60	2.90	2.68	2.58	2.70
4	2.17	2.25	2.03	2.10	1.97	2.04	2.24	2.09	2.02	2.10
5	1.80	1.84	1.70	1.74	1.65	1.70	1.83	1.73	1.69	1.74
6	1.54	1.57	1.47	1.50	1.43	1.47	1.57	1.49	1.46	1.49
7	1.35	1.37	1.31	1.32	1.28	1.30	1.37	1.32	1.30	1.32
8	1.21	1.22	1.19	1.19	1.17	1.18	1.22	1.19	1.18	1.19
9	1.10	1.11	1.09	1.09	1.09	1.09	1.11	1.09	1.09	1.09

[a]Numbers of records averaged to obtain the ratio factors.

Table 6. Ratio factors for extending cumulative production for Guernseys according to age and season of freshening

Milk

Test day	< 36 April–July (213)[a]	< 36 Aug.–March (1,036)	≥ 36 April–July (640)	≥ 36 Aug.–March (2,420)	< 36 (1,249)	≥ 36 (3,060)	Over-all (4,309)
1	7.43	8.09	6.64	7.29	7.98	7.15	7.39
2	3.74	4.11	3.36	3.71	4.05	3.64	3.75
3	2.61	2.82	2.34	2.58	2.78	2.53	2.60
4	2.05	2.18	1.86	2.02	2.16	1.99	2.03
5	1.71	1.80	1.58	1.68	1.78	1.66	1.70
6	1.49	1.54	1.39	1.46	1.53	1.45	1.46
7	1.33	1.35	1.26	1.29	1.35	1.28	1.30
8	1.20	1.21	1.16	1.17	1.21	1.17	1.18
9	1.10	1.10	1.08	1.09	1.10	1.09	1.09

Butterfat

Test day	< 36 March–June (206)	< 36 July–Feb. (1,043)	36–47 March–June (169)	36–47 July–Feb. (708)	≥ 48 March–June (481)	≥ 48 July–Feb. (1,702)	< 36 (1,249)	36–47 (877)	≥ 48 (2,183)	Over-all (4,309)
1	8.39	8.88	7.19	7.67	7.02	7.41	8.80	7.58	7.32	7.81
2	4.18	4.48	3.82	3.97	3.59	3.83	4.43	3.94	3.78	4.00
3	2.85	3.05	2.62	2.98	2.49	2.66	3.02	2.91	2.62	2.76
4	2.20	2.33	2.04	2.28	1.95	2.08	2.31	2.23	2.05	2.13
5	1.80	1.90	1.70	1.86	1.63	1.72	1.88	1.83	1.70	1.76
6	1.55	1.60	1.48	1.59	1.42	1.48	1.59	1.57	1.47	1.51
7	1.36	1.39	1.32	1.39	1.27	1.31	1.39	1.38	1.30	1.33
8	1.22	1.23	1.20	1.24	1.17	1.19	1.23	1.24	1.19	1.20
9	1.11	1.11	1.11	1.14	1.09	1.10	1.11	1.14	1.10	1.11

[a] Numbers of records averaged to obtain the ratio factors.

Table 7. Ratio factors for extending cumulative production for Jerseys according to age and season of freshening

Milk

Test day	< 36 April -July (100)[a]	< 36 Aug.- March (488)	≥ 36 April -July (276)	≥ 36 Aug.- March (1,014)	< 36 (588)	≥ 36 (1,290)	Over-all (1,878)
1	7.27	7.95	6.60	7.24	7.83	7.11	7.33
2	3.63	4.03	3.33	3.70	3.96	3.62	3.73
3	2.51	2.78	2.31	2.58	2.73	2.52	2.59
4	1.98	2.16	1.85	2.02	2.13	1.98	2.03
5	1.67	1.79	1.57	1.69	1.77	1.66	1.70
6	1.46	1.54	1.39	1.46	1.53	1.44	1.47
7	1.31	1.35	1.26	1.29	1.34	1.28	1.30
8	1.19	1.21	1.16	1.17	1.21	1.17	1.18
9	1.09	1.10	1.09	1.09	1.10	1.09	1.09

Butterfat

Test day	< 36 March -June (82)	< 36 July- Feb. (506)	36-47 March -June (67)	36-47 July- Feb. (306)	≥ 48 March -June (184)	≥ 48 July- Feb. (733)	< 36 (588)	36-47 (373)	≥ 48 (917)	Over-all (1,878)
1	8.29	8.74	7.00	7.60	7.30	7.50	8.68	7.49	7.46	7.85
2	4.13	4.38	3.63	3.90	3.74	3.82	4.34	3.85	3.80	3.98
3	2.80	2.97	2.51	2.70	2.57	2.64	2.95	2.67	2.63	2.73
4	2.17	2.28	1.99	2.10	2.00	2.06	2.26	2.08	2.05	2.12
5	1.78	1.85	1.68	1.74	1.66	1.72	1.84	1.73	1.71	1.75
6	1.53	1.58	1.45	1.50	1.44	1.48	1.57	1.49	1.47	1.50
7	1.34	1.38	1.30	1.32	1.29	1.31	1.37	1.32	1.31	1.32
8	1.21	1.22	1.19	1.19	1.18	1.19	1.22	1.19	1.19	1.19
9	1.11	1.11	1.10	1.10	1.10	1.10	1.11	1.10	1.10	1.10

[a] Numbers of records averaged to obtain the ratio factors.

Table 8. Ratio factors for extending cumulative production for Brown Swiss according to age and season of freshening

Milk

Test day	< 36 April -July (49)[a]	< 36 Aug.- March (160)	≥ 36 April -July (233)	≥ 36 Aug.- March (450)	< 36 (209)	≥ 36 (683)	Over-all (892)
1	8.59	8.65	7.55	8.08	8.64	7.90	8.07
2	4.24	4.34	3.75	4.07	4.32	3.96	4.05
3	2.83	2.96	2.55	2.78	2.93	2.70	2.76
4	2.17	2.26	1.99	2.14	2.24	2.09	2.12
5	1.79	1.84	1.65	1.76	1.83	1.72	1.75
6	1.54	1.56	1.44	1.50	1.56	1.48	1.49
7	1.37	1.36	1.29	1.32	1.36	1.31	1.32
8	1.23	1.21	1.17	1.18	1.21	1.18	1.19
9	1.12	1.10	1.09	1.09	1.10	1.09	1.09

Butterfat

Test day	< 36 March -June (43)	< 36 July- Feb. (166)	36-47 March -June (44)	36-47 July- Feb. (110)	≥ 48 March -June (192)	≥ 48 July- Feb. (337)	< 36 (209)	36-47 (154)	≥ 48 (529)	Over-all (892)
1	9.19	8.82	8.05	7.97	7.55	7.77	8.90	7.99	7.69	8.02
2	4.57	4.49	4.16	4.17	3.81	4.03	4.51	4.17	3.95	4.11
3	3.02	3.06	2.81	2.88	2.62	2.78	3.05	2.86	2.72	2.82
4	2.31	2.33	2.17	2.21	2.04	2.15	2.33	2.20	2.11	2.17
5	1.88	1.89	1.79	1.82	1.69	1.77	1.89	1.81	1.74	1.79
6	1.60	1.59	1.53	1.55	1.46	1.52	1.59	1.54	1.50	1.53
7	1.40	1.39	1.35	1.36	1.30	1.33	1.39	1.36	1.32	1.34
8	1.24	1.23	1.21	1.21	1.18	1.20	1.23	1.21	1.19	1.20
9	1.13	1.11	1.11	1.11	1.10	1.10	1.11	1.11	1.10	1.10

[a]Numbers of records averaged to obtain the ratio factors.

different from all older ages for both milk and butterfat. Factors for ages 36 to 47 months differed from those for older ages for butterfat but not for milk; while for both milk and butterfat all ages above 47 months were similar enough to be combined into one age grouping. Thus, it appears that only two age groupings are necessary in extending milk records, whereas three age groupings appear useful for butterfat.

Whether the use of a different number of age groupings for butterfat and milk is justified will depend somewhat on personal preference, on the mechanics of handling the extension of the records, and on the degree of precision desired. Three age groupings for butterfat are expected to give more precise estimates of extended production than are two, but extra time and effort are involved in computing them. However, the rapid advances now being made in machine processing of records makes it appear probable that this problem will largely be eliminated and three age groupings for butterfat will be justified.

The factors for the first lactation were distinctly different from those for the second or later lactations for both milk and butterfat for all four breeds. Those for second lactations for both milk and butterfat were so similar to to those for lactations three and above that the data for second lactations were incorporated with data for later records and one set of combined factors obtained.

