CALVING INTERVAL TRENDS IN MICHIGAN DAIRY HERDS

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
PHILIP LOWELL SPIKE
1972

ABSTRACT

CALVING INTERVAL TRENDS IN MICHIGAN
DAIRY HERDS

By

Philip Lowell Spike

Efficient reproduction is essential to every dairy farm. It is required both as a source of replacement cattle and a stimulus to produce milk. Calving interval, days between successive parturitions in a cow, was used to indicate changes in the over-all reproductive performance.

To determine the simultaneous effects of several variables, a multiple regression analysis was made. The variables included were type of service, breed, age, year, herd size, herd production, some squared terms and some interaction terms. The analysis first included all breeds but not herd production. Then the analysis was altered to include only one breed (Holstein) and all other variables.

The data were obtained from all of the recorded records which were initiated in Michigan D.H.I.A. herds from 1953 to 1970. Information was recorded when a record

was terminated or at 305 days, whichever came first. The 305 day records were age adjusted and averaged to get the herd production. The 402,013 calving intervals were calculated for cows with successive parturitions at least 280 and less than 1000 days apart.

The two regression analyses were significant, but they explained less than one percent of the variation. In the regression with all breeds, Brown Swiss had a significant regression effect of 11.2 days, but Jersey cows had a significant negative effect of -5.9 days. The other three breeds were not significantly different from the regression mean of 395.0 days. A significant breed by type of service interaction was observed for Ayrshire, Brown Swiss and Holstein. Three significant age group by breed interactions occurred along with three breed by year interaction effects. The breeds were then eliminated in favor of including herd production.

The intra-Holstein analysis resulted in significant regression values for all variables tested. The mean calving interval was 395.2 days with a standard deviation of 77 for the 295,355 Holsteins starting calving intervals from 1953 to 1967. Cows in artificially inseminated herds had calving intervals an average of 3.1 days shorter than those in naturally inseminated herds. Cows initiating calving intervals after 60 months of age had intervals 5.7 days longer than cows 36-60 months old at the beginning of their interval. Calving intervals followed a U-shaped curve over time. Calving intervals appeared to be decreasing with time until a significant jump was observed in 1964. Increasing herd size and production were associated with an increase in calving interval, but both had a significant negative interaction with year. This indicated that these effects decreased with time. Some seasonal fluctuations were also observed.

CALVING INTERVAL TRENDS IN MICHIGAN DAIRY HERDS

By

Philip Lowell Spike

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Dairy

1972

ACKNOWLEDGMENTS

The author would like to express his appreciation to Alvin Thelen and Michigan D.H.I.A. for the use of the data and computing facilities. Recognition is appropriately due to Dr. Clinton E. Meadows for his guidance throughout the period of graduate study. The author is also grateful to his wife, Barbara, for her encouragement and assistance in the preparation of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

INTRODUCTION

One of the distinguishing characteristics of mammals is the production of milk for their young. In dairy cattle, selection has increased the natural ability for milk production far beyond the demands of the young. This surplus provides food for human consumption. The natural cause for the initiation of lactation is the bearing of young. Currently this is still the most satisfactory stimulus in the dairy cow. This stimulus reaches a maximum shortly after parturition and then is considered monotonically decreasing. Therefore, dairy cows need to conceive and bear young periodically to provide the needed stimulus for milk production.

Cows are continually forced to leave the herd involuntarily because of such things as age or injury; therefore, a replacement is eventually required for each cow. Since only half of all calves are heifers, a minimum of two calves are required per cow. Allowing for calf mortality and selection for milk production, about three calves per cow are needed. With an average age of about four years, the necessity of a yearly calving interval in dairy cattle is apparent.

Current changes in American agriculture have not bypassed the dairy industry. Average herd size has grown steadily. This has created the need for changes in the handling of dairy cattle to reduce the man hours per cow. Developments such as artificial insemination, then frozen semen, and now direct service have all come to the dairy industry. Application of population genetics has increased production per cow. Feeding has shifted from pasture and hay to drylot with silage feeding. All of these things have affected the dairy industry.

The purpose of this investigation was to determine to the best degree possible the effect of year, herd size, level of herd production, type of service used in the herd, breed and parity on the calving interval in the state of Michigan.

REVIEW OF LITERATURE

In 1927, Gaines stated that three factors contributed to average yearly milk production in a dairy cow. In order of importance these were:

1. Frequency of calving
2. Maximum yield
3. Persistency of yield.

Assuming a constant lactation curve, he mathematically determined that a ten month calving interval would maximize average yearly milk production. Speicher and Meadows (1967) found a significant decline in average milk production per day with an increase in the length of calving interval within production ability groups. A decrease of 2.4 kg. of milk per day was noted by Louca and Legates (1967) for each additional day open. Both Louca and Legates (1967), and Speicher and Meadows (1967) calculated a decrease in potential income of about fifty cents per day per cow for delayed conception. An annual loss to dairymen in the United States of six hundred million dollars was estimated by Hafs and Boyd (1964) for sterility and infertility. They speculated that one half of this could be saved by proper management.

Interest in dairy cattle reproduction stems mainly from the need for a stimulus for lactation, and the production of viable young. Many measures have been devised to try to effectively measure reproductive performance. Calving interval, the interval from parturition to parturition, is a composite measure which is affected by most of the other measures of reproductive performance. Research dealing with several types of reproductive measures which could affect calving interval will be reviewed. The yardsticks of reproductive performance that were investigated are days from parturition to first breeding, days from first breeding to conception, services per conception, conception rate, and calving interval. Management, production, breed, age, season, heritability, and repeatability are the main factors which will be evaluated for their effect upon the various measures.

Parturition to First Breeding

The period of time as measured by this rule can be significantly altered by varying herd management practices. When herds were separated for their long and short calving intervals, Bozworth *et al*. (1972) noted that most of the difference was due to the time difference between calving and first breeding. Olds and Cooper (1970) observed that if first breeding occurred at 40 days as compared to 60 days postpartum, the calving interval would be shortened an average of 15 days. Morrow *et al*. (1966) measured the average interval to first estrus of 15 ± 3.9 days which was usually silent. A 32.1 ± 18.6 day period to first estrus was noted by Olds and Seath (1953). In a study of ten herds by Pelissier (1970), heat periods were observed in 65.5 percent of the cows by 60 days postpartum, and only 3.9 percent failed to be detected in estrus by 120 days. It is suggested (Shannon *et al.*, 1952) that first breeding should not occur prior to 50 days postpartum for satisfactory fertility. In a study of 36,276 Kentucky D.H.I.A. cows it was calculated that the average first breeding occurred at 82.2 ± 33.7 days postpartum, Olds and Cooper (1970). VanDemark and Salisbury (1950) reported average days to first breeding of 117 and noted an improved fertility up to 100-120 days postpartum. Olds and Cooper (1970) and Olds and Seath (1965) observed a lower conception rate on first service for cows bred at less than 35 days postpartum, but they could find no indication of any other reproductive problems such as abortions, infertility (at later service), metritis or delayed returns. Similar observations were made by Trimberger (1954) for cows bred less than 50 days postpartum.

