Causes of variation in calving interval of Holstein-Friesian cows

James Clarence Rennie
Iowa State College

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UMI
CAUSES OF VARIATION IN CALVING INTERVAL OF
HOLSTEIN-FRIESIAN COWS

by

James Clarence Rennie

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Major Subjects: Animal Breeding
Dairy Husbandry

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

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Dean of Graduate College

Iowa State College

1952
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I. INTRODUCTION

Doubtless man has attempted for many years to improve the producing ability of dairy cattle. In striving for this improvement, the breeders today, as well as in the past, are confronted with the problem of finding and using those measures of production which have a maximum association with the real breeding value of their livestock. Besides the selection imposed by the breeders, natural selection undoubtedly has been effective to some degree in developing individuals with producing abilities better adapted to the existing environmental conditions.

The purpose of the present study is to describe the length of calving interval and its variation and to learn if it has a genetic basis. The "calving interval" is the period of time elapsing between two consecutive parturitions. When the fertility of an animal is measured in this manner, it is considered as a net biological unit, composed of the integrated effects of many factors, up to and including parturition; i.e. gametogenesis, estrus, ovulation, fertilization, implantation, gestation and parturition. For example, it may be that the factors involved in the failure of fertilization are entirely separate from those involved in the failure of a gestation to be completed successfully. The length of calving interval is a single function of these separate factors.

The minimum length of calving interval is set by certain physiological limitations of the cow. Holstein-Friesian cattle, in general,
must have approximately 278 days for a normal gestation period. The standard deviation of this is about five days. The calving interval, therefore, cannot be less than the length of the gestation period. An interval as short as 278 days would require that a cow conceive on the day of parturition or within a few days thereafter. Actually few cows exhibit estrus until many days after calving and only about half of them conceive at the estrus period when first bred. Hence, almost all calving intervals will be at least a few weeks longer than the gestation period.

In studying the variation in length of calving interval three questions may be asked. First, what are the statistics regarding calving interval; i.e. mean, variance and frequency distribution? Second, what factors influence the length of calving interval? Third, what influence does the length of calving interval have on the production of milk and butterfat? An answer to the second question is important in determining whether the length of calving interval can be used as a reliable measure of fertility and how much it can be controlled by changes in management. It is also important to know the phenotypic and genetic relationship of calving interval to production since the economic value of a dairy cow depends primarily on her ability to produce milk and butterfat.

To obtain answers to these questions the following points were investigated.

1. The influence of the year of calving on the length of calving interval; i.e. whether the average calving interval really changes from
one calendar year to another.

2. The effect of age of cow on the length of calving interval.

3. The repeatability of the length of calving interval.

4. The heritability of the length of calving interval.

5. The influence of management on the length of calving interval.

6. The influence of the length of a calving interval on the production of milk and butterfat during the same interval, and on the production in the following interval.

7. The genetic correlation between the length of calving interval and the production of milk and butterfat.
that interval between occurrence and the next entry is too short. The problem of
of course occurs in different months of the year. The reason for the period
the courses of the system have been extended to the length of specific periods,
from the books of the period, which record the courses taken.

Hammed and Chanda (1969) studied the period recording in

The courses are entered, compiled from the calendars, from the jail,
that interval on to occurrence, whereas on the jail they reach the experience of
long ago the experience interval between courses was 37 days; again,
other pattern of the course lasted more than a semester. The
the last week of the course past the next semester a negative, the least
week of the course past the next semester a negative, and the
teachers of the two principal teachers were frequently met. The

The interval was reported by Whittle (1969). The data were compiled from the
among the longest periods for length of course intervals the above

II. REVIEW OF LITERATURE

A. Period in the Length of Course Interval

to both aspects of the subject.
the length of course interval. The literature reported these aspects
in which a few of them have been concerned with the courses of
the literature on the length of course interval. The literature of the
material, most of the literature relates to the length of course interval. as
the literature on the length of course interval, and on how this interval,
given several investigations have been conducted on the verification in the
service periods followed calvings in the month of November while the shortest periods followed calvings in the month of May. Variations in service period would be almost identical with variations in length of calving interval, since service period equals calving interval minus gestation length and variation in gestation length is so small (the standard deviation is about five days) that service period can almost be considered as calving interval coded by subtracting a constant.

Fredericksen and Fstedgaard (1931), in a study of 7,035 calving intervals taken from the Danish Cow Testing Association records, report an average calving interval of 399 days. These data were selected to some extent since only the records of the cows registered in the first six volumes of the Danish Cow Herd Books were included, and such cows were required to have been high producers over a period of three or more consecutive years. This would have excluded more of the cows with extremely long intervals than of the cows with medium or short intervals. When the calving intervals were grouped according to the month in which the calvings occurred, it was apparent that the longest intervals followed calvings in July and August, whereas the shortest intervals followed December calvings.

Johansson and Hansson (1940), in an intensive study of the records from 13 herds of Swedish Red and White cattle, found 391 days as the average length of calving interval for 8,799 cows. They also indicated that a slight, although relatively unimportant, association exists
between the length of calving interval and the month of calving. The differences among the monthly means for length of calving interval is less evident in the first calving interval than in the following intervals. In the mature cows the longest intervals occurred after September and October calvings, whereas the shorter intervals followed calvings in April to June. This monthly difference in length of calving interval probably reflects the observed fact that, in general, cows show more pronounced heat and are more likely to conceive during the summer months than when they are stabled. It is evident from the data of Johansson and Hansen that an association exists between the age of cow at first calving and the length of her first three calving intervals. The length of calving interval increased with increasing age at first calving. They also found considerable variation in the length of calving interval within each age group. It is apparent from their data, a summary of which is presented here in Table 1, that the first and fifth to eight intervals are about five to ten days longer than the second to fourth calving intervals. Although the numbers are small for the very old cows (nine and ten lactations) the mean length of interval tends to increase further with old age. The coefficients of variation tend to increase slightly with increasing age of cow, especially after seven years of age.

Cannon and Hansen (1943) studied the calving records of 153,610 cows taken from the data of the Iowa Dairy Herd Improvement Association for a sixteen year period, 1926 to 1941 inclusive. Small variations occurred from year to year in the mean length of calving interval, but
Table 1. Mean, standard deviation and coefficient of variation for calving interval of the first to tenth lactations

<table>
<thead>
<tr>
<th>Lactation</th>
<th>Number of cows</th>
<th>Age at calving (years)</th>
<th>Mean (♀)</th>
<th>Std. dev. (♀)</th>
<th>C. of variation (♀)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,189</td>
<td>2.8</td>
<td>396</td>
<td>70.7</td>
<td>17.8</td>
</tr>
<tr>
<td>2</td>
<td>1,799</td>
<td>3.9</td>
<td>386</td>
<td>62.3</td>
<td>16.1</td>
</tr>
<tr>
<td>3</td>
<td>1,432</td>
<td>5.0</td>
<td>367</td>
<td>65.6</td>
<td>17.0</td>
</tr>
<tr>
<td>4</td>
<td>1,137</td>
<td>6.0</td>
<td>366</td>
<td>63.1</td>
<td>16.3</td>
</tr>
<tr>
<td>5</td>
<td>833</td>
<td>7.0</td>
<td>396</td>
<td>74.3</td>
<td>18.8</td>
</tr>
<tr>
<td>6</td>
<td>571</td>
<td>8.2</td>
<td>392</td>
<td>70.2</td>
<td>17.9</td>
</tr>
<tr>
<td>7</td>
<td>380</td>
<td>9.2</td>
<td>393</td>
<td>70.5</td>
<td>17.9</td>
</tr>
<tr>
<td>8</td>
<td>218</td>
<td>10.3</td>
<td>397</td>
<td>76.8</td>
<td>19.3</td>
</tr>
<tr>
<td>9</td>
<td>136</td>
<td>11.3</td>
<td>406</td>
<td>74.0</td>
<td>18.2</td>
</tr>
<tr>
<td>10</td>
<td>74</td>
<td>12.4</td>
<td>404</td>
<td>73.5</td>
<td>18.2</td>
</tr>
</tbody>
</table>

This table was taken from the report of Johansson and Hessson (1940), except for the coefficients of variation which were calculated by the author.
the year means mostly fall close to the average of 451 days for the entire period. This mean length of calving interval of 451 days is similar to the mean of 446 days as found in the Iowa State College herd over a nineteen year period. For the college herd the number of calvings in each season within the year were quite similar. This suggests that no great effort had been made to control the freshening dates of the cows. This was not the situation for the B.M.I.A. cows since 66.1 per cent of calvings occurred during the fall and winter seasons and the remaining 33.9 per cent during spring and summer. It is apparent that a definite attempt was made by the breeders to have the majority of the cows calve during the fall and winter seasons. This must have influenced considerably the average length of calving interval.

Skjervold (1949) in an analysis of the records of 3,155 Red Trönder cattle reported that the season of calving influenced the length of calving interval. The long intervals followed calvings in August and September, whereas the short intervals followed May calvings.

It is apparent from the results of these various studies that only a slight association exists between the length of calving interval and the month of calving. The longest calving intervals followed calvings in the months of July to November whereas the shortest calving intervals followed calvings in the months of December to June.

Gaines and Palfrey (1931), using the calving records of 136 Red Danish cows in the data published by Langseck (1921), calculated a mean
The mean February rainfall over the period was 99 days during the period, 1937 to 1939 inclusive. These three years do not have the rainfall of 99 days from the mean.

The rainfall is presented in the following manner. The rainfall for each year was the number of days with rainfall of 99.5 days.

\[
\frac{\text{Number of days with rainfall}}{\text{Total number of days}} = 99.5\text{ days}
\]

The formula for the mean February rainfall over each year of means.

The mean February rainfall is the mean of the rainfall for each February from 1937 to 1939 inclusive. These three years do not have the rainfall of 99.5 days.

In a study of the rainfall records of 1937, 1938, and 1939, it was noted that the rainfall of 99.5 days is a significant amount of rainfall. Therefore, the rainfall of 99.5 days is considered to be the average rainfall for each February.
calving interval as occurring in the year in which the interval terminated. On this basis he found a significant difference between yearly means. His results indicate that a real tendency may exist for certain cows to have longer intervals than others, within the same breed.