The ratio factors for all four breeds indicate that the shape of the lactation curve for milk does not change much after 36 months of age, while the lactation curve for butterfat is flatter for cows 36-47 months of age than for older cows. Although 36-47 months is the approximate age for second lactations, the factors did not indicate any appreciable difference in the shape of the lactation curve between second and later lactations. This suggests that the difference in the shape of the butterfat curve for cows 36-47 months of age as compared to older cows is strictly an age effect and not due to parity; whereas, the difference in the shape of the lactation curve for cows less than 36 months as compared to that for older cows appears to be an effect of both age and parity.

Since ages and parities almost coincide within the limits used here and, in general, have the same effect, it seems necessary for only one of these variables to be taken into account in extending records. The choice of which to use is the same for both milk and butterfat and is similar to that reported for milk in an earlier study (38). From a practical standpoint, extension factors based on age should be used to extend first lactation records initiated after 36 months of age, since factors based on parity will overestimate production and favor an undesirable managemental situation. Factors for ages should also be used to extend second lactation records started prior to 36 months, since using factors for parity in this case will underestimate production and penalize a desirable breeding practice. The remaining 90 percent of the time either age or parity factors will work equally well. However, parity is less frequently reported than is age, and all incomplete records can be extended by factors for age irrespective of lactation number while factors for parity also should consider age 10 percent of the time. In addition, if three sets of factors are deemed preferable for extending butterfat records, then thes

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these must be based upon age rather than parity. In view of these considerations, factors based on age are preferable to factors based on parity for extending incomplete records, and factors based on parity have not been included in the tables.

If the age of a cow is not known but the lactation number is, the age factors for less than 36 months should be used for first lactations, the factors for 36-47 months used for second lactations for butterfat, and the remaining factors used for all later lactations.

The difference between the ratio factors for cumulative production for cows under 36 months and those for older cows indicates the importance of adjusting for age in extending part records. The factors for older cows underestimate the production for young cows. Based on what the total estimate should be for cows under 36 months, this underestimate for milk production amounts to approximately 10 percent for the first three cumulative months, gradually declining to 1 to 2 percent for 9 cumulative months. The difference is even larger for butterfat production, being about 10 percent for the first 3 cumulative months if the factors for 36-47 months are used to extend records for cows under 36 months of age and as high as 17 percent for the first month and remaining over 10 percent for the first four cumulative months if the factors for ages 48 months and older are used. Again the difference gradually declines to 1 to 2 percent by the end of 9 cumulative months.

If the over-all factors are used to extend part records, records for older cows will be overestimated while those for younger cows will be underestimated. Based on what the total estimate should be for cows under 36 months,

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months, the use of over-all factors will underestimate milk production for two-year-old cows as much as 6 to 7 percent and butterfat production as much as 9 to 11 percent when estimated from only one or two cumulative months. The error introduced by estimating with one over-all set of factors is smaller for older cows since the number of cows over 36 months of age is more than double that of the younger cows and the over-all factors are more nearly the same as those for older cows.

The factors adjusting for age in extending cumulative production of milk are almost identical to the factors reported earlier by Lamb (37) and Lamb and McGilliard (38) from a smaller sample of data. The factors adjusting for age in extending cumulative production for Holsteins are also very similar to factors obtained by Madden et al. (46) from Holstein HIR data.

Season of freshening

The calender months in which the lactations were initiated were grouped together in all possible combinations of three, four, or six adjacent months to find the seasons of freshening with the largest differences between their respective ratio factors. Adjustment for season of freshening on the basis of this grouping should remove more of the variation in factors due to season of freshening than adjustment based on any other grouping. A four and eight month system of grouping showed a larger difference for both milk and butterfat for all breeds than did any combination of two six-month groupings, three four-month groupings, or four three-month groupings. However, the best season grouping for the two measures of production differed, with April to

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July and August to March being the best grouping for milk and March to June and July to February being optimum for butterfat.

This system of grouping for month of freshening differs from that used by other workers inasmuch as in most of the earlier studies months were either arbitrarily grouped into quarters according to the calendar, into seasons according to feeding practices, or into season which had been shown to have the most influence on total production. However, the conclusion reached here that season of freshening does influence the relationship of total to part production as shown by the large differences between factors for the different seasons and that adjustment should be made for season of freshening in extending part records is in agreement with other studies (10, 11, 34, 37, 38, 39, 61, 71).

Groupings for season of freshening found to be optimum in this study may not be optimum for all areas of the nation. Since climatic seasons do vary from one part of the country to another, factors adjusting for season of freshening may be needed for each different area of the country. These data indicate that season of freshening should be considered in extending part records under conditions prevalent in Michigan. The factors presented in tables 1-8 take these conditions into account.

As far as can be ascertained, there are no other reports indicating that the season in which a cow freshens has a different effect on the relationship between total and part production for milk from what it does for butterfat. Previous studies of the influence of season of freshening on the relationship of total to part production have used the same seasonal grouping for butterfat

as for milk and have not been concerned as to whether the same grouping for seasons might not apply to both measures of production.

The choice of whether to use separate seasonal groupings for milk and butterfat must be made on an individual basis. The use of separate groupings will increase the accuracy of the extended records but may also make their extending more complicated. However, the increasingly widespread use of machine processing of records makes it appear feasible that separate groupings for seasons for milk and butterfat will not present any major problem. In case the decision is to use the same grouping for milk and butterfat, the grouping for milk (April to July and August to March) is best. This will not remove as much of the seasonal effect from the extended butterfat records as will the optimum grouping, but it will remove more than will the use of the grouping for butterfat (March to June and July to February) on milk records.

The factors for monthly production for both milk and butterfat are, in general, larger for the eight-month fall and winter season than for the four-month spring and summer season for the first four months of the lactation but are smaller during the remaining months of the lactation. In other words, the lactation curve is flatter for cows freshening during the fall and winter months.

It is quite common that because of less competition from other farm chores, better management is provided for cows freshening during the fall and early winter months. In addition, these same cows often get a boost in production from early spring pastures during the latter part of their lactation when production normally drops more rapidly. On the other hand, cows freshening during the spring and early summer months do not receive as much of a boost in production from spring pasture; and then just when they need additional feed to maintain a high level of production, the pastures hit a late summer slump and production drops rather drastically. Other factors, such as temperature and humidity, probably play an important role also in affecting the shape of the lactation curve of cows freshening during different seasons of the year.

The ratio factors for cumulative production for both milk and butterfat are larger for records initiated during the fall and winter months than for those started in the spring and summer season. The difference is largest for the first month where the factors for fall and winter months are approximately 8 percent larger for milk and 5 percent larger for butterfat than those for spring and summer months. This difference declines rapidly until it is almost negligible by the eighth cumulative month.

Adjusting for season of freshening does not appear as important as adjusting for age at freshening because the difference between seasons is not as large as the difference between ages. However, accounting for season of calving does have practical importance. Since it is practically as easy to adjust for both age and season simultaneously as for age alone by using the factors presented in tables 1-8, it is recommended that both be adjusted for in extending part records.

Breed

Factors for both cumulative and monthly production differ between breeds. Holstein and Brown Swiss factors for milk tend to be alike, while Guernsey factors resemble Jersey factors even more closely. The Guernsey and Jersey factors for cumulative production of butterfat are very similar to each other and fall approximately midway between those for Holsteins and Brown Swiss, which differ widely. Except for the first month, the Holstein factors for monthly production of butterfat are very similar to the factors for Guernseys and Jerseys, while the factors for Brown Swiss are larger during the early months and smaller during the latter months of the lactation than those for the other three breeds. Thus, both Holstein and Brown Swiss factors show a tendency for a flatter lactation curve for milk, but only the Brown Swiss factors show this tendency for butterfat. Apparently the butterfat test increases more rapidly towards the end of the lactation for Brown Swiss than for the other three breeds.

Because of this flatter lactation curve, Brown Swiss factors for both milk and butterfat, if applied to cumulative production for any of the other breeds, will overestimate 305-day production. Holstein factors will overestimate cumulative Guernsey and Jersey milk production but underestimate cumulative Guernsey and Jersey butterfat production. Guernsey factors for both milk and butterfat will overestimate Jersey production for younger cows but underestimate it for older cows. However, the difference between Guernsey and Jersey factors is so slight as to make little practical difference between the two in actual use. The overestimates in all cases are larger during early lactation, decrease as production for each succeeding month is added to the cumulative total and become almost negligible after the eighth cumulative month.