A small correlation between milk production in the previous lactation and period to first estrus was found by Carman (1955). This does not appear to be too important since Olds and Seath (1953) calculated that milk production had only accounted for .9 percent of the variation in time to first estrus in their study. Carman (1955) observed little effect of age and season on time to first estrus. Seasonal effects on time to first breeding could be noted if the manager was trying to maintain a seasonal calving pattern.

Carman (1955) calculated heritability and repeatability to be near zero (< .10), while Olds and Seath (1953) reported a heritability of .32 for days to first estrus. It would seem meaningless to calculate a heritability or repeatability for days from parturition to first breeding because of the apparent dependence upon the decision of the herdsman as to when to first breed the cow.

First Breeding to Conception

The length of this period can be affected by the interval to first breeding because of the rise in fertility following parturition as was indicated earlier. This period is then subject to the effects of management, but this is not as obvious as for days to first breeding. Another management variable which could affect this period would be the accuracy of detecting estrus in the herd. Olds et al. (1966) observed that in Wisconsin 29 percent of the variation in delayed returns to service (<26 days) was due to herd effects. Olds (1969) observed that 49 percent of the returns to service were delayed. It was estimated that one of every six heat periods was either missed or not recorded after the first observed estrus in a study by Pelissier (1970). One possible explanation for some of these missed heats would be silent heats. Foley et al. (1972) remarked that 15-25 percent of all heat periods occur without the full behavioral manifestations. Another possible cause of missed heats would be embryonic death caused by such things as disease, infections, or genetic incompetence. In a review of the literature on repeat breeders, cows with three or more services per conception, Olds (1969) calculated an average of 65.5 percent conception at 30-34 days after the service.

Touchberry et al. (1959) could not detect a significant correlation between genetic ability for fat production and time from first breeding to conception. Only a very small correlation was found by Gaines (1927) between milk production in the first month and the time from parturition to conception. Morrow et al. (1966) did observe a significantly higher rate of silent estrus in higher milk producing cows. No association was made between fat production and cystic ovaries by Casida and Chapman (1951).

No significant breed effects were noticed by Armstrong (1964), between Guernsey and Holstein in days from first breeding to conception. Age differences were significant in the same data to indicate that cows in their first lactation took longer to conceive than older cows up to their seventh lactation. In data analyzed by Carman (1955), age, parity, year, and season had little effect.

Labhsetwar et al. (1963) recorded 23.7 percent quiet ovulations with a significantly higher incidence in March through August as compared to September through February. Hall et al. (1959) suggested that warm temperatures such as found in the tropics and subtropics cause a shorter duration of estrus. A similar depressing effect of high ambient temperatures upon estrus expression was observed by Gangwar et al. (1965). Morrow et al. (1966) found a significant seasonal effect upon the occurrence of cystic corpora lutea with a higher incidence in August through January as compared to February through July. Armstrong (1964) could find no significant association between mean monthly temperature and days from parturition to conception or days from first breeding to conception with 11,626 conceptions.

Armstrong (1964), Carman (1955), and Pou et al. (1953) all reported heritabilities and repeatabilities of days from first breeding to conception near zero (< .10).

Services per Conception

The number of services per conception would be expected to be correlated with days from first breeding to conception, but the correlation would not be perfect since the days between services is not constant as alluded to previously. The effect of management on services per conception would be caused by timing of insemination and health of the cows to be bred. The fact that Boyd *et al*. (1954) found more variation between herds than within herds for services per conception would imply that herd management can have a definite influence upon this measure. Trimberger (1954) found that cows bred at less than 50 days postpartum required significantly more services per conception than cows bred after 50 days. Mean values of 1.8, 2.67, and 1.97 services per conception were found by Legates (1954), Pelissier (1970), and VanDemakr and Salisbury (1950), respectively. Pelissier (1970) also reported that 18.3 percent of the cows in his study required four or more services per conception.

A positive correlation of .19 was calculated by Morrow *et al*. (1966) between milk production and services per conception. Boyd *et al*. (1954) found no significant differences in the number of services per conception for the breeds of Jersey, Holstein, and Guernsey. These values were 1.59 $\pm$ .87, 1.76 $\pm$ 1.04 and 1.71 $\pm$ .93 respectively.

Age accounted for only insignificant effects on services per conception as determined by Carman (1955) and Branton *et al*. (1956). Carman (1955) found no influence of year or season on services per conception, but Branton *et al*. (1956) reported a noticeable effect of season.

Heritability was estimated at near zero (< .10) for services per conception by Branton et al. (1956), Carman (1955), Legates (1954) and Pou et al. (1953). The highest repeatability estimate was made by Branton et al. (1956) of .106 with the others close to zero.

Conception Rate

Conception rate as determined here will include designed experiments where cows were actually confirmed pregnant to a certain breeding, and nonreturn rates where the cow is assumed pregnant if no repeat service is performed. Specific mention will be made when considering nonreturn rates. In a study of nonreturn rates in Kentucky, Spears et al. (1965) calculated that 7.5 percent of the variation was due to herds. This would imply that herd management plays a relatively small part in determining this measure. Trimberger (1954) found an increase in conception at first service with increased days from parturition, with cows bred at less than 50 days postpartum having a significantly lower conception rate than those bred after 50 days. Service sire is apparently a source of variation in conception rate according to a study by Bearden et al. (1956). In his study, bulls were grouped in "high" and "low" categories according to their 60-90 day nonreturn rates. The "high" and "low" bulls recorded 96.6 percent and 76.9 percent conception at one day and 86.1 percent and 57.7 percent conception at 33 days after insemination, respectively. Foote and

Hall (1954) calculated 59.3 percent of first services result in a calf with a decreasing percent for each succeeding service. Pelissier (1970) calculated an average conception rate at first service of 43.3 percent. Olds and Cooper (1970) estimate that 71.8 percent of all cows bred in Kentucky remained in the herd to produce a calf.