The influence of contagious abortion on the length of calving interval in the University of Illinois dairy herd was studied by Yapp and Kuhlman (1933). The average calving interval for 110 calvings in the positive herd was 451 days after all abortions were eliminated, whereas the mean interval for 286 calvings in the negative herd was 424 days, or 27 days less than in the positive herd. These findings indicate that a high incidence of contagious abortion is likely to lengthen the interval between calvings.

The average length of calving interval as calculated by Ingels (1936) for the cows in the Iowa State College dairy herd during the three year period 1933 to 1935 inclusive, was 415 days. This mean calving interval is 44 days shorter than the value (459 days) reported by Beasley (1933) in his study of the same herd during the immediately preceding period of 1917 to 1922, inclusive. Since a definite attempt was made to shorten the calving interval during the period investigated by Ingels, the contrast between the two means, (415 and 459 days), yields some indication as to the effectiveness of management in influencing the length of calving interval.

An intensive study was conducted by Fine (1939) on the calving
records of 1,157 cows from 50 herds chosen at random from the Iowa Cow Testing Association herds, as well as on the records of the dairy herd at Iowa State College from 1907 to 1938 inclusive. For the college herd a highly significant difference was found between the yearly means for length of calving interval. In studying the influence of age of cow on length of calving interval, Fins reported that there is a slight, but regular decrease in length of calving interval from two to four years of age and then a gradual increase up to nine years of age. He did not test whether these age differences were real, since the variation among the means of the first seven age groups was so small that he concluded age to be unimportant as a source of variation in calving interval.

Boyton (1940), in a study similar to those reported by Buckley (1933) and Ingals (1936), investigated the calving records of 225 cows in the Iowa State College dairy herd for the period 1936 to 1939 inclusive. He found a mean interval between calvings of 399 days and a standard deviation of 69.4 days. In contrast, the mean length of calving interval in the same herd for the period 1916 to 1939 was 432 days.

A summary of the average calving intervals as reported by the various investigators is presented in Table 2.
Table 2. Summary of average calving intervals as reported by other investigators

<table>
<thead>
<tr>
<th>Average length of calving interval (days)</th>
<th>Source of data</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>362</td>
<td>123 calvings on the Rellors Ranch</td>
<td>Villegas, V. (1926)</td>
</tr>
<tr>
<td>337</td>
<td>76 calvings on the San Lorenzo Ranch</td>
<td>Fredericksen, L. and F.S. Petersgaard (1931)</td>
</tr>
<tr>
<td>399</td>
<td>7,035 calving records, Danish Cow Testing Assoc. records</td>
<td>Geines, W.L. and J.R. Falfrey (1931)</td>
</tr>
<tr>
<td>401</td>
<td>186 Red Danish cows</td>
<td>Beard, L.H. (1933)</td>
</tr>
<tr>
<td>415</td>
<td>108,522 cows from Iowa D.H.I.A. records</td>
<td>Bickley, F.A. (1933)</td>
</tr>
<tr>
<td>424</td>
<td>364 cows, Iowa State College dairy herd, 1917-1932</td>
<td>Yapp, W.W. and A.F. Kuhlman (1933)</td>
</tr>
<tr>
<td>424</td>
<td>110 positive calvings, Univ. Ill. dairy herd</td>
<td>Ingels, J.W. (1936)</td>
</tr>
<tr>
<td>424</td>
<td>286 negative calvings, &quot; &quot; &quot;</td>
<td>Johansson, L. (1940) and A. Hansson (1940)</td>
</tr>
<tr>
<td>426</td>
<td>Iowa State College dairy herd, 1936-1939</td>
<td>Boynton, C.R. (1940)</td>
</tr>
<tr>
<td>429</td>
<td>153,610 cows, Iowa D.H.I.A.</td>
<td>Cannon, G.Y. and E.N. Hansen (1943)</td>
</tr>
<tr>
<td>400</td>
<td>355 Louisiana state records</td>
<td>Seath, D.W. et al. (1943)</td>
</tr>
<tr>
<td>426</td>
<td>375 cows, Iowa State College dairy herd</td>
<td>Vicenio, J.A. (1944)</td>
</tr>
<tr>
<td>409</td>
<td>3,181 Simmental cows</td>
<td>Ivanovic, D. (1951)</td>
</tr>
<tr>
<td>459</td>
<td>629 cows, Univ. of Nebraska dairy herd</td>
<td>Davis, H.E. (1951)</td>
</tr>
</tbody>
</table>
2. Relation of Calving Interval to Production

Several investigators have been concerned with the relationship between the production of milk and butterfat and the length of calving interval. Most of these studies have been directed toward determining the length of calving interval optimum for obtaining a high level of production.

Sanders (1927a) in a study of the lactation records collected by the Norfolk M.R.S. dealt with the relation of current calving interval to current average weekly yield of milk during the same interval. From this study he indicated that the optimum calving interval was approximately 12 to 13 months with some variation in particular cases.

In a second study published in the same year, Sanders (1927b) reports correlations between the length of service period and total lactation yield which were .44 for the first calvers and .40 for the older cows. The difference between these two correlations was insignificant. Since calving interval is almost the same as service period plus a constant, the correlations between production and calving interval would be almost the same as the correlations he found between production and service period.

Matson (1929) in India studied the influence of preceding calving interval on production. He indicated that for low yielders nothing was gained by lengthening the preceding calving interval over a year.
The correlation between tenacity of water interface and prey addition was observed in the same experiment. The correlation between tenacity of water interface and prey addition was also observed during the experiment. The prey yield per day over the first three days of the experiment was expressed as:

\[ \text{Prey yield per day} = \text{prey density} \times \text{prey per cent correct per unit area} \]

The prey density was estimated from the difference between the observed and expected prey density, as described by Reay (1969) in a group of experiments involving the same species.

The results showed that the prey yield per day should be lower than expected, as previously reported.
correlation between the average length of calving interval over the first nine intervals and the production per day over the same period was .059. These workers indicated that calving interval does not have an important effect on yield and that in their data the high yielding cows were not bred to freshen less frequently than the low yielding cows. The analysis of these data was not conducted on a within-herd basis. Consequently, the effects of any differences between herd averages are included in the various estimates reported. Also it is to be remembered that correlation coefficients do not reveal the full importance of a relation if it is curvilinear.

Johansson and Håkansson (1949) studied the relation between the length of calving interval and production in 13 different herds of Swedish Red and White cattle. They found that, the daily yield of milk during the current calving interval decreases as the length of the interval increases. On the contrary, the average daily yield increased with increasing length of preceding calving interval up to 420 days, but after that no further increase was detected. The correlations between preceding calving interval and the butterfat yield in the first 300 days differed slightly for the various lactations, ranging from .134 to .230. The regression of yield (kilograms of butterfat) on preceding calving interval (measured in days) also varied slightly for the different lactations, ranging from .052 to .130. When the effect of calving interval on both the current and subsequent lactation yield was taken into consideration, Johansson and Håkansson found that the optimum length of the first calving
interval was from 410 to 430 days. The daily yield decreased for shorter or longer calving intervals. The optimum length of the second and third calving intervals was shorter, being about 400 days. An increase in length of calving interval above 430 days consistently caused a decrease in average daily yield.

In an investigation of 1,575 lactation records of 274 Holstein cows, Dickerson (1940) found that the variation in the length of calving interval was responsible for five per cent of the variation in the total production during the first 305 days of the lactation. One-tenth of the variation in 365-day records and one-fourth of the variation in the total lactation records were caused by variation in the length of calving interval. He reported that the regression of total butterfat yield on length of calving interval is essentially linear, with a .66 pound increase in fat per day of increase in calving interval. The intra-herd correlation between 305-day fat records of the same cow, corrected for age of cow and length of calving interval, was the same as for records corrected only for age. Dickerson concluded from this, that the length of calving interval was not an important source of variation unless the records were longer than 305 days and nothing would be gained by correcting for it.

Tyler and Hyatt (1951) studied the records of 2,203 cows each with three or more calving intervals and a completed lactation record following each of the first three calvings. They indicated that the
length of calving interval is an important source of variation in 365-day records, or total lactation records, but it is a relatively unimportant cause of differences in 365-day records. They suggested that cows with the shorter calving intervals are inherently poor producers. This may indicate that a positive genetic correlation exists between production and length of calving interval. Tyler and Eyatt concluded from their study, that dairymen should strive for a 12 to 13 month calving interval in order to produce a maximum amount of milk and the maximum number of calves with the least harmful effects on the herd.

Vincencio (1944) reported a significant correlation of .15 between the mean lifetime production of butterfat and the mean length of calving interval of 365 cows in the Iowa State College dairy herd. This relationship was reversed, however, when the correlation between the mean calving interval and the production per month of productive life was calculated, yielding a value -.11. In this same study Vincencio indicated that a slight, but insignificant positive correlation exists between calving interval and yield in the following lactation when yield is measured by average production per month. Calving interval had a more distinct influence on the current production, with the correlation coefficients ranging from -.27 to +.36, for the different lactations. These correlations were negative for the second to fifth lactations but became positive for the sixth and seventh lactations.

An investigation was conducted by Skjervold (1949) on the effect
of environment on the lactation records of 3,155 Red Trönder cattle.
His data covered the period 1926 to 1940 inclusive. He found that for
maximum production the length of calving interval should be 12 to 13
months. Considerable variation existed in the length of calving interval.
The first interval was eight days longer than the second to fourth
intervals. After the fourth interval some increase in the length of
interval was indicated.
3. Repeatability of Calving Interval

The repeatability of calving interval measures the tendency of a cow to have calving intervals of similar duration. A few workers have attempted to measure this and their results have shown fairly close agreement.

Hammond and Sanders (1923) in a study of the variation in length of service period, stated that cows tend to have all long or all short service periods, however, they did not present any evidence to support their contention. If this is true for service period, it is almost certain to be true for calving interval.

In one of the earliest studies on repeatability of calving interval, Gaines and Palfrey (1931) reported a correlation of \(0.086 \pm 0.019\) between the calving intervals of the same cow, not including the first interval. The data used in their analysis were taken from the report of Langmanck (1921) and included 186 cows of the Red Danish breed, each with nine calving intervals. The effects of any differences between herd averages would have been included in their data.