A comparison of the ratio factors indicates a definite difference between factors for extending milk records and those for extending butterfat production for at least the first eight cumulative months. Except for the first month for Brown Swiss and the first two months for Holsteins, the ratio factors for cumulative production of butterfat will overestimate milk production for the lactation in all breeds. These overestimates are larger for Guernseys and Jerseys than for Holsteins or Brown Swiss. Milk production for the lactation will be overestimated by factors for non-cumulative production of butterfat for the first five months but underestimated when extended by factors for butterfat for the last five months. The shape of the lactation curve for butterfat is flatter than the shape of the curve for milk production; hence, separate factors should be used for extending milk and butterfat records to estimate more accurately 305-day yield.

In view of the results obtained, breed, age, and season of freshening influence the relationship between total and part production and should be adjusted for in extending part records to a 305-day basis. Furthermore, separate factors should be used for extending milk and butterfat records. In order to remove adequately the effects of age from the extending of the records, separate factors are needed for milk records initiated before 36 months of age and for those started at 36 months or older, while separate sets of factors are needed to extend butterfat records started at less than 36 months, 36 to 47 months, and 48 months or older. Season of freshening can be adjusted for by extending records started during a four month spring and summer period separately from the other eight months.

Phenotypic Correlations

Phenotypic correlations between segments of lactations are useful to give an indication of the probable accuracy with which a part record can be extended to completion.

A phenotypic correlation between the total and a part of the same record or between a part of one lactation and the total of a succeeding lactation can result from either environmental or genetic causes or a combination of both. If both the environmental and the genetic correlations between a total and a part record are positive and the correlation between the genes and the environment is positive, the resulting phenotypic correlation should also be positive and fairly large. If both the environmental and genetic correlations are negative and the correlation between the genes and the environment is positive, the resulting phenotypic correlation should be negative and fairly large. If both the environmental and the genetic correlations are of the same sign but the correlation between the genes and the environment is negative, the resulting phenotypic correlation may be either positive or negative but should be close to zero. If the environmental and genetic correlations are of opposite sign or if one or both of them are zero, the resulting phenotypic correlation should be close to zero.

A small phenotypic correlation between the total and a part of the same record would indicate little or no value to extending part records. The larger the correlation is, the greater the expected accuracy with which a part record could be extended to full length. The phenotypic correlation reflects the frequency with which individual estimates may be expected to deviate in various amounts from the actual record.

Although a large positive phenotypic correlation between part and total may indicate a large degree of accuracy for extending records, the genetic progress in total production to be achieved from selection based on part records is dependent upon the genetic correlation between the two traits. Although the phenotypic correlations may indicate that estimates of total production made from cumulative production for 6 or 7 months are accurate enough for all practical purposes, they do not indicate what effect the use of such an estimate may have on genetic progress. Genetic correlations and the relative efficiency of selection will be discussed in subsequent sections.

Phenotypic correlations between production for a single month and total production for the same lactation are shown in table 9, while those between production for cumulative months and total production for the same lactation are given in table 10.

The phenotypic correlations between monthly production and total yield are largest for the fifth month followed closely by the fourth and sixth months. For cows in their first lactation, production for the third month is almost as closely correlated with total production as is production for the fourth or sixth months, while for older cows the seventh month is the next most

Table 9. Phenotypic correlations between monthly production and total production for the same lactation for Holsteins

Milk

Lactation number	D F	Month of lactation 1	2	3	4	5	6	7	8	9	10
1	1,628	.68	.80	.84	.86	.86	.85	.83	.77	.73	.60
2	2,311	.62	.76	.79	.83	.85	.85	.83	.80	.71	.55
3[a]	5,737	.54	.71	.78	.81	.84	.83	.82	.77	.69	.54

Butterfat

Lactation number	D F	Month of lactation 1	2	3	4	5	6	7	8	9	10
1	1,628	.71	.75	.81	.83	.82	.80	.78	.73	.70	.56
2	2,311	.62	.71	.75	.80	.81	.81	.79	.76	.68	.56
3[a]	5,737	.61	.70	.75	.77	.78	.80	.79	.75	.70	.57

[a]Third or later lactation.

Table 10. Phenotypic correlations between cumulative production and total production for the same lactation for Holsteins

Milk

Lactation number	D F	Number of cumulative months 1	2	3	4	5	6	7	8	9
1	1,628	.68	.81	.87	.91	.93	.95	.97	.98	.99
2	2,311	.62	.76	.83	.87	.91	.93	.96	.98	.99
3[a]	5,737	.54	.70	.79	.84	.89	.92	.95	.97	.99

Butterfat

Lactation number	D F	Number of cumulative months 1	2	3	4	5	6	7	8	9
1	1,628	.71	.81	.86	.90	.93	.95	.97	.98	.99
2	2,311	.62	.74	.81	.86	.90	.93	.95	.97	.99
3[a]	5,737	.61	.74	.82	.86	.90	.93	.96	.98	.99

[a]Third or later lactation.

accurate predictor of total yield for the lactation.

The difference between first calf heifers and mature cows suggests that the condition of the older cows at the time of freshening may influence the early months of the lactation in ways that do not carry through for the complete lactation, thereby reducing the value of early months for estimating total yield for the lactation. On the other hand, early production of first calf heifers may not be as easily influenced by conditioning prior to freshening or condition prior to freshening may affect the entire record. In all cases the correlations between the first and last months and total yield are the lowest, indicating that these months are more subject to temporary influences than are the center months of the lactation.

The correlations between monthly production and total production for the same lactation are larger for first lactations than for later lactations indicating that yield for the first lactation can be more accurately estimated from a single test than can production for later lactations. Correlations for second lactations are also larger than those for third and later making second lactations next best in accuracy of estimating from a single test. These results suggest that mature cows may be more susceptible to temporary environmental influences which affect some parts of the lactation but not other parts of the whole lactation than are younger cows, particularly those in their first lactation. It is also possible that different genes may be affecting production at different ages and that the genes operating at younger ages have more of an influence on both the part and the total record than do the genes operating in mature cows. The same effect could also be obtained by an increase in the variation between records as the age increased, with no change in either the genetic or the environmental influence on the relationship between total and part records.

The correlations between monthly production and total yield are slightly larger for milk than for butterfat; thus, extended milk records should be slightly more accurate measures of the actual records than extended butterfat records.

The phenotypic correlations between cumulative and total production increase rapidly until the fifth or sixth month and then more slowly until the end of the lactation. The biggest increase in accuracy of predicting total records from cumulative production comes with the addition of the second month. Correlations reach .90 by the fourth month for first lactation, by the fifth month for second lactations, and by the sixth month for third and later records. They are .95 by the sixth month for first records and by the seventh month for later records, and reach .99 by the ninth month for all records.

The results of this study are in agreement with those of Kennedy and Seath (36) that cumulative production for the first four months is at least as valuable as any single month for predicting total production for the lactation. For all practical purposes, total yield for the lactation can be estimated accurately enough from cumulative production for 6 or 7 months to make waiting for the ten-month total needless.

The magnitude of the phenotypic correlations between monthly and total production and between cumulative and total production, and the months which are the most accurate for extending part records are in agreement with the results of other investigations (5, 13, 23, 31, 46, 54, 56, 59, 62, 69, 73).

The phenotypic correlations between monthly production for a given lactation and total production for succeeding adjacent and non-adjacent lactations and between cumulative production for a given lactation and total production for succeeding adjacent and non-adjacent lactations are reported in tables 11-14.

These correlations are of interest in that they give an indication as to what degree of accuracy may be expected on the average in predicting the total of a future record of a cow from a monthly or cumulative part of a present record by the same cow. As would be expected, the accuracy of a part record in predicting a future record is much less than for predicting the total of the current record. Correlations between monthly production and total production for the same lactation reach .86, whereas the highest correlation between monthly production and total produced for a succeeding lactation is .54 for adjacent and .51 for non-adjacent lactations. For cumulative production the correlations reach .99 for the same lactation but only .56 and .53 for succeeding adjacent and non-adjacent records, respectively.

The phenotypic correlations between monthly production in one lactation and total production for a succeeding lactation are small for the first month, increase steadily to the seventh month, and decline rapidly to the tenth month. The correlations are slightly larger for milk than for butterfat. In general,

Table 11. Phenotypic correlations between monthly production and total production for the succeeding adjacent lactation for Holsteins

Milk

Lactation number[a]	D F	Month of lactation 1	2	3	4	5	6	7	8	9	10
1	1,246	.35	.40	.43	.46	.46	.48	.50	.45	.42	.31
2	955	.27	.35	.38	.45	.50	.51	.54	.54	.45	.33
3[b]	1,956	.26	.31	.37	.41	.44	.42	.45	.42	.37	.27

Butterfat

Lactation number[a]	D F	Month of lactation 1	2	3	4	5	6	7	8	9	10
1	1,246	.29	.31	.38	.41	.38	.41	.42	.39	.37	.26
2	955	.22	.30	.35	.44	.45	.45	.50	.48	.38	.33
3[b]	1,956	.22	.26	.32	.34	.36	.36	.41	.38	.36	.29

[a]Refers to the first recorded lactation of a pair of adjacent lactations.