With respect to nonreturn rate in New York, Tanabe and Salisbury (1946) concluded that fertility in the cow increases until four years of age and then slowly declines after an age of seven years.

The average monthly conception rate was significantly correlated with the average monthly length of daylight in a study by Mercier and Salisbury (1947). In the same study temperature appeared to have no measurable effect on fertility. Erb *et al*. (1940) found the highest conception rate occurred during May (74.3 percent) and the lowest in August (58.2 percent) for the Purdue herd over a 20-year period. Olds *et al*. (1966) reported no change in nonreturn rates over four years which would be due to a year effect.

An estimate of zero was calculated for heritability and repeatability of nonreturn rates in cows by Dunbar and Henderson (1953). The value of .55 $\pm$ .26 was tabulated as an estimate of heritability by Shannon and Searle (1962) for a bull's 49-day nonreturn rate using a sire-son comparison. They also calculated repeatability at .69 $\pm$ .05.

Calving Interval

As calving interval is a composite measure, it can be influenced by each of the preceding measures of reproductive performance. Days from parturition to conception plus days of gestation equals calving interval. Since the gestation period can be considered to be a constant value within breed, calving interval and days open should be highly correlated. Therefore, a few studies on days open will be included in this section, but they will be noted as days open at the time.

Bozworth et al. (1972) calculated a correlation of .76 between the average calving interval in a herd this year and next year. In this study of "long" and "short" calving interval herds, services per conception and conception rate were constant across the two groups of herds, but the time from parturition to first service, and the time between first and second service, and second and third service were significantly different. Olds and Cooper (1970) reported that for each day a cow was bred prior to 82 days postpartum that the calving interval would be shortened by .9 of a day. More than forty-five percent of the cows were open at least 119 days in a study of 5,000 cows by Pelissier (1970). Johnson and Ulberg (1967) found that for cows open 100 days or more in their investigation, that 17.9 days were due to missed estrus periods, and 19.1 days were due to unsuccessful services with less than 10 days due to all other causes.

Britt and Ulberg (1970) noted an improvement in reproductive performance in herds using their Herd Reproductive Status System, which involves average days open. They attributed this improvement to better managerial practices. Miller et al. (1967) found a phenotypic correlation of zero between herd life and calving interval. Wilcox et al. (1957) similarly found the measures of longevity and calving interval to be uncorrelated. These studies would imply that there exists very little selection intensity for calving interval by the herd owners.

A 406-day calving interval was reported by Legates (1954). Everett et al. (1966) calculated calving intervals of 387 days in Holstein cows and 392 days for Guernsey cows in the same herd. Norman and Thoele (1967) reported a 385-day calving interval. Olds and Cooper (1970) found a 382-day calving interval being the same as that calculated by Miller et al. (1967).

Branton et al. (1967) found a significant effect of 120-day milk production on calving interval, but Everett et al. (1966) observed no effect of 120 day milk production. The 305-day milk production was increased by changing the calving interval from 340 to 440 days as noted by Norman and Thoele (1967). They noted a progressively larger effect as cows matured. Miller et al. (1967) observed a positive correlation (.2) between first lactation yield and average calving interval. Morrow et al. (1966) found a positive correlation of .25 between milk production level and days open. Schaeffer and Henderson (1972), and Smith and Legates (1962) both report that as days open increases, 305-day milk production also increases, but at a decreasing rate up to 200 days open; here it seems to have little additional effect.

There is a natural breed effect upon calving interval due to the differences in gestation lengths. These lengths in days are 290, 284, 279, 279, and 278 for Brown Swiss, Guernsey, Holstein, Jersey, and Ayrshire respectively as quoted by Foley *et al*. (1972).

Miller *et al*. (1967) observed a significant difference between the parity groups for length of calving interval, but felt that it could have been due to production differences. Schaeffer and Henderson (1972) observed that age was significantly correlated (positive) with the length of dry period, and dry period length was significantly shorter for higher producing cows. Morrow *et al*. (1966) observed that cows in lactations two through five had fewer days open although it was statistically insignificant.

Britt and Ulberg (1970) obtained a seasonal difference in average days open with the best in March and April, and worst in August. A highly significant difference between years was seen by Branton *et al*. (1967) for calving interval.

Estimates of near zero (< .10) for heritability were calculated by Dunbar and Henderson (1953), Legates (1954), Miller _et al._ (1967), and Norman and Thoele (1967) for calving interval. Wilcox _et al_. (1957) calculated an estimate of +.32 for heritability using calving intervals in one herd over a 30-year period.

SOURCE OF DATA

Michigan D.H.I.A. herds served as the source of data for this study. All 305-day records, and records completed or terminated prior to 305 days were used when available. Some D.H.I.A. herds were recorded as early as 1953, and all D.H.I.A. herds on test after 1956 until January 1970 were included. The records were sorted by lactation within cow, within herd on a magnetic tape. All identified cows with two or more reported calvings, and days between calves of 280 to 999 days were included. There were approximately one million records on five tapes. These records reduced to 402,012 calving intervals. There were approximately 4,000 herds with calving intervals.

Completed and 305-day records were age adjusted to 2X-M.E. basis. The correction factors used were those of J. F. Kendrick; U.S.D.A.; ARS.-52-1; January, 1955.

METHODS OF ANALYSIS AND RESULTS

To determine if certain management factors, production, breed, or age affected the calving interval, a multiple regression equation was developed. From observation of what information was available, the following equation was proposed:

$$Y_{ijkl} = \beta_0 = A_i + B_j + (AB)_{ij} + P_k + (BP)_{jk} + \beta_1 X_1$$
$$+ \beta_{11} X_1^2 + \beta_2 X_2 + \beta_{22} X_2^2 + \beta_3 X_3 + \beta_{12}(X_1 X_2)$$
$$+ \beta_{13}(X_1 X_3) + \beta'_{1j}(X_1 B_j) + \varepsilon_{(ijk)l}.$$

See Table 1 for a description of the variables.

Due to computational difficulties, all terms involving level of herd production (X_3) had to be deleted to include breed effects. Since 85 percent of the total data was from Holsteins, it was decided to recalculate the regression within the Holstein breed and eliminate the terms involving breed.