Fiese (1939) in a study of the calving records of 1,157 cows from the Iowa Dairy Herd Improvement Associations and 321 cows from the Iowa State College dairy herd deduced a correlation of \(0.156\) between the calving intervals of a cow within a herd. He computed this correlation by use of the following ratio of the variances,
Intra-hard variance - Intra-cow variance

Intra-hard variance

which yielded a value nearly the same as would have been obtained by use of Fisher's (1946) method of intra-class correlation.

A comprehensive study was conducted by Johansson and Hansson (1940) on the calving records of 301 Swedish Red and White cows. All these cows had completed their first five calving intervals. Of the total variation in calving interval 95.3 per cent was accounted for by the variation within cows, whereas only 4.7 per cent was due to variation between cows. From this analysis they calculated a correlation of .036 between calving intervals of the same cow. The correlation between first and second calving intervals of 1,194 cows was only .029 ± .028. It was concluded that for most practical purposes the repeatability of calving interval could be neglected since only a very slight tendency existed for a cow to repeat a short or a long calving interval.

Dickerson (1940) reported an intra-cow correlation within herds of .07 for length of calving interval. This correlation was based on the calving records of 274 Holstein-Friesian cows, each of which had at least five lactations. This value is somewhat higher than those reported by Johansson and Hansson (1940) but quite similar to the value of .088 found by Gaines and Palfrey (1931).

Østergaard (1942) conducted a study of the calving intervals of 970 cows taken from the Danish Cow Herd Books. He found an intra-class
<table>
<thead>
<tr>
<th>Table 3.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Represenation 1, 2, 3, and 4</td>
<td>10%</td>
</tr>
<tr>
<td>Represenation 5</td>
<td>15%</td>
</tr>
<tr>
<td>Represenation 6</td>
<td>20%</td>
</tr>
<tr>
<td>Represenation 7</td>
<td>25%</td>
</tr>
<tr>
<td>Represenation 8</td>
<td>30%</td>
</tr>
<tr>
<td>Represenation 9</td>
<td>35%</td>
</tr>
</tbody>
</table>

The table shows the percentage of representation by various methods. The percentages are as follows:

- Representation 1, 2, 3, and 4: 10\%
- Representation 5: 15\%
- Representation 6: 20\%
- Representation 7: 25\%
- Representation 8: 30\%
- Representation 9: 35\%

Note: The total percentage may exceed 100\% due to rounding errors.
Correlation between covariance

...
In a recent study, Dunbar and Henderson (1950) considered the length of calving interval as a measure of fertility. They obtained a heritability value of zero for the length of calving interval. They concluded, therefore, that the length of calving interval could not be used as a satisfactory measure of breeding efficiency in dairy cattle.
III. SOURCE AND ADJUSTMENT OF DATA

The production and calving records of the 731 cows used in this investigation were taken from the herdbooks of the Iowa State College Holstein herd and the Iowa State Board of Control Holstein herds at Mount Pleasant and Cherokee, Iowa. The data included all cows that had calved at least once during the period from January, 1940, to August, 1951.

During this interval the management of these three herds remained fairly constant. No major change was made in the breeding plans. Some features of the breeding plans are, of necessity, quite similar since these herds are all required to produce a fairly constant supply of fluid milk throughout the year.

The following information was taken from the herd books and subsequently punched on I.B.M. cards for calculation.

1. Herb identification number
2. Cow's identification number
3. Dam's identification number
4. Sire's identification number
5. Year in which calving occurred
6. Month in which calving occurred
7. Age of cow at time of calving
8. Length of calving interval
9. Milk and fat production as measured by 305-day, 2X, M.E. records
For the Iowa State College herd further information was taken from the breeding records and likewise punched on the cards. This information included the following.

1. Number of days from date of parturition to first estrus
2. Number of days from first estrus to first breeding
3. Number of days from first breeding to the following parturition

All of the milk and butter fat production records as well as of the calving records for each cow were included in these data except when it was definitely recorded that an abortion had occurred. In such cases the current record during which the abortion occurred and all following records for that cow were discarded. Each card contained a single lactation record and the calving record corresponding to that lactation.

The production records used in these data were converted to a twice-a-day, 305-day, mature equivalent basis and are expressed in pounds. This basis was used since it is the standard which the various breed associations are now using for their official production records.

The conversion factors used for converting the records to a mature equivalent basis were those derived by Kendrick (1942). The correction factor of .833 for milking frequency was applied in converting the 3X, 305-day, M.E. records to a 2X basis. Where a cow milked for a period shorter than 305 days but longer than 240 days, the total production at the time of cessation of milking was used as the 305-day record without extrapolation for incompleteness of lactation. The only exception to
this was that the records of these cows which left the herd while they were still in milk were extrapolated to a 365-day basis by using a set of conversion factors developed from the factors presented by Turner and Bagwell (1924). This was done only where the fact of leaving the herd while still in milk was quite clear from the records.

The age of cow at date of calving was expressed in years and tenths of years without any gross grouping of the old cows. So fine a subdivision was probably unnecessary for the cows older than about four years, but it was thought valuable for the very young cows and was used for the older cows because the machine calculations were more convenient when all were on the same basis. The calving interval was expressed in days.
IV. ANALYSIS OF DATA

A. Influence of Non-Genetic Factors on Calving Interval

Many investigators have studied the reactions of dairy cows to the environment. These studies have been aimed mainly at determining the non-genetic causes of variation in production and at developing methods by which the variation caused by such factors can be eliminated. Variations in such things as age of cow, calving interval, dry period, season of calving and system of management have been considered as major non-genetic causes of variation in milk and butterfat production.

The primary purpose of the present study was to determine the suitability of calving interval as a measure of a cow's fertility. It is essential, therefore, to determine the non-genetic causes of variation in calving interval and to develop methods by which the more important of these can be eliminated or correction for their effects can be made. The elimination of such causes of variation is desired in order that a cow's real fertility can be estimated more accurately. In this analysis the causes of variation investigated were: year of calving, age of cow at time of calving, and herd management.

1. Influence of year of calving within herd

The data on length of calving interval were distributed over an eleven year period, 1940 to 1950 inclusive. Each calving interval was tabulated according to the year in which the interval began.
It seemed advisable, as a first step in the study of year effects, to determine whether the year means for length of calving interval exhibited any obvious trend. For this purpose, the year means for each herd were calculated and are presented in Table 4 and are illustrated graphically in Figure 1. From the table of means and the corresponding graphs it appears that the three herds differ somewhat in the yearly means for length of calving interval over the eleven-year period and probably also differed genuinely in their time trends. The yearly means for the college herd changed very little over the period studied, but in the Mount Pleasant herd it appears that the mean length of calving interval has become slightly shorter. In the Cherokee herd there are large differences between years without any sure indication of a trend towards a shorter or longer calving interval.

A test of significance calculated from the analysis of variance in Table 5 indicates that the differences between the year means are statistically significant. It is apparent from Figure 2 that the records included in this test of significance are not normally distributed but Cochran states (1947) that some non-normality in data will not introduce any serious error in the significance levels of the F-test.

For certain of the analyses it seemed advisable to eliminate the effects of years within herd, especially, for estimating heritability and repeatability. Since daughters have most of their calving intervals in different years than their dams the existence of yearly environmental
Table 4. Year means for length of calving interval in each herd

<table>
<thead>
<tr>
<th>Year</th>
<th>I.S.C. herd</th>
<th>Mount Pleasant herd</th>
<th>Cherokee herd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of intervals</td>
<td>Number of intervals</td>
<td>Number of intervals</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>1940</td>
<td>49</td>
<td>402</td>
<td>48</td>
</tr>
<tr>
<td>1941</td>
<td>51</td>
<td>384</td>
<td>48</td>
</tr>
<tr>
<td>1942</td>
<td>51</td>
<td>379</td>
<td>55</td>
</tr>
<tr>
<td>1943</td>
<td>59</td>
<td>384</td>
<td>36</td>
</tr>
<tr>
<td>1944</td>
<td>40</td>
<td>370</td>
<td>46</td>
</tr>
<tr>
<td>1945</td>
<td>40</td>
<td>411</td>
<td>54</td>
</tr>
<tr>
<td>1946</td>
<td>46</td>
<td>403</td>
<td>51</td>
</tr>
<tr>
<td>1947</td>
<td>53</td>
<td>381</td>
<td>71</td>
</tr>
<tr>
<td>1948</td>
<td>50</td>
<td>396</td>
<td>60</td>
</tr>
<tr>
<td>1949</td>
<td>49</td>
<td>391</td>
<td>69</td>
</tr>
<tr>
<td>1950</td>
<td>22</td>
<td>382</td>
<td>23</td>
</tr>
<tr>
<td>11-year average</td>
<td>504</td>
<td>389</td>
<td>561</td>
</tr>
</tbody>
</table>
Figure 1. Graphic illustration of the year means for the different herds.
Figure 2. Frequency distribution of the length of calving interval (20-day groups).

Mean: 413 days
Modal Class: 360-380 days
Std. Dev.: 78 days
Range: 277-884 days
mean difference will reduce the regression of difference on year.

The third component is the component between the fourth component and the second component. The third component is the component between the regression of the fourth component and the second component.

The fourth component is the component between the second component and the first component. The fourth component is the component between the regression of the second component and the first component.

The fifth component is the component between the first component and the zero component. The fifth component is the component between the regression of the first component and the zero component.

The sixth component is the component between the zero component and the negative value of the mean difference. The sixth component is the component between the regression of the zero component and the negative value of the mean difference.

The seventh component is the component between the negative value of the mean difference and the mean difference. The seventh component is the component between the regression of the negative value of the mean difference and the mean difference.
Table 5. Analysis of variance of calving interval for the influence of herd (H), year within herd (Y), and cow within herd (C)

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>Expected composition of mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1662</td>
<td>6,094</td>
<td>E + .999 C + .369Y + .666 H</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>260.136</td>
<td>E + 3.160 C + 25.590 Y + 553 H</td>
</tr>
<tr>
<td>Between years within herd</td>
<td>30</td>
<td>20.245</td>
<td>E + .761 C + 50.161 Y</td>
</tr>
<tr>
<td>Within year within herd</td>
<td>1630</td>
<td>5.497</td>
<td>E + C</td>
</tr>
<tr>
<td>Between cows within herd</td>
<td>726</td>
<td>7.618</td>
<td>E + 2.271 C + .787 Y</td>
</tr>
<tr>
<td>Within cow within herd</td>
<td>932</td>
<td>4.733</td>
<td>E + Y</td>
</tr>
<tr>
<td>H = 464</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y = 298</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C = 1012</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E = 1485</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
square between herds.