[b]Third or later lactation.

Table 12. Phenotypic correlations between monthly production and total production for a succeeding non-adjacent lactation for Holsteins

Milk

Lactation number[a]	D F	Month of lactation 1	2	3	4	5	6	7	8	9	10
1	382	.28	.31	.40	.39	.34	.42	.42	.38	.30	.25
2	110	.35	.36	.40	.45	.47	.48	.51	.46	.34	.25
3[b]	189	.16	.25	.27	.33	.39	.38	.41	.33	.23	.15

Butterfat

Lactation number[a]	D F	Month of lactation 1	2	3	4	5	6	7	8	9	10
1	382	.23	.35	.35	.37	.26	.33	.30	.30	.25	.17
2	110	.42	.41	.40	.46	.42	.39	.47	.43	.32	.24
3[b]	189	.21	.17	.24	.35	.38	.36	.39	.38	.33	.27

[a]Refers to the first recorded lactation of a pair of non-adjacent lactations.

[b]Third or later lactation.

Table 13. Phenotypic correlations between cumulative production and total production for the succeeding adjacent lactation for Holsteins

Milk

Lactation number[a]	D F	Number of cumulative months 1	2	3	4	5	6	7	8	9
1	1,246	.35	.41	.44	.47	.48	.50	.52	.53	.54
2	955	.27	.34	.38	.42	.46	.49	.51	.54	.56
3[b]	1,956	.26	.31	.36	.40	.43	.45	.47	.49	.50

Butterfat

Lactation number[a]	D F	Number of cumulative months 1	2	3	4	5	6	7	8	9
1	1,246	.29	.34	.37	.40	.42	.43	.45	.46	.47
2	955	.22	.29	.33	.38	.42	.45	.48	.50	.51
3[b]	1,956	.22	.27	.31	.35	.37	.39	.41	.43	.44

[a]Refers to the first recorded lactation of a pair of adjacent lactations.

[b]Third or later lactation.

Table 14. Phenotypic correlations between cumulative production and total production for a succeeding non-adjacent lactation for Holsteins

Milk

Lactation number[a]	D F	Number of cumulative months 1	2	3	4	5	6	7	8	9
1	382	.28	.32	.37	.40	.40	.42	.44	.44	.45
2	110	.35	.39	.41	.44	.46	.48	.50	.51	.53
3[b]	189	.16	.23	.27	.30	.34	.37	.40	.42	.42

Butterfat

Lactation number[a]	D F	Number of cumulative months 1	2	3	4	5	6	7	8	9
1	382	.23	.31	.35	.37	.37	.37	.38	.39	.40
2	110	.42	.46	.47	.49	.50	.50	.51	.52	.53
3[b]	189	.21	.22	.27	.31	.34	.36	.39	.41	.42

[a]Refers to the first recorded lactation of a pair of non-adjacent lactations.

[b]Third or later lactation.

the correlations are largest between parts of a second lactation and a complete later lactation and lowest between a part of a mature lactation and the total of a later mature record. Thus, prediction of a complete future record from a single month is best made during the second lactation, with the first lactation being next best in predictive value. The best single month for making an estimate of future complete records is the seventh, followed by the sixth, fifth, and eighth month, with the first and last months being the poorest months for estimating future production. Except for the first four months of the second lactation the correlations between a monthly record and an adjacent complete record were larger than those involving a non-adjacent complete record. This is to be expected since environmental correlations are likely to become smaller with an increase in the time interval between records.

The phenotypic correlations between cumulative production in one lactation and total production for a succeeding lactation increase rapidly up to the fourth cumulative month for the first lactation and the seventh cumulative month for later lactations, after which the increase is much slower.

A cumulative record needs to be at least five months in length in order to estimate a complete succeeding record at least as accurately as can the best monthly estimate. In general, the second lactation gives the most accuracy in estimating the total yield of a succeeding lactation from a cumulative part record, while the least accuracy is attained from a third or later record.

Genetic Parameters

Repeatability

The repeatability of milk or butterfat records measures the tendency for cows to produce as much above or below the average of the herd in subsequent lactations as they did in current lactations. Thus, repeatability can be used to estimate the probable producing ability of the cow. The fraction $\frac{nr}{1 + (n - 1)r}$, where n is the number of records by the cow and r is the repeatability of single records, represents the confidence to be placed in the superiority or inferiority of the cow's own production as compared to the herd average. With perfect repeatability this fraction becomes 1.0 and a single record is accepted as a perfect indication of a cow's ability to produce.

The repeatability of monthly or cumulative production measures the tendency for cows to produce as much above or below the average of the herd for the same period of subsequent lactations as they did in current lactations.

The variation due to differences which occur between herds, between age-herd groups, and between age-season-herd groups was removed separately to allow a comparison as to which most effectively removes the variation. It was found that the analysis within herds removed practically as much of the variance as did the analyses within herd-age and within herd-age-season except for the first and last months of lactation. Season and age at freshening appear to have some effect in these months. However, much of the effect of age appears to have been removed by separating the data according to lactations. The analysis within herds did not remove quite as much of the variation when the repeatability of non-adjacent records was considered; however, the number of degrees of freedom was small for the analysis within herd-age-season and the results were somewhat erratic. For all practical purposes, removing the effects of herd gave the most useful results since this left a larger number of degrees of freedom and since the additional removal of effects of age and season made little difference in the results. The resulting repeatabilities are in line with other published estimates (44, 62) and are particularly similar to those of VanVleck and Henderson (69).

The repeatabilities for single months of adjacent and non-adjacent lactations are reported in tables 15 and 16, respectively, while tables 17 and 18 give the repeatabilities for cumulative months of adjacent and non-adjacent lactations, respectively.

Repeatability of single months of adjacent lactations increased gradually up to the seventh month and then declined rapidly so that the repeatability of the tenth month was about the same as the first month. Repeatability of single months of non-adjacent lactations increased with stage of lactation up to the fifth or sixth month and then declined. This pattern indicates that the first and last months of the lactation are influenced more by temporary environmental conditions while the center months of the lactation are influenced more by permanent differences between cows. This trend is similar to that found by VanVleck and Henderson (69) but differs from the trend reported by Madden et al. (44) who found repeatability to be largest early in lactation and

Table 15. Repeatability of single months of adjacent lactations for Holsteins

Milk

Lactation number[a]	D F	Month of lactation 1	2	3	4	5	6	7	8	9	10
1	1,246	.32	.37	.40	.44	.45	.47	.48	.40	.39	.31
2	955	.31	.37	.39	.44	.47	.45	.51	.51	.48	.36
3[b]	1,956	.32	.32	.37	.40	.40	.39	.46	.43	.38	.30

Butterfat

Lactation number[a]	D F	Month of lactation 1	2	3	4	5	6	7	8	9	10
1	1,246	.26	.24	.30	.38	.34	.38	.37	.36	.36	.30
2	955	.28	.27	.33	.36	.41	.40	.47	.44	.45	.25
3[b]	1,956	.26	.26	.26	.30	.30	.33	.41	.38	.39	.32

[a]Refers to the first recorded lactation of a pair of adjacent lactations.

[b]Third or later lactation.

Table 16. Repeatability of single months of non-adjacent lactations for Holsteins

Milk

Lactation number[a]	D F	Month of lactation 1	2	3	4	5	6	7	8	9	10
1	382	.27	.25	.38	.33	.35	.38	.37	.30	.22	.18
2	110	.20	.26	.35	.36	.48	.49	.48	.36	.44	.37
3[b]	189	.19	.31	.20	.36	.40	.34	.32	.32	.20	.20

Butterfat

Lactation number[a]	D F	Month of lactation 1	2	3	4	5	6	7	8	9	10
1	382	.25	.27	.31	.31	.23	.30	.23	.25	.25	.16
2	110	.33	.39	.45	.36	.47	.43	.38	.34	.32	.39
3[b]	189	.18	.20	.15	.37	.37	.37	.32	.34	.29	.29

[a]Refers to the first recorded lactation of the pair of non-adjacent lactations.

[b]Third or later lactation.