From the five magnetic computer tapes the calving intervals were calculated and written on other tapes. The herd number, cow identification, breed, length of calving interval, age in months at the initiation of the interval, and date when the interval was started were included for

Table 1. Description of regression variables.

Variable	Description
Y	interval in days between successive parturitions
β_0	constant value (y-intercept)
A_1	effect of artificial insemination in the herd
A_2	effect of natural service in the herd
B_1	breed effect of Ayrshire cattle
B_2	breed effect of Brown Swiss cattle
B_3	breed effect of Guernsey cattle
B_4	breed effect of Holstein cattle
B_5	breed effect of Jersey cattle
$(AB)_{ij}$	interaction effect of service type i and breed j
P_1	effect of age group 1 (< 36 months)
P_2	effect of age group 2 (36-60 months)
P_3	effect of age group 3 (> 60 months)
X_1	year (coded middle year = 0)
X_2	herd size
X_3	level of production (herd)
β_i	regression coefficient of X_i
X_1X_2	interaction of year x herd size
X_1X_3	interaction of year x level of production
β_{ij}	regression coefficient of X_iX_j
(X_1B_j)	interaction of year x breed j
β'_{1j}	regression coefficient of (X_1B_j)
$\varepsilon_{(ijk)l}$	error term

calving interval. The day of month of calving was not recorded until 1964, so the days were all set at 15 previous to this time.

Simultaneously a herd average was calculated. The yearly herd average was composed of all completed records, 305 days or less, age adjusted which were initiated in a year. Herd size was calculated as the total number of lactations initiated in that year. Each cow was identified as the result of a natural or artificial mating. The herd was then declared to be artificially inseminated if 50 percent or more of the cows were identified as the result of artificial insemination. All other herds were classified as naturally bred herds. Cows culled for sterility prior to 305 days were coded as such. The average days before culling and the number of cows culled were calculated for each herd. This was of little value subsequently, because of the small number culled per herd. The herd number, A.I. classification, herd production, herd size, average days before reproductive culling and the number of culls were printed on two Hollerith cards per herd.

The method of least squares was used to solve the regression equations. An X'X matrix was computed from the calving interval tapes and herd summary cards, after constraints were placed on some of the factors. The corresponding X'Y matrix was also calculated. The X'X inverse was calculated, and a solution was derived. The analysis of variance for each of the two regressions is given in Table 2.

Table 2. Analysis of variance for regression equations.

Source	D.F.	S.S.	M.S.	F ratio
A. All Breeds				
Total (corrected)	402,012	2,224,328,578		
Regression[a]	28	11,409,798	407,492	74.02*
Dev. from Reg.	401,984	2,212,918,781	5,505	
B. Within Holstein				
Total (corrected)	295,354	1,767,390,738		
Regression[b]	11	10,443,551	949,414	159.59*
Dev. from Reg.	295.343	1,756,847,187	5,949	

*Significantly different from 1 P (α = .01)

[a](Multiple correlation coefficient) R^2 = .0051.

[b](Multiple correlation coefficient) R^2 = .0059.

From Table 2 it is apparent that the chosen variables have a significant effect upon the variation in calving interval, as can be detected by the large size of the F ratios. The multiple correlation coefficients are very small which implies that the regression equations account for only a small part of the variation. The change in the mean square error is due to the fact that the first regression was over all years, and the second regression did not include the last three years. The estimates of the standard deviations were 74.0 and 77.1 for the first and second regressions, respectively.

The various values calculated from these regressions are listed in Table 3. The values were tested by the "t" test to determine if they were significantly different from zero. Each of the categories of management, production, breed, age, and season were investigated for their possible effect upon calving interval.

Management

The variables which were tested and are classified in this category are type of service used in the herd, herd size, and year to year changes. Kucker (1970) reported that in a survey of Michigan dairymen, the main reason for discontinuing the use of artificial insemination was poor conception. The purpose here was to determine if those herds identified as using artificial insemination had a significantly different calving interval length. As can be seen

Table 3. Estimates of parameters in multiple regression models.

variable[a]	estimate (all breeds)	estimate (Holstein)	variable[a]	estimate (all breeds)	estimate (Holstein)
β_0	395.02	391.15	B_5P_1	.73	
A_1	-2.89*	-1.54*	B_1P_2	1.56	
A_2	2.89*	1.54	B_2P_2	-1.15	
B_1	-2.78		B_3P_2	-.37	
B_2	11.20*		B_4P_2	-.05	
B_3	-1.54		B_5P_2	.02	
B_4	-.99		B_1P_3	-.21	
B_5	-5.90*		B_2P_3	4.02*	
A_1B_1	-7.75*		B_3P_3	-2.33*	
A_2B_1	7.75*		B_4P_3	-.68	
A_1B_2	7.08*		B_5P_3	-.80	
A_2B_2	-7.08*		β_1	.89*	1.12*
A_1B_3	.17		β_{11}	-.018	.31*
A_2B_3	1.57*		β_2	.040*	.081*
A_1B_4	1.57*		β_{22}	.000049*	.000062*
A_2B_4	-1.57*		β_3		-.241*
A_1B_5	-1.07		β_{33}		.001791*
A_2B_5	1.07		β_{12}	-.017*	-.027*
P_1	-1.17	-.41	β_{13}		-.012*
P_2	-2.60*	-2.65*	β'_{11}	2.18*	
P_3	3.77*	3.06*	β'_{12}	.12	
B_1P_1	-1.35		β'_{13}	-.72*	
B_2P_2	-2.87		β'_{14}	-1.18*	
B_3P_1	2.70*		β'_{15}	-.40	
B_4P_1	.73				

[a]See Table 1 for variable description.
*Significantly different from zero with $P(\alpha < .01)$ by "t" test.

from Table 3, those herds classified as artificially inseminated had a significantly shorter calving interval for all breeds with the possible exception of Brown Swiss. Brown Swiss have a significant interaction effect with type of service which is positive for A.I. and larger than the main effect. When the analysis was run within Holstein, the significance is retained. Whether the regression value is due to the use of artificial insemination or to correlated managerial practices is unimportant. What should be recognized is that artificially inseminated herds were able to maintain a shorter calving interval than herds using natural service.

The same conclusion is reached when looking at the mean values in Table 4. Herds classified as naturally bred had a longer mean calving interval for each breed except Brown Swiss. It can also be noted that the Holstein breed has used A.I. much more than the other breeds. This is probably due to the emphasis of the A.I. organizations since the Holstein breed is the most numerous.