Since calving intervals were classified according to the year in which the interval started, it was possible for a few cows to have two intervals recorded in the same year. This would change slightly the composition of the mean square within years and within cows from that shown in Table 5. The coefficients for the year and cow components in these mean squares would be actually less than one. However, the error introduced by assuming that a cow had only one interval in a given year was very small because the exceptions were so few.

The components of variance are presented in Table 6 in absolute values and also expressed as fractions of the total and intra-hard variance.

Table 6. Components of variance, expressed as fractions of the total and intra-hard variance

<table>
<thead>
<tr>
<th>Component</th>
<th>Value of component</th>
<th>Fraction of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>H</td>
<td>4.64</td>
<td>.074</td>
</tr>
<tr>
<td>Y</td>
<td>293</td>
<td>.048</td>
</tr>
<tr>
<td>C</td>
<td>1012</td>
<td>.162</td>
</tr>
<tr>
<td>E</td>
<td>4485</td>
<td>.716</td>
</tr>
</tbody>
</table>

The herd component accounts for 7.4 per cent of the total variance in calving interval. The size of this component for herd differences offers only a very uncertain basis for generalizing, since it is part
of the description of the three particular herds studied. These data offer little or no basis for estimating whether these three herds were unusually similar or unusually different from each other, as compared with what would be true of a typical sample of three herds. At any rate this value of 7.4 per cent is distinctly larger than the 1.1 per cent reported by Johansson and Hansson (1940).

The year component accounts for only 4.8 per cent of total variance and 5.1 per cent of the intra-hard variance of individual calving intervals. This estimate agrees closely with the value of between five and six per cent reported by Johansson and Hansson (1940) in their analysis of lactation records. From a comparison of these findings it seems that year to year differences within a hard influence individual lactation records and calving intervals to a similar degree.

Since herd to herd differences appear fairly important in the present investigation, all of the analyses have been conducted on a within-hard basis. The effect of intra-hard, year to year differences were slight in these data. These intra-hard year effects are eliminated in certain analyses and the value of such procedure is discussed in the respective sections with the analysis.
2. **Age of cow at first calving**

Since many studies have been conducted concerning the influence of age at first calving on the production of milk and butterfat in subsequent lactations, it seemed advisable to determine if an association existed between the age of cow at first calving and the length of subsequent calving intervals. It is conceivable that cows calving for the first time at an early age possess superior fertility which is exhibited in later life by short intervals between calvings. In this analysis the first, second and third intervals were classified according to age of cow at first calving for each herd separately and for all herds combined.

The graphs in Figure 3 indicate that the relationship between age of cow at first calving and the length of the first calving interval is slightly curvilinear and is similar for all three herds. Those cows calving for the first time at 25 to 28 months of age appear generally to have a short first calving interval. The graphs in Figures 4 and 5 seem to indicate that little if any relationship, either linear or curvilinear, exists between age at first calving and length of the second and third calving intervals.

The means for the different ages at first calving, based on the records of all three herds, are presented in Table 7. It is indicated by these general means, as well as by the graphs in Figures 3, 4 and 5 for each herd separately, that the shorter calving intervals are
Figure 3. Relation between age at first calving and length of first calving interval.

Figure 4. Relation between age at first calving and length of second calving interval.
Figure 5. Relation between age at first calving and length of third calving interval.

Figure 6. Relation between age of cow at time of calving and average length of calving interval.
exhibited by those cows calving for the first time prior to 36 months of age. The major exception is the mean of 436 days for the first calving interval of those cows calving at 24 months of age or less.

Table 7. Relation between age of cow at first calving and the length of her first three calving intervals (C.I.)

<table>
<thead>
<tr>
<th>Age at first calving (months)</th>
<th>Average length of calving interval (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st C.I.</td>
</tr>
<tr>
<td>24 and under</td>
<td>438</td>
</tr>
<tr>
<td>25 - 26</td>
<td>391</td>
</tr>
<tr>
<td>27 - 28</td>
<td>392</td>
</tr>
<tr>
<td>29 - 30</td>
<td>427</td>
</tr>
<tr>
<td>31 - 32</td>
<td>420</td>
</tr>
<tr>
<td>33 - 34</td>
<td>412</td>
</tr>
<tr>
<td>35 - 36</td>
<td>424</td>
</tr>
<tr>
<td>over 36</td>
<td></td>
</tr>
</tbody>
</table>

aData includes all herds

Since this group of cows calved at an early age, it is possible that they were intentionally not rebred as soon after parturition as those cows calving for the first time at older ages. This would be in accord with many published recommendations to allow dairy heifers plenty of time to recover from the strain of calving and lactation at an unusually early age. Such delayed breeding of the early calvers could account for the extremely long interval of 436 days.
The intensity of the linear relationship between age of cow at first calving and the length of her subsequent calving intervals is shown by the intra-herd correlation and regression coefficients presented in Table 8.

Table 8. Coefficients of correlation and regression for age at first calving and the average length of first, second and third calving intervals

<table>
<thead>
<tr>
<th>Interval</th>
<th>Number of cows</th>
<th>r</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>581</td>
<td>.034</td>
<td>.77</td>
</tr>
<tr>
<td>Second</td>
<td>346</td>
<td>.031</td>
<td>.58</td>
</tr>
<tr>
<td>Third</td>
<td>214</td>
<td>-.010</td>
<td>-.19</td>
</tr>
</tbody>
</table>

The correlation coefficients are all very small and in no case are they statistically significant. The regression coefficients indicate that increases of less than a day are expected in the length of the first and of the second calving intervals for each month of increase in age at first calving, but, because this is so far below the level of statistical significance, it merits little attention. The age of cow at time of first calving has practically no linear association with the length of the third calving interval, \( r = -.01 \).

Analyses of the variance in length of the first, second and third calving intervals indicate that the mean calving intervals differ significantly for the different age groups. Since this test includes
curvilinear trends as well as linear ones and Table 8 showed practically no linear trends, it appears that the association of age of cow at first calving with the length of the first, second and third calving intervals is largely non-linear. Therefore, correction factors based on the linear association of age at first calving with the length of the first, second and third calving intervals would be of no value.

3. Age of cow at beginning of calving interval

It is a well established fact that the production of milk or butter-fat increases with the age of cow until a maximum is reached and then the production decreases as the cow grows older. Whether the length of calving interval follows a similar trend has not been so well determined. It might be that a cow reaches a maximum with regard to fertility, at a certain age and after that the level of fertility decreases. This decline in fertility might in turn be reflected by an increase in the length of calving interval with increasing age, after the age of maximum fertility had been reached. Such a trend could be determined satisfactorily only if the managerial conditions remained fairly constant during the lifetime of the cow.

The calving intervals in this study were classified according to the age of cow at the calving when the interval begins, for each herd individually and for all herds combined. The mean standard deviation and coefficient of variation for each age group, the data from all herds being combined, are presented in Table 9. The graphs of the herd means
in Figure 6 indicate that the relationship between length of calving interval and age at time of calving is practically zero and is similar for each herd, except that the herd means are different for cows up to seven years of age. The mean length of calving interval for the age groups over seven varies considerably, both within and between herds, and does not show any apparent trend, but the records at those ages are few. The means in Table 9 show the shortest calving interval for the three-year-old cows. The next shortest is for the four-year-olds, but the difference between them and the remaining ages is small. There is a hint that the interval is longer for the cows over six, but the data are too few and irregular for this to be convincing.

Table 9. Mean, standard deviation and coefficient of variation for calving intervals grouped according to age of cow when the interval began

<table>
<thead>
<tr>
<th>Age</th>
<th>Number of intervals</th>
<th>Mean (days)</th>
<th>σ</th>
<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 and under</td>
<td>514</td>
<td>412</td>
<td>70.5</td>
<td>17.1</td>
</tr>
<tr>
<td>3</td>
<td>363</td>
<td>402</td>
<td>67.0</td>
<td>16.7</td>
</tr>
<tr>
<td>4</td>
<td>280</td>
<td>409</td>
<td>66.7</td>
<td>16.3</td>
</tr>
<tr>
<td>5</td>
<td>196</td>
<td>413</td>
<td>79.8</td>
<td>19.3</td>
</tr>
<tr>
<td>6</td>
<td>133</td>
<td>416</td>
<td>64.2</td>
<td>15.4</td>
</tr>
<tr>
<td>7</td>
<td>80</td>
<td>439</td>
<td>106.1</td>
<td>24.2</td>
</tr>
<tr>
<td>8</td>
<td>39</td>
<td>415</td>
<td>62.1</td>
<td>15.0</td>
</tr>
<tr>
<td>9</td>
<td>26</td>
<td>471</td>
<td>118.6</td>
<td>31.6</td>
</tr>
<tr>
<td>10 and over</td>
<td>32</td>
<td>433</td>
<td>57.4</td>
<td>13.2</td>
</tr>
<tr>
<td>All ages</td>
<td>1663</td>
<td>413</td>
<td>70.5</td>
<td>17.1</td>
</tr>
</tbody>
</table>

Standard deviation on an intra-hard and intra-year basis
The standard deviations for the different age groups vary closely with the mean, as is perhaps to be expected since gestation length imposes a lower limit on calving interval but nothing imposes so sharp an upper limit.

The analysis of variance in Table 10 indicates that the differences between the various age groups are statistically significant. The age component (A) accounts for 10.3 per cent of the total variance and 11.7 per cent of the intra-hard and intra-year variance of individual calving intervals.

Johansson and Hansson (1940) found that the differences between age groups (by order of lactations) accounted for only 3.2 per cent of the total variance in calving interval. This value was based on a selected group of cows, however, as the 301 cows used in their analysis had 5 lactations each. The lactations after the fifth and hence the calving intervals after the fourth were omitted from their analysis. This would have caused a reduction in the variance between age groups if the relation in their material was the same as in the present analysis.