Table 17. Repeatability of cumulative months of adjacent lactations for Holsteins

Milk

Lactation number[a]	D F	1	2	3	4	5	6	7	8	9	Total
		Number of cumulative months									
1	1,246	.32	.40	.45	.47	.49	.51	.53	.54	.54	.54
2	955	.31	.40	.44	.47	.50	.52	.54	.56	.56	.57
3[b]	1,956	.32	.38	.43	.45	.47	.48	.49	.50	.51	.50

Butterfat

Lactation number[a]	D F	1	2	3	4	5	6	7	8	9	Total
		Number of cumulative months									
1	1,246	.26	.32	.35	.39	.41	.43	.45	.47	.48	.47
2	955	.28	.33	.38	.41	.45	.46	.49	.50	.51	.52
3[b]	1,956	.26	.31	.33	.36	.38	.39	.41	.43	.44	.45

[a]Refers to the first recorded lactation of a pair of adjacent lactations.

[b]Third or later lactation.

Table 18. Repeatability of cumulative months of non-adjacent lactations for Holsteins

Milk

Lactation number[a]	D F	1	2	3	4	5	6	7	8	9	Total
		Number of cumulative months									
1	382	.27	.31	.38	.41	.42	.43	.45	.45	.45	.45
2	110	.20	.29	.36	.40	.43	.47	.48	.50	.51	.53
3[b]	189	.19	.31	.31	.34	.37	.38	.40	.41	.41	.41

Butterfat

Lactation number[a]	D F	1	2	3	4	5	6	7	8	9	Total
		Number of cumulative months									
1	382	.25	.31	.36	.39	.39	.38	.39	.39	.39	.39
2	110	.33	.34	.47	.48	.52	.53	.53	.53	.53	.54
3[b]	189	.18	.24	.25	.30	.32	.36	.38	.39	.41	.43

[a]Refers to the first recorded lactation of a pair of non-adjacent lactations.

[b]Third or later lactation.

less important as the lactation progressed past the second month. Searle (62) found that repeatability of monthly records increased to the fourth or fifth month and then remained rather constant to the end of the lactation. The repeatability values are somewhat smaller for butterfat than for milk and are also smaller for non-adjacent records than for adjacent records as would be expected. The repeatability values found in this study are about the same magnitude as those obtained by the other workers (44, 62, 69).

Repeatability estimates for cumulative production show an upward trend until the eighth or ninth month of the lactation where they are as high as for ten month total yield. Repeatability for cumulative milk production is larger than for cumulative butterfat production and repeatability is larger for adjacent than for non-adjacent records. Except for the first four months for milk the correlations between second and later records are largest, followed by those between first and later, and then by those between third and later lactations.

The trend for repeatability of cumulative production, which increases as the lactation progresses, is similar to that reported in most other studies (15, 17, 62, 69). However, Madden et al. (44) reported an almost opposite trend, with the repeatability value increasing up to the third cumulative month and then declining.

The repeatability estimates for total yield range between .39 and .57, which is within the range of other reported estimates, but is slightly higher than the average estimate which is between .3 and .5.

Heritability

As applied specifically to this study, heritability is a measure of what proportion of the differences between individuals in the production of milk or butterfat for a given part of a lactation is caused by a difference in the genetic constitution of the individuals. In other words, how much of this difference can be expected to be passed on to their offspring. This information is needed in order to estimate what rate of genetic progress in total production can be expected by selecting on the basis of part records. A comparison between the expected rate of genetic progress in total production from selection on the basis of part records and the rate of progress expected from selection using the whole record will determine which method results in the fastest progress.

The regression of daughter on dam was used as the method of analysis. The influence of herd and sire was removed by analyzing within herd and sire. The effect of age was removed by analyzing the data in six separate age groups. This attempt to remove extraneous environmental correlations reduced the number of degrees of freedom to a point where sampling appeared to be playing a major role. The data were then combined into fewer age groups from which a pooled regression of daughter on dam was obtained. Twice the pooled regression was used to estimate heritability. Whenever the pooled regressions were negative, heritability was considered to be zero since heritability may range between zero and one and negative values are meaningless. The pooled estimates of heritability for monthly production of both milk and butterfat are given in table 19, while table 20 gives the pooled estimates of heritability for cumulative and total production of both

Table 19. Heritability of monthly production for Holsteins

Month of lactation	First lactation (532)[a]		Second lactation (206)		Second and later lactations (435)		All lactations (967)	
	b_c	h^2 [b]	b_c	h^2	b_c	h^2	b_c	h^2
			Milk					
1	-.010	.00	.120	.24	.133	.27	.050	.10
2	.006	.01	.068	.14	.041	.08	.021	.04
3	.038	.08	.118	.24	.021	.04	.031	.06
4	-.005	.00	.115	.23	.074	.15	.030	.06
5	.046	.09	.145	.29	.065	.13	.055	.11
6	.072	.14	.091	.18	.026	.05	.051	.10
7	.074	.15	.114	.23	.021	.04	.051	.10
8	.094	.19	.083	.17	.044	.09	.072	.14
9	.116	.23	.006	.01	.032	.06	.078	.16
10	.123	.25	.061	.12	.039	.08	.085	.17
			Butterfat					
1	-.030	.00	.014	.03	.074	.15	.016	.03
2	.047	.09	-.015	.00	-.050	.00	.003	.01
3	.022	.04	-.034	.00	-.045	.00	-.009	.00
4	-.004	.00	.111	.22	.047	.09	.020	.04
5	.075	.15	-.002	.00	-.040	.00	.020	.04
6	.096	.19	.107	.21	.054	.11	.076	.15
7	.106	.21	.101	.20	-.012	.00	.058	.12
8	.120	.24	.097	.19	.041	.08	.085	.17
9	.099	.20	-.034	.00	.020	.04	.064	.13
10	.114	.23	-.011	.00	-.022	.00	.054	.11

[a]Number of degrees of freedom.

[b] h^2 is heritability and b_c is the pooled estimate of regression of daughter on dam.

Table 20. Heritability of cumulative production for Holsteins

Number of cumulative months	First lactation (532)[a]		Second lactation (206)		Second and later lactations (435)		All lactations (967)	
	b_c	h^2[b]	b_c	h^2	b_c	h^2	b_c	h^2
				Milk				
1	-.010	.00	.120	.24	.133	.27	.050	.10
2	.012	.02	.103	.21	.100	.20	.049	.10
3	.024	.05	.112	.22	.075	.15	.046	.09
4	.017	.03	.124	.25	.074	.15	.042	.08
5	.031	.06	.130	.26	.066	.13	.046	.09
6	.058	.12	.133	.27	.059	.12	.059	.12
7	.067	.13	.144	.29	.055	.11	.062	.12
8	.083	.17	no estimate		no estimate		no estimate	
9	.095	.19	.140	.28	.045	.09	.073	.15
10	.108	.22	.132	.26	.042	.08	.079	.16
				Butterfat				
1	-.030	.00	.014	.03	.074	.15	.016	.03
2	.004	.01	.006	.01	.000	.00	.020	.04
3	.018	.04	.046	.09	.023	.05	.021	.04
4	.017	.03	.072	.14	.025	.05	.012	.02
5	.029	.06	.023	.05	-.008	.00	.012	.02
6	.046	.09	.022	.04	-.023	.00	.014	.03
7	.062	.12	.020	.04	-.034	.00	.018	.04
8	.071	.14	.028	.06	-.033	.00	.024	.05
9	.087	.17	.019	.04	-.032	.00	.034	.07
10	.095	.19	.038	.08	-.024	.00	.042	.08

[a]Number of degrees of freedom.

[b] h^2 is heritability and b_c is the pooled estimate of regression of daughter on dam.

milk and butterfat.

The heritability of monthly production of milk increases steadily with each successive month during the first lactation, reaching .25 by the tenth month. For the second lactation heritability is approximately .20 to .30 for all months except the last three, where it declines. Heritability for second and later lactations combined is less than .10 for all months except one, four, and five. When data from the first lactation are added to all later data, the estimate of heritability declines the second month and then increases gradually to a maximum of .17 for the tenth month.

The heritability of cumulative production of milk increases gradually with each additional month of the first lactation, reaching .22 by the end of ten cumulative months. It remains somewhat constant around .25 for the second lactation with the low occurring after two months and the high at seven cumulative months. Maximum heritability for cumulative second and later lactations combined is reached the first month and then declines as production for each additional month is added to the cumulative total. When all lactations are considered together, heritability declines slightly from three to five cumulative months and then increases as the lactation progresses to completion.