According to the Michigan D.H.I.A. annual summaries (1953-1969), the average herd size of D.H.I.A. herds increased from 20.3 to 50.8 in the period from 1953 to 1969. With the change to larger herds, a corresponding decrease in individual attention for the cows would be expected. Other management factors could also change. The main emphasis was to determine if larger herds did experience a change in reproductive performance as measured by calving interval.

Table 4. Calving intervals in A.I. and natural herds.

Breed	Percent Total	A.I. herds		Natural herds	
		% intervals	raw mean[a]	% intervals	raw mean[a]
Ayrshire	.4	32	387.2 ± 3.36	68	402.3 ± 2.32
Brown Swiss	1.4	31	412.8 ± 1.79	69	403.9 ± 1.19
Guernsey	7.5	36	$391.2 \pm .72$	64	$396.7 \pm .53$
Holstein	85.2	53	$391.6 \pm .17$	47	$395.0 \pm .18$
Jersey	5.5	30	$385.8 \pm .91$	70	$393.9 \pm .60$
All	100.0	50	$391.6 \pm .17$	50	$395.3 \pm .17$

[a]Calving interval in days $\pm$ approximate standard error.

From the regression equations (Table 3), it is seen that the term for herd size (X_2) and the squared term for herd size have a positive regression coefficient which is significantly different from zero. This is true in both of the regression equations, but the Holstein regression shows an even larger value. The size of the coefficients indicates that it would take a large increase (about 100) in herd size to make a noticeable change in calving interval. It should also be noted that a significant negative coefficient exists for the year by herd size interaction. In order to further examine the effect of herd size and the herd size by year interaction, herd size was stratified into four groups. These four groups are graphed in Figure 1 by year.

The herd sizes chosen were less than 25 cows, 25 to 50 cows, 51 to 100 cows and greater than 100. These sizes were chosen to represent a marginal size herd, a one-man operation, a two-man operation and an operation requiring more than two men, respectively. For the herd sizes greater than fifty, the first three or four points in Figure 1 are based on a small number of herds. This could easily account for their large departures from the mean. All of the points have at least 100 observations. The significance of the interaction is probably caused by the fact that the herds with more than 100 cows got closer to the mean as the years passed. The mean calving interval lengths and approximate standard errors were 400.7 $\pm$ .34, 394.0 $\pm$ .21, 392.1 $\pm$ .27 and 400.9 $\pm$ .51 for the smallest to largest herd size groups.

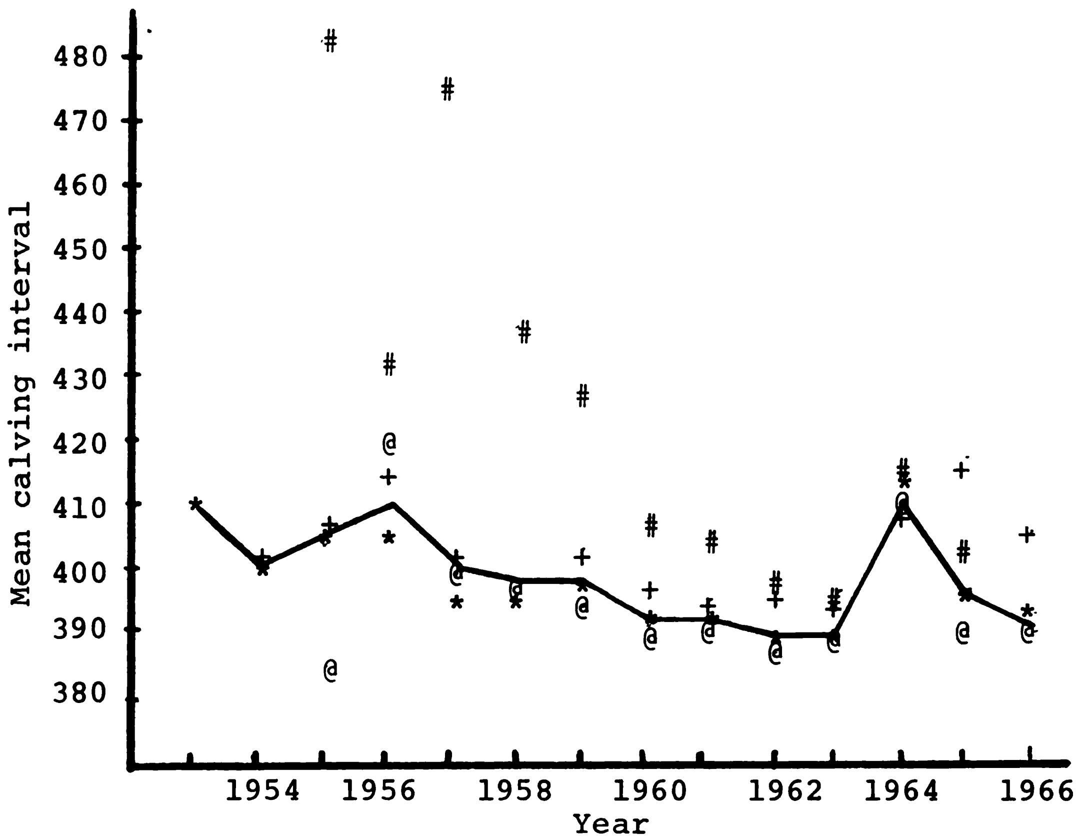

Figure 1. Calving interval by herd size for Michigan Holsteins.[a]

•mean for year
+herd size < 25 cows
*herd size 25-50 cows
@herd size 51-100 cows
#herd size > 100 cows

[a]see Appendix for table of values (Table 9).

A constant shift upward in the proportion of calving intervals occurring in larger herds was noted. This is consistent with the increase in average herd size already mentioned. With the size of the large herd's calving interval in the early years, it is apparent why the squared term for herd size had a highly significant coefficient.

Year to year changes were measured to indicate any general shifts in herd management over time. The regression estimates (Table 3) for the coefficients of years were significantly different from zero. Years were coded by subtracting 1961 for the first regression and 1960 for the regression within Holstein. The squared term for year was significant only in the analysis within Holstein. This significance can be seen in the U-shaped curve of Figure 1. All of the significant coefficients were positive indicating a general increase in calving interval over the period of study. In observing Figure 1, it appears that the mean is decreasing until 1964. Then it takes a significant jump when compared to the previous and following year. This jump is apparently enough to cause the positive regression estimate, especially for the squared term, but this is complicated by the significant interaction effects with year.