Fine (1939) considered age of cow as an unimportant source of variation in calving interval. His conclusion was based on the small differences which he observed amongst the means of the different age groups.

From the analysis of variance and covariance in Table 11, the correlation and the regression of calving interval on age were obtained.
<table>
<thead>
<tr>
<th>Source</th>
<th>Expected Composition of Mean Square</th>
<th>Mean Square</th>
<th>d.f.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Herds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td>90</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>90.496</td>
<td></td>
</tr>
<tr>
<td>Within Age-Groups</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td>90</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>90.496</td>
<td></td>
</tr>
</tbody>
</table>

*Table 10. Summary of variance for the influence of age of cow.*

\( V = 6.99 \)
Growth by correlation in the length of catatonic age of com
under seven years of age, it is obvious, however, that nothing can be
then the equation in Figure 6 seems to be exactly true for those o
coefficient varies between length of catatonic and age of com-
that be referred to. It may be assumed then that the equation to
verbalage in the length of catatonic and length and age of
previously at some of the Z.s. the entire and all into-year.
the inverse relation of catatonic to age would account for
the inverse relation of catatonic to age. The nature of the cor
the average of the catatonic in each decade of age at that
length of catatonic in the length of age is the same as that
the length of the catatonic and length of the age at that
at time of catatonic and the length of the catatonic inter-

<table>
<thead>
<tr>
<th>Age in catatons</th>
<th>With in years</th>
<th>z = 0.09</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.7</td>
<td>3.9, 495.0</td>
<td>20.4</td>
</tr>
<tr>
<td>27.6</td>
<td>3.5, 493.7</td>
<td>16,6</td>
</tr>
<tr>
<td>26.5</td>
<td>3.0, 490.5</td>
<td>17,6</td>
</tr>
<tr>
<td>26.0</td>
<td>3.0, 490.0</td>
<td>16,6</td>
</tr>
<tr>
<td>25.0</td>
<td>3.0, 490.0</td>
<td>17,6</td>
</tr>
</tbody>
</table>

Table II. Height of correlation and covariance of age
If it is considered for the amplitude that $T_{\text{diff}}$ and $T_{\text{det}}$ are coexistent, then

$$\frac{\varepsilon}{\delta} \rightarrow \frac{\varepsilon}{\gamma} \rightarrow \frac{T_{\text{diff}}}{T_{\text{det}}}$$

The expected to be exact

In order to understand the expected to be exact

In order to understand the expected to be exact
bred during the first estrous period following parturition, \( P_2 \) would then be zero for all intervals. To obtain values of \( P_2 \) greater than zero, some intentional delay in breeding had to occur. The magnitude of \( P_2 \), therefore, will provide one measure of the management effect.

The means and standard deviations for the three periods are presented in Table 12.

**Table 12. Mean and standard deviation of \( P_1 \), \( P_2 \) and \( P_3 \)**

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean</th>
<th>( \sigma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_1 )</td>
<td>55</td>
<td>29.0</td>
</tr>
<tr>
<td>( P_2 )</td>
<td>26</td>
<td>29.2</td>
</tr>
<tr>
<td>( P_3 )</td>
<td>309</td>
<td>52.2</td>
</tr>
</tbody>
</table>

\( a \) Standard deviation on an intra-cow basis

On the average, the first visible estrus occurs 55 days after parturition. The standard deviation of 29 days for \( P_1 \) indicates, however, that considerable variation does exist in the length of interval from parturition until first estrus. The mean of 26 days for \( P_2 \) indicates that, on the average, breeding was delayed for slightly more than one estrous cycle\(^a\) after first estrus had occurred. \( P_3 \) includes the length

\(^a\)The average length of estrous cycle for dairy cows is approximately 21 days with a standard deviation of 3.68 days, (Adell, 1946).
of gestation as well as the period of time from first breeding until conception. If 278 days is considered as the mean length of gestation in Holstein-Friesian cattle, it then can be deduced from $P_3$ that an average of 31 days elapsed from the time of first breeding until conception. This indicates that an average of approximately 2.5 services were required per conception.

Although it was indicated by the mean of $P_2$ (26 days) that some delayed breeding is practiced, a further analysis was conducted to determine the approximate portion of the intra-cow variance in calving interval for which variation in $P_2$ is responsible. In this analysis calving interval was considered as the dependent variable and $P_1$, $P_2$ and $P_3$ the independent variables as illustrated by the path coefficient diagram in Figure 7. The double headed arrows in Figure 7 represent the simple correlations between the two variables to which the arrows are pointed.

Figure 7. Path coefficient diagram indicating the inter-relationships of $P_1$, $P_2$, $P_3$ and calving interval

The single headed arrows are the path coefficients (Wright, 1934), or standard partial regression coefficients (Snedecor, 1946). The problem in this analysis reduces essentially to that of computing
The coefficients of the two sets of values are

<table>
<thead>
<tr>
<th>$\theta^\circ$</th>
<th>$\varepsilon_1$</th>
<th>$\varepsilon_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>590</td>
<td>$\varepsilon_1$</td>
<td>$\varepsilon_2$</td>
</tr>
<tr>
<td>980</td>
<td>$\varepsilon_1$</td>
<td>$\varepsilon_2$</td>
</tr>
<tr>
<td>662</td>
<td>960</td>
<td>618</td>
</tr>
</tbody>
</table>

Table 2.8, Corrected Coefficients

The corrected coefficients for Table 2.8, Corrected Coefficients, have been obtained by analyzing the data from the experiment. The values for $\varepsilon_1$ and $\varepsilon_2$ are given in the table. The values for the path coefficients are obtained by

$\varepsilon_1$ and $\varepsilon_2$.
.994 and .924 were computed for a, b and c respectively.

\[ r_{C1} P_1 = a + r_{P1} P_2 + r_{P1} P_3 + c \]
\[ r_{C1} P_2 = a + r_{P1} P_2 + b + r_{P2} P_3 + c \]
\[ r_{C1} P_3 = a + r_{P1} P_3 + b + r_{P2} P_3 + c \]

According to Wright, (1934) the square of a path coefficient represents the portion of the variance in the dependent variable which the independent variable causes directly, provided the causal relations really are those shown in the diagram. Values of .261, .244 and .354, were obtained by squaring a, b and c, respectively. The sum of the direct values is greater than one because some of the joint terms, 2abrp_1p_2, 2acrp_1p_3 and 2bcrp_2p_3, are negative. The strong negative joint term (-.312) between a and b means merely that the variations in C.I. which are caused directly by P_1 and P_2 largely cancel each other. Values of .034 and -.069 were found for the joint terms between a and c, and b and c, respectively.

The direct values indicate that P_1 and P_2 account for less of the intra-cow variance in calving interval than P_3. When the joint terms are considered also, it is apparent that P_1 and P_2 together are of far less importance than P_3 in determining the variance in calving interval.

This study indicates that the physiological mechanisms of the cow
as well as the effect of chance which govern the length of $P_3$ and $P_4$, especially $P_3$, are of considerably greater importance than management as a factor influencing the length of calving interval.
E. Repeatability of Calving Interval

Repeatability is the tendency for a cow to have calving intervals of similar duration. It is measured by the correlation among the several records of the same cow. Repeatability includes heritability in the broad sense, which defines as heritable the additively genetic portion of the variance, as well as that portion of the variance due to dominance and epistatic deviations, and also that due to any permanent effects of environment on the cow.

Repeatability of calving interval was estimated from the analysis of variance in Table 5, (page 33) by the method of intra-class correlation. The intra-herd repeatability after correcting for the variance due to yearly differences in environment is defined as a ratio of the cow component of variance (C) to the cow and error (E) components of variance, \( \frac{C}{C + E} \). This ratio is .154 in these data. The practical usefulness of such an estimate cannot be realized, however, until all calving intervals are correctly adjusted for yearly environmental differences.

The intra-herd repeatability for calving interval without adjusting for year differences would be \( \frac{C}{C + E + Y} \) and, in these data, is equal to .175 if none of the cows being compared are contemporary. In actual data, however, a certain number of cows are contemporary and the Y component will not be represented completely in the mean square "between cows within herds", although fully represented in the mean square
"within cow". This will lead to a slight underestimate of repeatability when C is obtained by subtracting the mean square within cows from the mean square between cows and then dividing the remainder by the coefficient (2.271) for C in the mean square between cows within herds. The value obtained for the intra-hard repeatability by using C and E estimated in this manner was .171. This repeatability value represents more closely what can be realized in a practical breeding program where a method of adjusting the length of calving interval for yearly effects is not available. Using the Z transformation of Fisher (1946) the 95 per cent confidence interval for the repeatability of .171 was found to be .125 to .217.
C. Heritability of Calving Interval

When it is assumed that the genetic and environmental effects are uncorrelated, the phenotypic or observed variance of a character can be written as

\[ \sigma_p^2 = \sigma_G^2 + \sigma_D^2 + \sigma_I^2 + \sigma_E^2 + \sigma_{EH}^2 \]

where \( \sigma_p^2 \) is the phenotypic variance between individuals in the population,

\( \sigma_G^2 \) is the variance due to the additive effects of the genes,

\( \sigma_D^2 \) is the variance due to non-additive effects of allelic genes,

\( \sigma_I^2 \) is the variance due to non-additive effects of non-allelic genes,

\( \sigma_E^2 \) is the variance due to existing environmental conditions,

and \( \sigma_{EH}^2 \) is the variance due to the interaction of environment and heredity. The term \( \sigma_D^2 \) includes the variation caused from interaction between alleles (dominance in any of its degrees) and it is not transmitted from parent to offspring. The epistatic variance \( \sigma_I^2 \) includes all forms of interaction between non-allelic genes. A small portion of this variance can be transmitted from one generation to another.

The term \( \sigma_E^2 \) includes both the permanent \( \sigma_{PE}^2 \) and temporary \( \sigma_{TE}^2 \) environmental effects which affect some practical breeding procedures differently. Any correlation between the environment and the
Genes, dominance and epistatic effects which may exist in the total population is included in the $\sigma_{MN}^2$ term.