Heritability of butterfat production is more erratic as well as lower than for milk. It follows the same pattern for the first lactation, but is lower for both monthly and cumulative periods. For the second lactation heritability of butterfat production is essentially zero for all individual months except the fourth, sixth, seventh, and eighth where it is approximately .20. For cumulative periods of the second lactation, it reaches a maximum of .14 the fourth month, after which it declines. Maximum heritability for cumulative periods of second and later lactations combined is .15 for one month, declines to .05 for three and four cumulative months and is zero thereafter, while monthly estimates reach approximately .10 for the fourth, sixth, and eighth months. For all lactations combined, heritability is near zero for the first five individual months and then jumps to between .10 and .20 for the last five months. It remains near zero for the first six cumulative months and then increases to .08 for the complete lactation.

Although the pooled estimates of regression for the second lactation and for second and later lactations combined are still rather erratic, especially for butterfat, they do give some indication that differences exist between lactations in the heritability of part records. For the first lactation, heritability increases steadily throughout the ten month period, indicating that in the early months of a first lactation there is proportionately more non-genetic variation between cows than in the later months. Although no definite trend is evident for second or later lactations, there is some indication that in the second lactation there is proportionately less non-genetic difference between cows during the center months than either the first or last months, while in third or later lactations the non-genetic differences are proportionately smaller in early lactation.

The downward trend in heritability from first to last months is similar to that reported by Madden et al. (44) and by Searle (62). VanVleck and

Henderson (69), using a paternal half-sib analysis, obtained lower estimates of heritability for the first and last months of the lactation than for the center months. In these other studies the data were not separated by ages or parities nor was the age or parity composition of the data reported.

The estimates of heritability of monthly and cumulative production are, in general, lower in this study than reported by some other workers (30, 44, 48, 59), particularly for cumulative production of butterfat. However, the estimates are of about the same magnitude as those reported by Searle (62) and VanVleck and Henderson (69). The heritability of total production of milk for the first and second lactation falls within the range of .20 to .30 found in most other studies, but all other estimates are lower than .20, particularly those for butterfat.

Results from this study generally agree with those of other studies (12, 21, 28, 30, 40, 48, 59) that heritability of first records is higher than that for later records. The exception in this study is heritability of milk production for the second lactation is slightly higher than for the first lactation.

<u>Genetic correlations</u>

In terms of this study, a genetic correlation measures the extent to which the same genes affect production during various parts of the same lactation. If the same genes are operating to the same extent throughout the lactation, then one should be able to select among those genes by selecting a part record.

With genetic correlations as with heritabilities, the small samples caused somewhat erratic estimates individually. Therefore, estimates of genetic correlations were pooled. Table 21 shows the genetic correlations between monthly and total production for milk and butterfat, while the genetic correlations between cumulative and total production are given in table 22.

The genetic correlations between monthly and total production of milk for the first lactation are essentially .90 or higher, being highest for the second through seventh months. Except for the first, third, and tenth months, the genetic correlations for the second lactation are also above .90. For second and later lactations combined, the estimates of genetic correlations are quite erratic. The over-all estimates of genetic correlations for milk are more stable, increasing from .63 for the first month to 1.07 for the seventh month and then decreasing to .56 for the tenth month.

The genetic correlations between monthly and total production of butterfat are less stable than those for milk. During the first lactation they are quite erratic for the first four months, but near 1.00 for the last six months. They are even more erratic for the second lactation, being less than .35 for months one, five, nine, and ten, but range from .70 to larger than unity for the remaining months. They are also erratic for second and later lactations combined. The over-all genetic correlations for butterfat are low for the first and last months of the lactation, but .89 or above for months four through eight.

A more noticeable trend is evident for the genetic correlations between cumulative and total production for both milk and butterfat. For first lactation production of milk the genetic correlations are above unity for months two through five and between .96 and .99 for the next four cumulative months.

Table 21. Genetic correlations between monthly and total production for the lactation for Holsteins

Month of lactation	First lactation (532)[a]	Second lactation (206)	Second and later lactations (435)	All lactations (967)
		Milk		
1	.11[b]	.71	.52	.63
2	1.63	.99	.91	.97
3	.98	.74	.31[b]	.85
4	.12[c]	.96	.73	.80
5	.99	.97	.65	.87
6	.98	.91	.26	.93
7	1.08	.96	.80	1.07
8	.92	.95	.67	.86
9	.96	1.71	.39[b]	.75
10	.90	.55[b]	.35[b]	.56
		Butterfat		
1	.69	.23[b]	.39[c]	.03[b]
2	.40	.89	1.05	.18[b]
3	1.09	1.73	.53[c]	.70
4	.14[c]	1.08	-.14[c]	.90
5	.99	.05[c]	.43[c]	.98[b]
6	1.00	1.03	1.02	.92
7	1.01	.73	1.37[b]	1.03
8	.94	.70	.44	.89
9	.74	-.11[c]	.59	.12
10	1.00	.07[c]	1.08[b]	.45

[a]Number of degrees of freedom.

[b]Genetic correlation calculated using method b.

[c]Genetic correlation calculated using method c.

Table 22. Genetic correlations between cumulative and total production for the lactation for Holsteins

Number of cumulative months	First lactation (532)[a]	Second lactation (206)	Second and later lactations (435)	All lactations (967)
		Milk		
1	.11[b]	.71	.52	.63
2	1.33	.83	.57	.69
3	1.10	.86	.58	.77
4	1.27	.90	.68	.83
5	1.09	.96	.75	.87
6	.96	.97	.80	.89
7	.98	.98	.78	.92
8	.98	no estimate	no estimate	no estimate
9	.99	.99	.96	.99
		Butterfat		
1	.69	.23[b]	.39[c]	.03[b]
2	1.52[b]	.11	1.22[c]	-.03[c]
3	.46	.60	1.17[c]	.39[b]
4	.65	.74	1.14[c]	.60[b]
5	.95	.31	1.53[c]	.70[b]
6	.95	.50	1.40[c]	.55
7	.97	.19	1.26	.73
8	.98	.65	1.21	.85
9	.99	.63	1.14	.91

[a]Number of degrees of freedom.

[b]Genetic correlation calculated using method b.

[c]Genetic correlation calculated using method c.

For the second lactation they increase from .71 for one month to .96 by the end of five cumulative months and .99 for nine cumulative months. Second and later lactations combined increase from .52 for one month to .96 for nine months and the over-all estimate increases from .63 for one month to .99 for nine cumulative months.

The genetic correlations between cumulative and total butterfat production for the first lactation are rather erratic for the first three months but increase to .95 by the end of five cumulative months and .99 at the end of nine cumulative months. The estimates are erratic for the entire second lactation, while for second and later lactations combined they are larger than unity except for the first month. The combined estimate for cumulative production of butterfat is low for the first two months but then increases to .91 for production for nine cumulative months.

The genetic correlations between monthly and total production of both milk and butterfat show a tendency to be higher during the center months of the lactation. Thus, genes affecting production during the center months of the lactation have more influence on total production for the lactation than do genes operating only at the first or last of the lactation. Apparently some of the genes which influence early and late production have little or no influence on total yield although most of the genes affect monthly yield as well as total yield. These results are in close agreement with those of VanVleck and Henderson (69) and follow a pattern similar to those of Searle (62).

In general, the genetic correlations between cumulative production and total yield increase with an advance in the stage of lactation. The estimates for milk reach .96 by the end of nine cumulative months while those for butterfat reach .91 or larger. Although the results are not as clear as those reported by VanVleck and Henderson (69), they do follow the same pattern. Madden et al. (44) reported results which showed genetic correlations between cumulative and total production to be near unity for all months, suggesting that genes affecting production early in lactation also affect the remainder of the same lactation. This is slightly different from the conclusions which can be drawn from the present study or from the one by VanVleck and Henderson (69), that many of the same genes operate throughout the entire lactation but that some genes affect only early or late production. As production for the lactation accumulates with each successive month, so do the effects of the genes operating throughout the lactation, resulting in an increase in the genetic correlation between cumulative and total production as the lactation progresses.

Relative Efficiency of Selection Based on Part Records

The relative efficiency of selection for a whole record using a part record as the criterion for selection is indicated by the ratio ${}^{r}G_wG_p \frac{h_p}{h_w}$, where ${}^{r}G_wG_p$ is the genetic correlation between whole and part records and h_p and h_w are the square roots of the heritabilities of part and whole records, respectively. This ratio compares the genetic change in production expected for whole lactations where a part record is the criterion for selection, with the progress expected from using the whole record itself in selection. The intensity of selection is the same for both part and whole records. Changes in the length of the generation interval or economic considerations are not included in this measure of efficiency of selection.