Level of Production

If genetic progress to improve milk production is to continue, then milk production and efficient reproduction must be compatible. According to the Michigan D.H.I.A. Annual Summaries (1953-1969), the average milk production has increased by more than 3,000 pounds over the period of study. It has been shown previously, Shaeffer and Henderson (1972), and Smith and Legates (1962), that an individual 305 day milk production record is influenced by the number of days open. The purpose here was to determine if the herds with high milk production could maintain a calving interval comparable to other herds.

The herd production was calculated as the average of all the completed M.E. records, 305 days or less, which were initiated in the herd in any particular year. This was then truncated by removing the two digits to the left of the decimal. The average milk production for all breeds was 12,913 and 13,402 pounds for the Holstein breed.

The regression coefficients in Table 3 are based on the truncated herd average values. The regression coefficients for the intra-Holstein analysis are both significantly different from zero. The size of the squared term coefficient causes it to dominate, and the net effect of increasing herd production is positive over the range of the data. This would indicate that an increase in herd production level would also cause an increase in calving interval.

Level of herd production has a significant interaction with year. The interaction can be seen in Figure 2 along with the effect of herd production. The calving

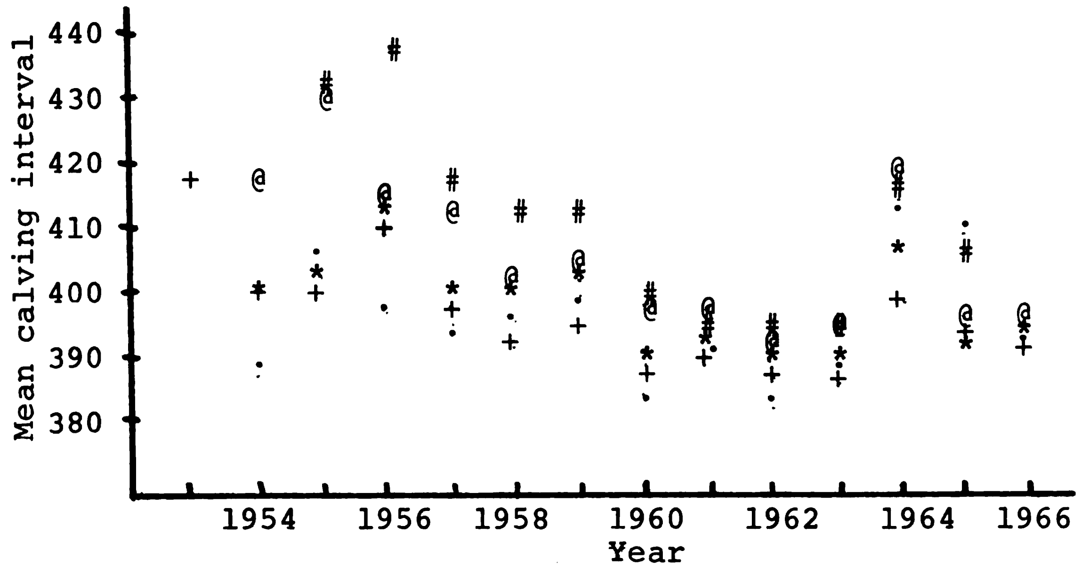

Figure 2. Calving interval by level of herd production for Michigan Holsteins.[a]

.herd average < 10,000 lbs. milk
+herd average 10,000-12,000 labs milk
*herd average 12,000-13,000 lbs. milk
@herd average 14,000-16,000 lbs. milk
#herd average > 16,000 lbs. milk

[a]see Appendix for table of values (Table 10).

intervals were stratified into four groups by year according to herd production. All points were eliminated that had fewer than 100 observations. The interaction is probably due to the decrease in average calving interval for the high production group in later years. The herds with production less than 10,000 pounds of milk also have an increased calving interval. This increase could be due to the fact that this level of milk production became much less profitable in later years; those remaining were producing milk for other reasons than economic gain. The percent of calving intervals occurring in the 16,000 pound group increased from only 2 percent the first two years, to more than 14 percent in the last two years.

Breed

With the differences in gestation period between the breeds, it was expected that if enough data were available, the breed differences would be significant. The calculated effects for breeds in the regression analysis (Table 3) do show some significance. Brown Swiss are significantly longer, and Jersey are significantly shorter. The over-all gestation length (Table 5) was calculated by using the proportion of each breed and the average gestation length for that breed. Comparing the regression effect with the difference in the gestation length from the mean gestation length, we find that Brown Swiss cattle have a longer calving interval due almost entirely to gestation length. The

Table 5. Breed differences in gestation length and calving interval.

Breed	Calving interval[a]	Gestation length[b]	Regression effect[c]
Ayrshire	397.4 ± 1.91	278	-2.78
Brown Swiss	406.6 ± .99	290	11.20*
Guernsey	394.7 ± .43	284	-1.54
Holstein	393.2 ± .13	279	-.99
Jersey	391.5 ± .50	279	-5.90*
All	393.4 ± .12	279.5	

[a] raw mean in days ± approximate standard error

[b] quoted from Foley *et al*. (1970)

[c] from Table 3

* significantly different from zero P ($\alpha < .01$)

Jersey effect may be due to a difference other than gestation length with only 0.5 day accounted for in the difference in gestation length. None of the other breeds are significantly different from the mean calving interval length in the regression.

The raw mean values for the various breeds in Table 5 should not be compared too closely since there are some significant breed interactions. In Table 4 it was noted that there were differing frequencies of use of A.I. among the breeds. This could affect these raw mean values since A.I. has a significant influence as indicated by the regression value in Table 3.

When the breeds were separated by age groups, it was noticed that they did not seem to be equally distributed in the age groups. The number of calving intervals started in each of the age groups is listed in Table 6. The expected number and the deviation squared over the expected value is also listed. The frequencies were tested by chi-square; the value of 355.2 was obtained. Therefore, the probability that the breeds are distributed the same in these age groups is less than .01.

In Table 6 the Brown Swiss seem to deviate the most in their age distribution from the mean, but the other breeds also contribute a large amount to the chi-square. It appears that the Brown Swiss, Guernsey and Jersey initiated a larger proportion of their calving intervals at older ages than did the Holstein breed. Part of this may be due

Table 6. Distribution of calving intervals by breed and age at initiation.