The fraction of the phenotypic variance which is due to the whole genetic composition of the individual, considered as a unit, is referred to as heritability in the broad sense and is written as:

$$\frac{\sigma_G^2 + \sigma_D^2 + \sigma_I^2}{\sigma_G^2 + \sigma_D^2 + \sigma_I^2 + \sigma_E^2 + \sigma_{MN}^2}$$

In some cases a portion of the $\sigma_{MN}^2$ term will be in the numerator.

Heritability in the narrow sense has been defined by Lush (1945), as that fraction of the total phenotypic variance which is genetic, i.e.:

$$\text{Heritability} = \frac{\sigma_G^2}{\sigma_P^2} = \frac{\sigma_G^2}{\sigma_G^2 + \sigma_D^2 + \sigma_I^2 + \sigma_E^2 + \sigma_{MN}^2}$$

It is actually the fraction of the total observed variance that is due to the average effects of the genes. Heritability in this sense is more meaningful for ordinary breeding practice than is heritability in the broad sense, since selection for non-additive effects of dominance, epistasis, and of interactions between environment and heredity does not contribute to a permanent change in a population.

---

6Genes is defined as the sum of the average effects of all genes in an individual and is synonymous with "additively genetic" value.
Numerical estimates of heritability are usually between the broad
and narrow definitions since our present methods of computing
heritability do not allow for estimating \( \sigma_e^2 \) without including some
portion of the non-additive genetic variance. How much of the dominance,
epistasis and other non-linear variance is included in the estimates
of heritability depends somewhat on the method employed.

1. **Daughter-dam regression**

Twice the intra-sire regression of daughter on dam was used as
one means of estimating the heritability of calving interval in the
present investigation. This method is especially applicable to dairy
cattle data since the dams are generally more numerous than the sires.
Since the present analysis was conducted on an intra-herd basis, the
estimate of heritability from the intra-sire regression of daughter
on dam will not be increased by the portion of \( \sigma_e^2 \) due to herd differences.

Some environmental differences are likely to remain in the intra-
sire regression of offspring on dam if a breeder treats each individual
offspring similar to the way he treated its dam. This would result in
an environmental correlation between daughter and dam, even on an intra-
sire, intra-herd basis. It is doubtful, however, if this is important
enough to cause any great discrepancy in the present estimate of
heritability, especially since the data indicate that intra-herd
variations in management had only small effects on calving interval.
The intra-sire regression of offspring on dam is desirable for this analysis since the data extend over a period of ten years during which there were considerable fluctuations in the average length of calving interval for the different years. Most of the environmental differences caused by these time trends are removed when the analysis is made on an intra-sire basis.

The effect of year to year environmental differences was not eliminated from the daughter-dam regression, except so far as that was done automatically by doing the analysis on an intra-sire basis. Since only 5 per cent of the intra-hard variance of calving interval was accounted for by yearly environmental differences anyhow, it seems reasonable to assume that the heritability estimates would be increased only a little by first eliminating the year effects. The study of Lagates (1949) yields some corroborating evidence for this assumption since in his analysis the daughter-dam regression for individual lactation records of fat was increased by only .003 by eliminating the variance due to yearly environmental differences. In his study year differences accounted for 4.9 per cent of the total variance. He indicated that in a population where the year variance is a much larger fraction of the total variance than the 4.9 per cent found in his investigation a greater difference would be noticed in estimates of heritability if year effects were not removed. In the present analysis the average of all intervals for each daughters and each dams was used. This would reduce considerably the confusing influence of yearly
\[
\left[ \frac{\mu}{(\mu^2 - 1)(\mu - 1)} + \frac{\mu}{(\mu^2 - 1)(\mu - 1)} \right], \quad q = q
\]

The correlation between the two measures of the dependent variable would have been

depended by correlation to compensate for changes in the regression equation on an

had only a single regression. Thus, when patients were confused and damp enough

take out of 0.05 to 0.77 the results would be expressed in terms of each

don't. In the average of 0.77 regression of drencher and dam, correlation

In the present example the regression of drencher on dam was read

needed.

The influence of the influence of various differences has been evaluated

interacted with a standard error of ±0.98. Effectively it would have been

estimated as an estimate of the height of the student or

don't. By the extended 0.05 to 0.77 modified. The correlation and variance are taken from Table 7 and 75, correlated.

\[
\text{cov.} \frac{0.05}{0.05} = \frac{0.05}{0.05}
\]

The correlation of drencher on dam and by 62

effectual differences.
Table 14. Analysis of variance of calving interval, milk and butterfat production of dams and calving interval of daughters

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Daughters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>446</td>
<td>3,566</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>74,882</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>2,292</td>
</tr>
<tr>
<td>Within sires</td>
<td>365</td>
<td>3,300</td>
</tr>
<tr>
<td><strong>Dams</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>416</td>
<td>3,461</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>83,526</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>2,585</td>
</tr>
<tr>
<td>Within sires</td>
<td>335</td>
<td>3,214</td>
</tr>
<tr>
<td>Total</td>
<td>416</td>
<td>5,007,212</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>69,701,764</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>10,982,176</td>
</tr>
<tr>
<td>Within sires</td>
<td>335</td>
<td>3,211,954</td>
</tr>
<tr>
<td>Total</td>
<td>416</td>
<td>5,333</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>77,984</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>6,655</td>
</tr>
<tr>
<td>Within sires</td>
<td>335</td>
<td>4,340</td>
</tr>
</tbody>
</table>

The following abbreviations will be used when presenting the data in tabular form.

- C I₀ and C I₀ = Calving interval of daughter and dam respectively.
- M₀ and M₀ = Milk production of daughter and dam respectively.
- F₀ and F₀ = Fat production of daughter and dam respectively.
Table 15. Analysis of covariance of milk production, fat production and calving interval for daughters and dams

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Covariance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>446</td>
<td>C 1.0 C l.0</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>305.86</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>73.293.0</td>
</tr>
<tr>
<td>Within sires</td>
<td>365</td>
<td>87.46</td>
</tr>
<tr>
<td>Total</td>
<td>446</td>
<td>M.0 M.0</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>513.923</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>49.689.706</td>
</tr>
<tr>
<td>Within sires</td>
<td>365</td>
<td>831.249</td>
</tr>
<tr>
<td></td>
<td></td>
<td>175.792</td>
</tr>
<tr>
<td>Total</td>
<td>446</td>
<td>F.0 F.0</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>131.19</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>24.261.50</td>
</tr>
<tr>
<td>Within sires</td>
<td>365</td>
<td>139.63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57.59</td>
</tr>
<tr>
<td>Total</td>
<td>446</td>
<td>M.0 C 1.0</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>5.328</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>69.580</td>
</tr>
<tr>
<td>Within sires</td>
<td>365</td>
<td>2.459</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.336</td>
</tr>
<tr>
<td>Total</td>
<td>446</td>
<td>C 1.0 M.0</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>- 12.045</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>- 3.419.414</td>
</tr>
<tr>
<td>Within sires</td>
<td>365</td>
<td>- 7.336</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.649</td>
</tr>
<tr>
<td>Total</td>
<td>446</td>
<td>F.0 C 1.0</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>268.08</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>26.013.50</td>
</tr>
<tr>
<td>Within sires</td>
<td>365</td>
<td>706.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32.07</td>
</tr>
<tr>
<td>Total</td>
<td>446</td>
<td>C 1.0 F.0</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>- 303.68</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>79</td>
<td>- 58.278.50</td>
</tr>
<tr>
<td>Within sires</td>
<td>365</td>
<td>- 973.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>156.96</td>
</tr>
</tbody>
</table>
where \( b \) is the regression of daughter on dam on a single record basis,

\( b' \) is the regression when averages are used for daughters and dams,

\( r_{dd} \) is the repeatability of calving intervals of the same cow,

\( \overline{m} \) is the mean number of intervals for the dams and

\( \sigma_m^2 \) is the variance of \( m \).

In the present data \( \overline{m} \) is 2.78 and the value of \( .271 \) (page 54) is used for \( r_{dd} \).

After adjusting the intra-sire regression of daughter on dam to a single record basis, the estimate of heritability of differences in length of calving interval becomes .031. This value supports the statement made by Johansson and Hansson, (1940) that probably not more than five per cent of the total variance in calving interval could be genetic. This present value of .031 for the heritability of calving interval does deviate, however, from the value of zero reported by Dunbar and Henderson (1950). Since the sampling errors associated with these values are usually quite large, as is apparent by the standard error of \( \pm .103 \) for the present heritability estimate, the difference in these two estimates could easily have occurred by chance.
2. **Paternal half sister correlation**

The method of estimating heritability from paternal half sister resemblance was used in this study in addition to the method of intra-sire regression of daughter on dam. To calculate the correlation between paternal half sisters the component of the intra-herd variance for the differences between sires must be obtained.

Table 16 gives the analysis of variance from which components of variance for difference between full sisters (F), paternal half sisters (D), sires (S) and herds (H) were obtained. From a ratio of these components of variance the paternal half sister correlation is computed. The effect of yearly environmental variation was not eliminated from this analysis since yearly differences accounted for such a small portion (5 per cent) of the intra-herd variance of calving interval. The full sister component (F) is highly significant whereas the D component is not significant and the S component is significant only at the 95 per cent level.

The reasons for the paternal half sister component (D) actually being negative are not clear. It is likely that sampling error is the major cause of this negative component, but this is not necessarily the only one. The situation may exist where the error variance ($E^2$) between records of paternal half sisters is somewhat less than the pooled estimate of error ($E$) for all cows. If the value of $E^2$ in the mean square between dams within sire and herd is less than the value
Table 16. Analysis of variance of calving interval between sires, dams within sires and full sisters

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Mean square</th>
<th>Expected composition of mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1663</td>
<td>6,094</td>
<td>E + .999 F + .998 D + .981 S + .665 H</td>
</tr>
<tr>
<td>Between hards</td>
<td>2</td>
<td>280,136</td>
<td>E + 3.152 F + 3.164 D + 31.730 S + 553 H</td>
</tr>
<tr>
<td>Between sires within hards</td>
<td>129</td>
<td>9,424</td>
<td>E + 2.653 F + 2.774 D + 12.149 S</td>
</tr>
<tr>
<td>Between dams within sire and</td>
<td>560</td>
<td>6,453</td>
<td>E + 2.215 F + 2.324 D</td>
</tr>
<tr>
<td>hard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between full sisters</td>
<td>39</td>
<td>7,433</td>
<td>E + 1.814 F</td>
</tr>
<tr>
<td>Within cow</td>
<td>932</td>
<td>4,783</td>
<td>E</td>
</tr>
</tbody>
</table>

H = 481  S = 217  D = -674  F = 1461  E = 4,783
substituted (E), the size of D would be underestimated. On the other hand the error variance (E₁₁) between records of full sisters may be greater than the pooled estimate of E for all cows. This would result in an over-estimation of \( F \) and in turn a further reduction in the paternal half sister component D.