Table 23 presents the relations between rates of progress for production during complete lactations, from selecting on the basis of monthly records and complete records for milk and butterfat. Table 24 shows the relative progress from selecting on the basis of cumulative records. Genetic correlations between part and whole records larger than unity were considered to be 1.00.

During the first lactation, selection based on a single test in the ninth or tenth month for milk and the sixth, seventh, eighth, or tenth month for butterfat provides approximately as much progress in the complete record as selection on the whole record which requires waiting for completion. The relative efficiency of using the part record is lowest early in the lactation and increases as the lactation progresses. In the second lactation, selection on the basis of milk production during the fifth month provides as much progress in the complete record as waiting for completion, while the fourth and seventh months provide 90 percent as much progress. For second and later lactations combined, selection for total milk production is over 90 percent as effective when made during the first, second, or fourth months as waiting for the complete record. The results for butterfat for second lactations and second and later lactations combined are not as clear. The main problem is that heritability of both part and whole records is so low that little or no genetic increase is expected. When all the data are combined, the relative efficiency

Table 23. Relative efficiency of selection for complete lactations for Holsteins using monthly records as the criterion for selection[d]

Month of lactation	First lactation (532)[a]	Second lactation (206)	Second and later lactations (435)	All lactations (967)
		Milk		
1	*[c]	.68	.96	.50
2	.21	.73	.92	.48
3	.56	.71	.22[b]	.52
4	*	.90	1.00	.49
5	.63	1.02	.83	.72
6	.78	.76	.21	.74
7	.83	.90	.57	.79
8	.86	.77	.71	.80
9	.98	.20	.34[b]	.75
10	.96	.37[b]	.34[b]	.58
		Butterfat		
1	*	.14[b]	*	.02[b]
2	.28	*	*	.06[b]
3	.46	*	*	*
4	*	1.66	*	.64
5	.88	*	*	.69[b]
6	1.00	1.62	*	1.26
7	1.05	1.15	*	1.22
8	1.06	1.08	*	1.30
9	.76	*	*	.15
10	1.10	*	*	.53

[a]Number of degrees of freedom for estimation of the heritabilities and genetic correlations

[b]Genetic correlation calculated using method b.

[c]Genetic progress not possible because heritability was zero.

[d]Genetic correlations between part and whole records larger than unity were considered to be 1.00.

Table 24. Relative efficiency of selection for complete lactations for Holsteins using cumulative records as the criterion for selection[d]

Number of cumulative months	First lactation (532)[a]	Second lactation (206)	Second and later lactations (435)	All lactations (967)
		Milk		
1	*[c]	.68	.96	.50
2	.30	.75	.90	.54
3	.48	.79	.79	.58
4	.37	.88	.93	.59
5	.52	.97	.96	.65
6	.71	.99	.98	.77
7	.75	1.03	.92	.80
8	.86	no estimate	no estimate	no estimate
9	.92	1.03	1.02	.96
		Butterfat		
1	*	.14[b]	*	.02[b]
2	.23[b]	.04	*	-.02[e]
3	.21	.64	*	.28
4	.26	.98	*	.30
5	.53	.24	*	.35
6	.65	.35	*	.34
7	.77	.13	*	.52
8	.84	.56	*	.67
9	.94	.45	*	.85

[a]Number of degrees of freedom for estimation of the heritabilities and genetic correlations.

[b]Genetic correlation calculated using method b.

[c]Genetic progress not possible because heritability was zero.

[d]Genetic correlations between part and whole records larger than unity were considered to be 1.00.

[e]Genetic correlation calculated using method c.

of selection using monthly records increases up to .80 by the eighth month for milk and is greater than 1.00 for the sixth, seventh, and eighth months for butterfat. Except for the months mentioned, selection based on single monthly records appears not to provide as much progress as using the completed record unless using the part record can reduce the generation interval markedly or increase the selection pressure considerably.

For first lactations and all lactations combined, the relative efficiency of selecting for a complete record using a cumulative part record as the basis for selection increases as production for each succeeding month is added to the cumulative total, reaching .92 for milk and .94 for butterfat by the ninth cumulative month for first lactations and .96 for milk and .85 for butterfat by the ninth cumulative month for all lactations combined. Selection for a complete record for milk production from a second record five or more months in length is as accurate as waiting for the complete record. Selection for a complete butterfat record from a cumulative part of a second record is as accurate by the fourth month as waiting for the completed record, but the accuracy then declines as production for each additional month is added to the cumulative total. Because the heritability for complete second and later lactations combined is lower than for cumulative months for these same lactations, selection on the basis of a cumulative record of any length is essentially as accurate as waiting for the finished record.

Few other investigators have studied the relative efficiency of selecting for a whole record using a part record as the criterion for selection. VanVleck and Henderson (69) studied the relative genetic progress in complete milk records from selection based on production for a single month, a function of production for sequential months, and on cumulative production. Their results for single months are almost identical to the results reported here for milk production for the second lactation. Their results for the use of cumulative production follow the same trend as reported here, particularly for first lactations and for all lactations combined, but show greater relative genetic progress from selection based on cumulative part records.

The method used in this study to separate the data by ages in order to remove the effect of age from the estimates of heritability and genetic correlations has not been reported previously. That the resulting estimates of heritability tend to be reduced when age is considered indicates something of the extraneous correlations included in heritability when age is ignored. Also, in comparing the results of this study with those of Searle (62) and VanVleck and Henderson (69), it should be remembered that they used an analysis of paternal half-sisters whereas daughter-dam comparisons were used in this study. Environmental correlations usually associated with paternal sisters may have given them a more consistent set of results than in this study where at least part of these environmental correlations were removed to provide more accurate answers which appear to be a little more variable because of reduced degrees of freedom.

Since the genetic correlations between part and whole records are high, heritability becomes the important factor in determining whether selection based on part records is as relatively effective in increasing genetic merit for whole records as is selection after waiting for the completed record.

When the heritability of a part record is considerably lower than that for the completed record, selection should not be made on the basis of the part record if fastest genetic gains are sought. Conversely, where heritability for the complete lactation is low and for a monthly or cumulative part of the record is high, it becomes beneficial to use the part record as the criterion for selection.

The most rapid genetic progress will be made by selecting on first or second records since heritability is largest for these early records and since by selecting early the generation interval will be shorter. Any reduction in the generation interval should proportionately increase the genetic progress per year with the same genetic progress per generation. Using complete records as the basis of selection, the generation interval in dairy cattle is approximately 4.5 to 5.0 years. Selection on the basis of a partial first record can shorten the generation interval as much as 9 months or approximately 15 percent. By shortening the generation interval 3 or 4 months (5 to 7 percent), selection on the first 6 or 7 months of the first lactation becomes essentially as effective as waiting for the 10 month total. The savings in feed and other costs resulting from early selection, or the genetic increase resulting from obtaining a larger number of offspring from genetically superior sires because of earlier selection of these sires for heavy use in artificial insemination also favor selection on the basis of part records.

Since repeatability of both part and whole records is incomplete, animals are continually being reevaluated in a selection program. The use of both whole and part records in sequential culling should be useful in increasing genetic progress. For example, selection on the basis of the fourth or fifth individual month or the first four cumulative months of the second lactation in addition to the first record will be just as effective as using the complete second record, which requires waiting for the end of the second lactation, and will not lengthen the generation interval as greatly.

The rate of genetic change in a population in one generation is equal to the heritability of the trait being selected for times the selection differential or the amount by which the animals selected to be parents exceed the average of the population from which they were selected. An increase in the intensity of selection will increase the size of the selection differential it is possible to attain. In estimating the relative efficiency of selection for a whole record using a part record as the criterion for selection the intensity of selection was considered the same for part and whole records. However, selection using part records makes it possible to sample more young animals in a given period of time, improving the chances of increasing the intensity of selection and consequently the rate of genetic improvement.

APPLICATION OF RESULTS

Two types of ratio factors have been presented, factors for extending monthly production and factors for extending cumulative production. The ratio factors for cumulative production are more useful and more widely applicable since they utilize all of the test-day information which is available rather than production information from only one test day. Since most testing programs report total production to date, an even more practical means of using extension factors for cumulative production is to interpolate them so that the cumulative production for any number of days can be extended to 305 days by multiplication by a single factor. Lamb (37) has described a method whereby ratio factors for cumulative production as presented here can be interpolated for this purpose.