Breed	Age (months)	Number observed	Number expected	$\frac{(\text{Deviation})^2}{\text{expected}}$
	<36	461	454	.11
Ayrshire	36-60	589	597	.12
	>60	459	458	.00
	<36	1,369	1,695	62.53
Brown Swiss	36-60	2,038	2,229	16.37
	>60	2,224	1,707	156.26
	<36	8,660	9,053	17.03
Guernsey	36-60	11,793	11,908	1.12
	>60	9,630	9,122	28.29
	<36	103,796	103,093	4.79
Holstein	36-60	136,347	135,615	3.96
	>60	102,447	103,882	19.83
	<36	6,689	6,680	.01
Jersey	36-60	8,370	8,788	19.87
	>60	7,141	6,732	24.89
Total	All	402,013	402,013	355.18

to the fact that these breeds have been declining in numbers while the Holstein breed has been more stable. These differences could also be real differences due to the longevity of the different breeds. Andrus et al. (1970) found similar differences for Iowa data indicating that the different breeds do indeed have different age distributions.

Some significant coefficients exist for the year by breed interactions. This indicates that the various breeds may be taking different trends in calving interval length over time.

Age

Everett et al. (1966) calculated a correlation of .96 $\pm$ .001 between age and parity. They concluded that these were measures of the same thing. Since the lactation numbers had been coded on the original records, age was used in this study. The effect of previous pregnancies was the variable which was of interest. The ages were divided into three groups: less than 36 months, 36 to 60 months, and greater than 60 months. Age was determined at the initiation of the calving interval. The group less than 36 months of age should be comprised mainly of cows that started their calving interval with their first parturition. Those cows 36 to 60 months old simply represent an intermediate group. The cows over 60 months of age would represent mature cows with two or three parturitions prior to the start of this calving interval.

Referring to Table 3 it can be seen that age group 1 was not significantly different from the mean of the population. The calving interval for age group 2 was significantly shorter than the mean calving interval. It should also be noted that there are three significant breed by age interaction effects. It appears that Guernsey cattle do not have as much difference between the first and third age groups in calving interval. Brown Swiss seem to have an even longer calving interval in the third age group. Combining this last fact with the fact that the Brown Swiss have the greatest proportion of calving intervals in the third age group, the large raw mean calving interval found in Table 5 is further explained.

The raw means for the various age groups by breed are listed in Table 7. From the table it can be seen that the group of cows from 36 to 60 months of age had the shortest calving interval, except in Brown Swiss where it was not significantly longer than the first age group. The third age group had the longest calving interval for each breed.

Season

Wunder and McGilliard (1971) found a significant difference in lactation milk yield for lactations initiated in different months of the year. In this Michigan data, July and August were the low months while the high months were January and February. It was cited earlier that lactation yield was found to be influenced by days open. It was

Table 7. Calving interval length by age group.

Breed	<36 months[a]	36-60 months	>60 months[a]
Ayrshire	396.1 ± 3.45	395.8 ± 3.05	400.8 ± 3.45
Brown Swiss	401.7 ± 2.00	402.2 ± 1.64	413.8 ± 1.57
Guernsey	396.5 ± .80	392.0 ± .68	396.5 ± .75
Holstein	393.0 ± .23	390.8 ± .20	396.7 ± .23
Jersey	391.2 ± .90	389.0 ± .81	394.5 ± .88
All	393.2 ± .21	390.9 ± .19	396.9 ± .21

[a]raw mean calving interval ± approximate standard error

decided to determine if the effect of season on lactation was due to the effect of season on the calving interval.

The Holstein calving intervals were averaged by month from 1953 through 1966. The raw mean values are listed in Table 8. The seasonal effect on lactation yield is plotted in Figure 3 along with the corresponding days open (calving interval minus gestation length). These values do not appear to explain any of the seasonal differences for lactation yield.

In Table 8 a marked tendency for seasonal calving can be seen from the number of calvings in the various months. This is probably due to the base pricing of milk in Michigan.

Table 8. Calving interval by month of initiation for Holsteins.

Month	Calving interval[a]	Number	Month	Calving interval[a]	Number
January	395.7 ± .52	20,309	July	397.0 ± .44	28,394
February	397.9 ± .56	17,230	August	393.6 ± .38	37,171
March	400.3 ± .54	18,906	September	392.0 ± .38	37,847
April	399.0 ± .61	14,750	October	393.4 ± .39	35,141
May	399.3 ± .64	13,344	November	391.9 ± .43	30,161
June	399.9 ± .59	15,788	December	393.1 ± .48	23,316

[a]mean length in days ± approximate standard error

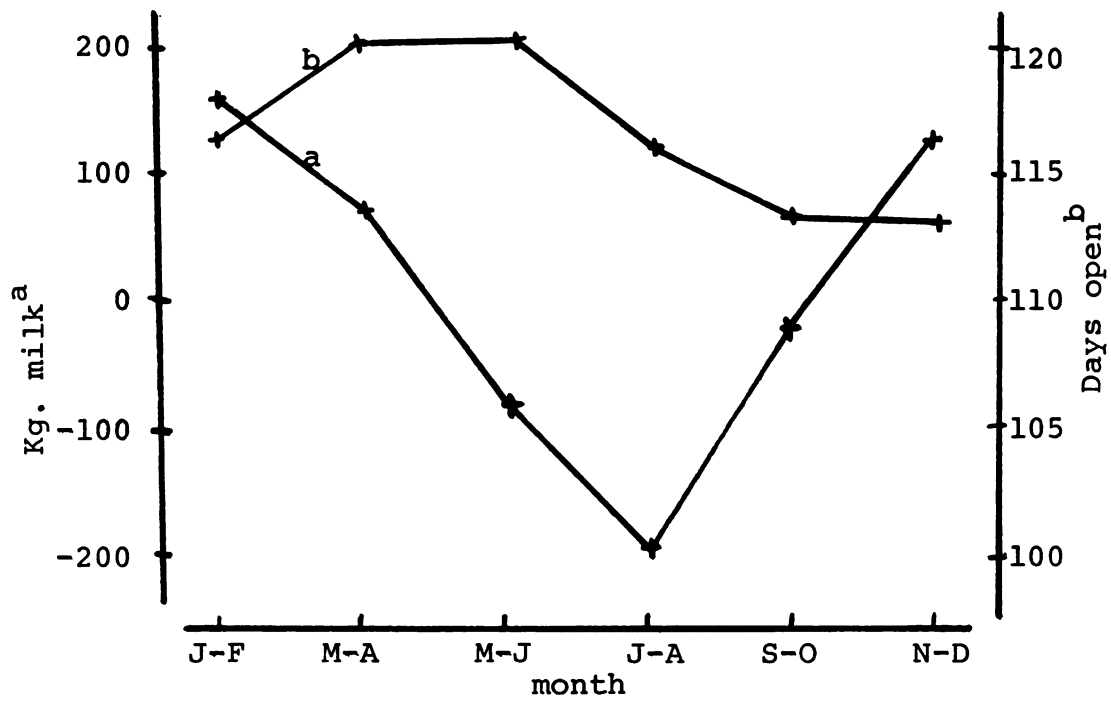

Figure 3. Days open and 305-day lactation yield by season.