For these data it seems that sampling error is likely to be the major cause of the extraordinarily large \( F \) component and the improbable small D component. Following this reasoning, the correlation between paternal half sisters all kept in the same herd was determined in two different manners.

The correlation between paternal half sisters using the components of variance presented in Table 16 is \( \frac{E}{S + D + E} = .037 \). A second estimate of the correlation between paternal half sisters was obtained by using values for S, D and E calculated in a manner (page 67) such that a full sister component was not determined.

Considering the analysis in Table 16, if the yearly environmental differences had been eliminated, the components \( S \) and \( E \) would have been decreased and D increased. It is very unlikely, however, that the removal of the year effect in these data would have changed the correlation value (.037) to any appreciable amount. Under the assumption of random mating and in the absence of any environmental contribution to the likeness of full and half sisters
\[ S = \frac{1}{4} \sigma^2_G + (1/4)^n \sigma^2_I \]
\[ D = \frac{1}{4} \sigma^2_G + \frac{1}{4} \sigma^2_D + \text{approx.} \ (1/4)^n \sigma^2_I \]
\[ W = \frac{1}{2} \sigma^2_G + \frac{3}{4} \sigma^2_D + \text{approx.} \ 3/4 \sigma^2_I \]

where \( \sigma^2_G \), \( \sigma^2_D \) and \( \sigma^2_I \) are the variances attributable to the additively genetic variance, dominance and epistatic source of variance respectively, and \( n \) is the number of factor pairs involved in any epistatic effect.

On this basis an estimate of heritability from the paternal half sister intra-class correlation is computed as \( \frac{4S}{S + D + E} \). This yields a heritability value of \( .468 \). The reliability of this estimate depends upon the validity of the assumption concerning random mating, the size of the environmental correlation between sisters, the contribution to the sire component of variance by epistasis and the magnitude of the sampling errors.

The assumption of random mating will not be completely met in these data since a little inbreeding has been practised, especially in the Iowa State College Holstein herd. Since the degree of inbreeding in the two Board of Control herds involved in this study is not known, the average inbreeding over the entire data could not be computed. As the degree of inbreeding increases, the genetic variance within sires is likely to decrease and the portion of epistatic variance will increase. It is expected, however, that the effect of correcting for the inbreeding in the data involved in the present study would be so small that it could be neglected without seriously affecting the results.
presented in Table 16. Since there is little disagreement in these financial
estimates for the value of OECD adjusted GNP of the ratio of the components
receiving the greatest share of income. Despite this, the correlation between
components of variance is quite high, indicating that these components are
tightly linked. The correlation between components partially explains some of the variance of the factors of income and economic activity.

* It appears that the correlation between the variance due to these factors
varies for 5 and 10 years and beyond, the factors that influence the mean
income of the components G, D and F are very common. The mean income for
the components B, C and E by the following relationship was very common for the
mean income of the components A, D and F.

In view of the existence of two equations of the same form of the

opposition by the method of denominator correlation (or) for the two equations of the

presentation of the second case, it can be seen that the second case is

more appropriate, and so on. In the second case, the relationship between the

factors in the equation will be maintained. According to these equations, we can

order in order to obtain an estimate of the components of the relationship.

As a result of these equations between the factors and the estimate to be made,

estimation variation among the estimates obtained to be compared to the case.

Another important point is that between parts of the results of the
correlation coefficients of the components correlation and the general correlation,

and the current component correlation. Performing this step will have a

year between the estimated value of a component of the OECD adjusted
GNP since the analysis of variances in Table 16 was not yet in

69
correlations, heritabilities calculated from them would be very similar.

For this study heritability was estimated as .146.
The genotype correlation between a trait and the environment may be expressed as the correlation between an

I. General Correlation

9
Table 15. These genetic correlations computed as Hazel suggested are:

\[
\begin{align*}
(1) \quad \rho_{\text{CI}}^{2} &= \sqrt{\frac{(5.648)(6336)}{(175.792)(87.46)}} = 1.326 \\
(2) \quad \rho_{\text{CI}}^{2} &= \sqrt{\frac{(22.07)(158.78)}{(57.59)(87.46)}} = 1.006
\end{align*}
\]

where (1) is the genetic correlation between length of calving interval and milk production and (2) is the genetic correlation between calving interval and butterfat production.

The sampling error of a genetic correlation is undoubtedly very large, especially when the numbers involved are small, since it is computed from four statistics which have some correlation between their sampling errors. This allows sampling errors to cause the correlations to fall outside the range from +1.0 to -1.0, especially when the heritability estimates of the two traits involved are small. The present estimates of the genetic correlation between calving interval and production (milk and fat) are both more than one. It seems likely that the true genetic correlations are large and positive although certainly lower than the values, 1.326 and 1.006 obtained. It is not possible to determine how much lower the true values really are. A method of calculating fiducial limits for estimates of genetic correlation is as yet not available.

Theaverage length of calving interval and the average record of milk and fat production for daughters and dams were used in calculating the covariances involved in the estimation of the genetic correlations.
Since the expected value of any one of the four covariances is the same as if the analysis had been done with single records, the genetic correlations obtained are automatically on a single record basis.
In the present study the production of milk and butterfat are

...
Table 17. Analysis of variance and covariance for milk, fat and current calving interval\textsuperscript{a}

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>M.S. milk</th>
<th>M.S. fat</th>
<th>M.S. C.L</th>
<th>Gov. milk - C.L</th>
<th>Gov. fat - C.L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1621</td>
<td>6,431.317</td>
<td>7.535</td>
<td>4.987</td>
<td>36.147</td>
<td>13.985</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>197,748,142</td>
<td>143,398</td>
<td>281,091</td>
<td>-5,160,504</td>
<td>-29,190</td>
</tr>
<tr>
<td>Between years within herds</td>
<td>30</td>
<td>47,339,081</td>
<td>46,612</td>
<td>20,485</td>
<td>137,951</td>
<td>2,826</td>
</tr>
<tr>
<td>Within years</td>
<td>1589</td>
<td>5,410,185</td>
<td>6,520</td>
<td>5,535</td>
<td>40,690</td>
<td>1,338</td>
</tr>
</tbody>
</table>

\[
f_{.01}^{2} = .235 \quad f_{.01}^{2} = .219 \quad b_{.01}^{2} = 7.35 \quad b_{.01}^{2} = .293
\]

\textsuperscript{a} Units of measurement are one pound for milk and fat and one day for calving interval.
indicate that for each increase of ten days in length of the current calving interval one would expect a total increase during that 305-day period of 2.38 pounds and 73.5 pounds in fat and milk production, respectively.

The squares of the correlation coefficients (.235 and .219) indicate that if the length of the current calving interval is held constant variation in the milk and fat yield would be reduced by 5.5 per cent and 4.6 per cent, respectively. These results are similar to those reported by Dickerson (1940) who found that 5 per cent of the variation in 305-day lactation records was caused by variation in length of calving interval.

The relation between length of current calving interval and production as expressed by the coefficients of correlation and regression in Table 17 can also be detected from the graphs in Figure 7. It appears that production increases in a curvilinear fashion with increasing length of calving interval up to an interval length of 320 to 400 days. This trend becomes quite irregular, however, for calving interval groups involving intervals longer than 400 days. It appears that very little production would be gained by increasing the length of the current calving interval above 320 to 400 days.
Figure 7. Relation of average milk and fat production to length of current (C.C.I.) and preceding (P.C.I.) calving intervals. (Calving intervals by 20-day groups).
2. **Proceeding calving interval**

Several investigators have studied the degree of association between the production during a certain lactation and the length of the preceding calving interval, and have reported a small but positive relationship. According to Johannsson and Hansson (1949), this relationship is not strictly linear since an optimum length of preceding calving interval is reached, after which no further increase in production is obtained.

Table 18 gives the analysis of variance and covariance for preceding calving interval, milk and fat production. This analysis was made on an intra-hard but not on an intra-year basis since a calving interval and the production record immediately following that interval are generally recorded in two different years. The influence of year to year differences are likely to affect the results of this analysis slightly, but not to an appreciable amount since the differences between adjacent years would be small.

Table 18 indicates that a positive but small association does exist between production and the length of the preceding calving interval. The regressions indicate that an increase of 10 days in length of the preceding calving interval results in an increase of 60.9 pounds of milk and 2.30 pounds of fat in the following lactation.