Interpolated ratio factors are simple and easy to apply. Cumulative production, as reported by the testing program, is multiplied by the factor for the number of days involved to obtain estimated 305-day production. Meadows (52) has developed an inexpensive slide rule using ratio factors from this study and interpolated by the method described by Lamb (37). With this device cumulative production can be quickly extended to 305 days. An added feature of this slide rule is the mature equivalent factors published by Kendrick (33) so that an incomplete record can be extended and corrected to a mature equivalent basis quickly and easily in the same operation.

Uninterpolated factors for cumulative production may be used in cases where only the production on test day for several test days is known. Cumulative test-day production is multiplied by 30.5, the average number of days in a month, to give cumulative monthly production which is then multiplied by the factor for the number of test days involved to obtain estimated 305-day production.

The factors for monthly production are more useful than factors for cumulative production for comparing one set of factors with another for all months or for studying environmental influences on the shape of the lactation curve, since with factors for cumulative production any differences in early months tend to mask differences in later months. From a practical standpoint, factors for monthly production are not as readily applicable and will be used only when cumulative production is not available. To use these factors, production from an individual test day is multiplied by 30.5 to get monthly production which is multiplied by the factor for that particular month to obtain estimated 305-day production.

The magnitude of the phenotypic correlations between a part record and the complete record for the same lactation is such that consideration of the use of extended part records as an estimate of yield for the lactation seems warranted. Cumulative records of 6 or 7 months length give practically as much information about the complete record as does the complete record itself.

If only a single test can be obtained during a lactation, either the fourth, fifth, or sixth month of the lactation would be the best time to test a cow.

The correlation of these monthly records with a complete record is .81 or greater for milk and .77 or greater for butterfat. This is not as accurate as prediction from cumulative production for 3 or more months, but the single test can certainly contribute a significant part of the information on production possible with complete testing.

A practical means of using single test day information would be to test dairy herds on a bi-monthly or quarterly basis and to use some weighted average of the extended records as the measure of yield for the complete lactation. Even on a quarterly basis, every cow would normally be tested once during the fourth, fifth, or sixth month of the lactation. Any additional tests should increase the accuracy of the estimate. Additional study of this method is needed to measure the practicality of such a scheme as compared to current testing methods. A material reduction in the cost of testing for individual dairymen and an increase in the number of different cows tested by a DHIA supervisor without any loss of income to him could result from the use of such a program. An increase in the number of cows on test should aid considerably in plans to improve the genetic merit of dairy cattle.

The repeatability of production in individual months in different lactations is practically as great for the center months or for 6 or more cumulative months of a lactation as for a completed lactation. For all practical purposes, as much reliability can be placed on production for a fourth, fifth, or sixth individual month or on 6 or more cumulative months as an indication of how much a cow will produce above or below the herd average for that same period of the subsequent lactation as can be placed upon production for the complete lactation. This coupled with the high phenotypic correlations between these same parts of a record and the total for that record indicate that little accuracy would be sacrificed in using these parts of records to estimate a complete future record as compared to using a completed record.

Factors for extending incomplete records can be used with considerable accuracy to complete records, particularly when breed, age, and season of freshening are taken into account in the factors. These factors may have a potential usefulness in developing new systems of production testing to reduce the cost of testing and to induce more dairymen to measure the production of their cows. However, because of the low heritability of part records, their use as a criterion of selection for maximum genetic gains is limited. Nevertheless, part records are a potential means of preliminary selection whereby extremely low producing cows can be eliminated early in lactation and those closer to average production can be held for further evaluation at the completion of the lactation or even after the first 4 to 6 months of the second lactation. Sons of cows performing well at the start of their first lactation could be saved at least until more evidence of the cow's producing ability became available.

Artificial insemination organizations should also be able to make preliminary evaluations of young sires based on partial first records of their daughters. The least promising bulls could be eliminated sooner and the most promising brought back into service quicker under this system. Final evaluation of those young bulls closer to the average would have to be reserved until more complete data were available. The savings which could be made on feed and other costs normally associated with maintaining animals until complete information becomes available would have to be balanced against any loss in efficiency of selection resulting from the use of part records.

Including in a sire proof records from all daughters which freshen is almost necessary in order to eliminate some of the biases in evaluating bulls caused by differential culling among progeny of sires resulting from the removal of disproportionate numbers of potentially low-producing daughters on the basis of early parts of the first lactation. Since, in all probability, these daughters will be removed from the herd anyway, the use of appropriately extended records to obtain additional information for evaluating the sire should aid selection by increasing numbers as well as by removing some of the biases resulting from differential cullings.

The large phenotypic correlations between total and part production indicate definite value for using extended records in conducting research with dairy cows. Total yield for each individual cow estimated from production during an early portion of her lactation could be used as the control for that cow in physiology, nutrition, or management experiments. Deviations from the extended lactation curve or from estimated total yield would serve to estimate the treatment effects.

SUMMARY

Early parts of records may be used to increase genetic gain through selection if the early months of a lactation provide a reliable estimate of a cow's ability to produce for a complete lactation. The objective of this study was to ascertain the usefulness of part records in estimating the breeding value of dairy cattle.

Complete lactation records for 24,602 Holsteins, 4,309 Guernseys, 1,878 Jerseys, and 892 Brown Swiss compiled in Michigan DHIA-IBM from June 1954 through December 1957 were analyzed to ascertain the effects of breed, age, and season of freshening on the relationship of total to part production and to develop factors which adequately take into account the effects of these variables in extending milk and butterfat records to 305 days. The same data were used to measure heritabilities and repeatabilities of monthly, cumulative, and total production, to obtain genetic and phenotypic correlations between monthly and total production and cumulative and total production, and to use the estimates of genetic parameters to measure the relative efficiency of selecting for genetic gain in 305-day records using part records as the criterion for selection.

Breed, age, and season of freshening influence the relationship between total and part production sufficiently to require adjustment in extending part records to 305 days. Separate factors should be used in extending milk and

butterfat records. In order to remove adequately the effects of age in extending records, separate factors are needed for milk records by cows calving before 36 months of age and for those 36 months and older at freshening, while separate factors are needed to extend butterfat records initiated at less than 36 months, 36 to 47 months, and 48 months and older. Season of freshening can be adjusted for by using different factors for extending records started during a 4 month spring and summer period separate from the other 8 months. The grouping for season differs between milk and butterfat records.

Ratio factors for separately extending milk and butterfat records from each of 10 monthly test days and from cumulative test-day production are presented for different ages and seasons of freshening for each of the four breeds. Combined factors for age and season of freshening are also presented for each breed separately.

Repeatabilities of single months increase gradually through the lactation up to as high as .51 for the seventh month and then decline rapidly. Repeatability of cumulative production shows an upward trend until the eighth or ninth month of the lactation where it is as high as for total yield. The repeatabilities for total yield range between .39 and .57, which is within the range of other reported estimates. The repeatabilities for milk are slightly larger than those for butterfat and repeatability is larger for adjacent than for non-adjacent records.

Heritabilities of monthly production range between zero and .29 for milk and between zero and .24 for butterfat. Heritabilities of cumulative production generally increase with each additional month and range between zero and .29 for milk and between zero and .19 for butterfat. The heritability of butterfat production is more erratic as well as lower than for milk. Lactations differ in heritability of monthly, cumulative, and total production of milk and butterfat.

Phenotypic correlations between monthly and total production are largest for the fifth month and smallest for the first and last months of the lactation. Phenotypic correlations between cumulative and total production increase rapidly to .90 by the fourth to sixth month and then more slowly to .99 by the ninth cumulative month. The correlations are slightly higher for milk than for butterfat, for first lactations than for later lactations, and considerably higher between a part and total of the same record than between a part of one record and the total of a succeeding record.

The genetic correlations between monthly and total production tend to be higher for the center months of the lactation and generally exceed .90. The genetic correlations between cumulative and total production increase as the lactation progresses, reaching .99 by the ninth cumulative month of milk production.

Except for 1 or 2 months during the lactation, selection based on a single monthly record will not provide as much genetic progress in the complete record as selecting on the complete record. The relative efficiency of selecting for a complete record using a cumulative part record as the basis for selection increases as each succeeding month is added to the cumulative total, reaching .90 or higher by the ninth cumulative month.

In practice breed, age, and season of freshening should be considered in extending incomplete records to 305 days. The phenotypic correlations between part and whole records indicate that partial records can be extended with considerable accuracy, but the genetic parameters indicate that in general the genetic progress in complete records will not be as rapid if part records are used as the criterion for selection. However, genetic progress can still be made under this system and if the generation interval can be reduced markedly, if the selection pressure can be increased considerably, or if the economic conditions justify, it may be advantageous to use a part record as an aid in selection.

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