The square of the correlation coefficients (.154 and .169)
Table 18. Analysis of variance and covariance for milk, fat and preceding calving interval
d

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>M.S. milk</th>
<th>S.E.</th>
<th>M.S. C.I.</th>
<th>Cov. milk - C.I</th>
<th>Cov. fat - C.I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1584</td>
<td>7,575,510</td>
<td>9,426</td>
<td>6,049</td>
<td>19,256</td>
<td>941</td>
</tr>
<tr>
<td>Between herds</td>
<td>2</td>
<td>255,032,482</td>
<td>31,144</td>
<td>1,111,580</td>
<td>7,665,476</td>
<td>103,015</td>
</tr>
<tr>
<td>Within herds</td>
<td>1582</td>
<td>2,258,077</td>
<td>9,336</td>
<td>4,052</td>
<td>28,340</td>
<td>1,072</td>
</tr>
</tbody>
</table>

\[ F_{01} = .154 \quad F_{0.01} = .169 \quad b_{M.C1} = 6.09 \quad b_{F.C1} = .23 \]

*Units of measurement are one pound for milk and fat and one day for calving interval.*
indicate that if the length of the preceding calving interval was
held constant, variation in the 305-day milk and fat records following
these intervals would be reduced by 2.4 per cent and 2.6 per cent,
respectively. Those production records which are not preceded by a
calving interval are automatically excluded from this analysis. The
coefficients of correlation and regression presented in Table 13 in-
volving the preceding calving interval and production are all slightly
smaller than the corresponding coefficients in Table 17 involving
current calving interval and production. The correlations and re-
gressions presented in Table 13 measure only the linear association
between length of calving interval and production in the following
lactation. However, it appears from the graphs in Figure 7 that a
curvilinear association exists for those calving intervals shorter
than 400 days. It would appear from these graphs that very little
production would be gained by increasing the length of the preceding
calving interval above 400 days. The trend for the average production
is very irregular as the length of the preceding calving interval in-
creases above 440 days. The graphs in Figure 7 indicate that the
trend for increased production as length of calving interval increases
is very similar for both current and preceding calving interval groups.
The average level of production per calving interval group is con-
siderably lower when the lactations are classified according to the
length of the preceding calving interval than when the production
records are grouped according to the length of the current calving
interval. Such a difference in the mean level of production per calving interval group is possible since not all of the lactation records involved in the mean for a certain current calving interval group are the same as those included in the mean for the preceding calving interval group of the same length. Generally, the last record a cow makes will not be included in the means for the current calving interval groups since she will not have calved again to complete the calving interval, whereas such records will be included in the averages for the preceding calving interval groups unless a cow has only one production record but has calved twice. Likewise, the averages for the preceding calving interval groups will not include the first production record of a cow.
The age at which a cow first calves has a significant influence on the

immediate and subsequent reproductive performance of the cow. However, the effect is not as pronounced as it is for the first time. The influence of age on reproductive performance would be accounted for by age. In general, the performance of each cow would be expected to improve with age. However, the effect of age on reproductive performance is not as significant as it is for the first time. The influence of age on reproductive performance would be accounted for by age.
The influence of non-exercise factors can be obtained by measuring the correlation factors. Before the correlation factors can be obtained, further information is needed about the association of age with cognitive impairment. The linear regression of cognitive function on age of some subjects and the regression of age on some subjects could not be computed. It is obvious that these correlation factors could not be computed because the age of the patient at death is unknown. Therefore, the prevalence of the prevalence of the correlation factors in the elderly is expected to be very low. The only correlation factor that could be estimated is the regression of age on cognitive function. It seems that in the elderly, the correlation factor is significant, and it could be estimated that if one is studied for a short period of time, the age of the patient at death of the elderly would be less than 50 years. This could be expected if one is studied for a short period of time.
In the West partitionation, there are three main periods: the first, second, and third. Each of these periods is characterized by certain events that occurred during that time. The first period is marked by the establishment of the West partitionation, which led to the loosening of its structure. In the second period, the West partitionation continued to evolve, with significant changes occurring in the third period. The third period saw the complete dissolution of the West partitionation.
practical breeding program since a suitable method for eliminating
the effects of yearly environmental differences is not available for
use.

The intra-sire regression of calving interval of daughter on
calving interval of dam was .027 ± .050 when the average calving
interval for both daughter and dam was used. When the formula given
by Lush and Straus (1942) was applied in order to place the estimate
on a single record basis, this regression of .027 was reduced to .016
± .054.

The covariance term for the regression of daughter on dam within
sires was based on 365 degrees of freedom since the record of a dam
was repeated for each daughter. In the denominator the variance term
for dams was based on 335 degrees of freedom. The proper degrees of
freedom for calculating the standard error of the intra-sire regression
coefficients will be somewhere between 334 which would be correct if
each dam had only one daughter and 365 which is the degrees of freedom
for daughters within sires. For these data there was an average of
1.07 daughters per dam. Since the average number of daughters per dam
is so close to one it is expected that little error would be involved
in using as degrees of freedom, the number of dams within sires minus
one. The standard errors and the 95 per cent fiducial limits for the
regression coefficients were calculated, therefore, on the basis of
334 degrees of freedom. Although this is not entirely correct the
result of using 334 degrees of freedom will tend to make the estimates more conservative. The 95 per cent confidence interval for the heritability estimate of .031 was +.24 to -.18. The repeatability value of .171 was used when adjusting the intra-sire variances of daughter and dam to a single record basis.

The only restriction on the daughter-dam pairs (447) used in this study was that each cow had both a calving interval and a production record. This excludes from the present analysis those cows which had calved only once. That the intra-sire variances of calving interval were about equal for daughter and dam (Table 14) seems to indicate that practically no selection for a shorter calving interval was practiced on the dams. This is supported by the fact that the mean length of calving interval for the dams was seven days longer than the mean for the daughters.

Eliminating yearly effects in order to estimate the correlation between paternal half sisters did not seem justified in view of the slight importance of yearly environmental differences and the additional labor required. If all the daughters of a sire made their records in the same year and the data extended over a number of years, it would be more desirable to eliminate the effect of yearly environmental changes.

The heritability of .148 obtained by multiplying the correlation between paternal half sisters by four is considerably larger than the
.031 obtained by doubling the intra sire regression of daughter on dam. The difference in these two estimates of heritability is probably the result of sampling error since they are based on only a limited number of degrees of freedom and also the result of the influence of yearly differences.

The estimates of heritability of calving interval obtained in this study from the intra sire regression of daughter on dam and from the paternal half sister correlation may be biased slightly since the effect of differences in age of cows was not eliminated. Since nothing would be gained by correcting the length of calving interval for age of cow using correction factors based on linear regression, and since the data were not extensive enough to make all analyses within age of dam, the effect of age differences had to be ignored for the present study.

The length of calving interval has a positive but small linear correlation with production (milk and fat) during the first 305 days of a lactation. This is the case for both current and preceding calving intervals although the latter exhibits the smaller association as illustrated by the correlations in Tables 17 and 18. These correlations do not measure the true relation between length of calving interval and production since it appears from the present study that some degree of curvilinearity exists between production and calving intervals shorter than 400 days. It seems, however, that the length
of calving interval can be considered as a rather unimportant source of variation in 305 day lactation records. If lactation records of shorter duration (8 or 9 months) are used as measures of production it is expected that length of calving interval would have a still smaller effect.

The graphs in Figure 7 clearly indicate that increasing the length of the current calving interval beyond 400 days would increase production very little. These graphs make it seem inadvisable to increase the length of the preceding calving interval beyond 440 days and it appears that very little production would be lost by reducing this interval to about 400 days which would correspond to what seems optimum for the current calving interval.
VI. SUMMARY AND CONCLUSIONS

The main purpose of this investigation was to describe the length of calving interval and its variation, and to determine if it has a genetic basis. Also of interest were the phenotypic and genetic relationships between length of calving interval and the production of milk and fat.

The data covered a period of approximately eleven years and were taken from the herd books of the Iowa State College Holstein herd and the Iowa State Board of Control Holstein herds at Mount Pleasant and Cherokee, Iowa.

The frequency distribution of the calving intervals used in this study deviates markedly from a normal distribution as shown by Figure 2, (page 31). The modal class was 360-380 days with a mean of 413 days or 13.6 months and an overall standard deviation of 78 days. The calving intervals ranged in length from 277 to 664 days.

Age at first calving had practically no influence on length of calving interval. The correlations between age at first calving and the length of the first, second and third calving intervals were 0.034, -0.030 and -0.010, respectively.

Differences in age of cow at time of calving accounted for 10.3 per cent of the total variance and 11.7 per cent of the intra-herd, intra-year variance of individual calving intervals. The intra-herd,
intra-year correlation of age of cow at time of calving and the length of the ensuing calving interval was 0.029. Its smallness, as compared with the other figures just quoted, indicate that most of the association of age with length of calving interval is not linear.

The records of 222 cows from the Iowa State College Holstein herd were used in studying the influence of management on length of calving interval. An average interval of 26 days elapsed from the time of first estrus until first breeding, indicating that the length of calving interval is influenced by intentional delay in breeding. In these data, management as a factor influencing the length of calving interval was secondary to the combined effect of the physiological mechanisms of the cow and chance which govern the length of time from parturition until first estrus and from first breeding until the following parturition.

Evidence on the effect of yearly environmental changes came from 1663 calving intervals from 731 cows. The year component of variance accounted for only 4.8 per cent of the total variance and 5.1 per cent of the intra herd variance in individual calving intervals. Consequently, the effect of year to year differences in these data may be considered of slight importance. The intra herd correlation between calving intervals of the same cow in these data was .184 after year effects were eliminated. When yearly environmental differences were ignored the repeatability estimate reduced to .175. A repeatability value of .171 obtained by a second method (page 54) appears to be more suitable for practical application.
The correlation between the estimates of the increase in yield of wheat due to the use of fertilizer would be expected with each additional ton of fertilizer at the rate of 60 pounds of 5-0-9 and 2.96 pounds of 5-0-9 would be expected to increase the yield by an average of 5.35 pounds of 5-0-9 and 2.96 pounds of 5-0-9 would be expected, the increase being 7.6 pounds of 5-0-9 and 2.96 pounds of 5-0-9 for each increase of ten days in length of the internode and internode. Lower journeys of the estimates give the positive and negative correlations of these estimates, respectively. The estimates are considered only in a statistical context. Because the sampling error of these are so general, the estimates cannot be expected to have any practical significance.

The deuterium-17 estimate were expected to have no effect on the rate of change and the change in the deuterium-17 estimate were expected to have no effect on the correlation of the change in the deuterium-17 estimate. The change in the deuterium-17 estimate was not expected to have any effect on the correlation of the deuterium-17 estimate.
was .171. The heritability estimates indicate that only a small portion of the variation in calving intervals is genetic. It may be concluded then, that selection would not be very effective in changing the length of calving interval in dairy cattle.
VII. LITERATURE CITED


--------. 1948. The genetics of populations. Unpublished mimeographed notes.


ACKNOWLEDGMENTS

The author wishes to express his gratitude to Dr. Jay L. Lush for his helpful suggestions throughout the analysis and preparation of this thesis. To the other members of my committee for their constructive criticism of this thesis and to Dr. L. McGilliard for his assistance in the operation of the I.B.M. equipment and in the interpretation of parts of the statistical analysis, the author is also indebted.

A note of thanks goes to Mr. E. Wright for his cooperation in making the original data available from the Iowa State Board of Control Herds.