[a]reported by Wunder and McGilliard (1971)
[b]calving interval minus gestation length

DISCUSSION

Calving interval is not intended to be a perfect measure of reproductive performance. It does not consider those animals which were a complete reproductive failure. Cows which initiate and complete intervals in separate herds would not be included. Herds leaving or entering D.H.I.A. test would also cause intervals to be missed. A long calving interval does not indicate what the particular problem is in a herd. Calving interval is an over-all measure; it only indicates if a physiological or managerial problem exists.

The mean calving interval of 393.4 days was obtained for the Michigan D.H.I.A. cows calving from 1953 through 1969. It contains some negative bias because calving intervals initiated in the last years were forced to be short. A positive bias could result if a calving was not recorded, resulting in two calving intervals being recorded as one. The estimate of 395.2 days for the Holstein breed did not include the intervals initiated in the last three years. Both estimates are within the range of those cited previously, but they tend to be longer than most, due to a larger upper limit. The removal of the natural year bias or its inclusion would not be expected to alter the effect of any of the regression variables except year. When the Holsteins were analyzed on both sets of data, the regressions were essentially identical except for the year coefficients.

The intra-Holstein analysis is probably the most applicable regression in this study. It includes the effect of herd production which is statistically significant and could not be included in the over-all regression. The Holstein data have sufficient observations for even small differences to be detected. With all of the regression estimates except one being statistically significant, only one percent of variation was explained by the regression. Some of this could be expected from the cyclic nature of reproduction. That is, if a variable caused every third cow to conceive one cycle late, the variable would have an average effect of lengthening calving interval by seven days. The variable may completely explain the variation, but a regression curve would not explain the variation. The measure desired here was not a prediction equation but the measurement of trends that may exist.

The statistically significant effect of the type of service used in a herd was surprising. Although this does not indicate that if a cow is bred artificially, she will have a shorter calving interval, it does indicate that herds using artificial insemination were able to maintain a shorter calving interval. As the herds were classified for the entire period as A.I. or natural, the effect of alternating between A.I. and natural was not measured. Perhaps the effect of having a calving interval in an A.I. herd was due to some other correlated managerial practice.

Increasing herd size, another potential managerial problem, caused an increase in calving interval. This effect declined in later years as was noted by the significant year by herd size interaction. This decline could be due to improved managerial practices for large herds. Upon observing the mean values for the various herd size groups, it appears that the herds with less than 25 and those greater than 100 cows had equal length calving intervals. The two middle size herd groups were shorter and essentially equal in their calving intervals. It seems apparent that herd size exerts an increasing effect on calving interval for small and large herds, but the latter effect has decreased in recent years.

With the economic costs of longer calving intervals reported earlier, it was hoped that calving interval had decreased over time. It appeared that this was true until 1964, when a significant jump was observed. Checking with the A.I. organization (Michigan Animal Breeders Cooperative) which serves the greatest number of cows per year in Michigan, it was discovered that they changed from fresh to frozen semen that year. M.A.B.C. reported their nonreturn rate had shown some increase until 1964. Then their nonreturn rate dropped three percent to a value lower than any other year as far back as 1955. The nonreturn rate has not increased past the 1964 level to the present time. The decline in nonreturn rate does not seem to explain all the increase in calving interval for 1964, but it may have caused at least some of the increase.

The positive relationship between the level of herd milk production and calving interval length is more apparent in the early years than in the later years. This could be caused by the need for a herd to have a longer calving interval in order to achieve a herd average greater than 16,000 pounds in the early years. This would follow from the positive relationship between days open and 305-day milk production previously cited. A time difference for reproductive culling may exist between herds with different production levels. The higher producing herds may try longer to achieve conception, thus getting a longer calving interval. This study intended to investigate this, but there was limited reproductive culling per herd, and only those culled prior to 305 days were recorded. Herds were unable to maintain both high milk production and short calving intervals simultaneously and especially in the earlier years of the study.

Breed effects appeared to be small and unimportant. This would be expected since reproductive efficiency would be expected to have equal natural selection pressure across all breeds. Any real differences in fertility between breeds as measured by calving interval minus gestation length were small.

Age appeared to have a curvilinear relationship with calving interval. A shorter claving interval occurred with some advance in age and then an increasing calving interval occurred with further advance in age. The final increase could be due to management which keeps older high producing cows in the herd longer than other cows if conception problems occur. The shorter calving interval for the middle group is confusing. This could be due to improved fertility with age, but it would have to decline after this to explain the observed effect. The effect of previous parturitions is either nonlinear or masked by other effects, but it does not seem to be a valid explanation. The relationship appearing between age and reproductive performance noted here is consistent with that reported earlier by Lasely and Bogart (1943) and Armstrong (1964).

A seasonal fluctuation was observed, but the effect on calving interval was small. If 4 months were added to the date of initiation of an interval to get the month that the average cow would conceive, seasonal effects become clearer. Cows most likely bred in summer had consistently longer intervals, and those in winter had consistently shorter intervals. Those bred in spring and fall have intervals intermediate in length but longer in those months closer to summer. The reason for seasonal fluctuations could be due either to temperature or length of daylight as both are correlated. Research investigating the possible effects of these variables on reproduction has been cited previously.

In a review of the literature by Foote (1970), it was stated that the additive component in the genetic variation is small. This was determined from the practically general agreement on the small size of heritability for measures of reproductive performance. This does not mean that fertility is not influenced by genetics, but that mass selection for this trait would be mostly wasted. This still leaves open the possibility for nonadditive genetic control.

SUMMARY

To investigate possible trends in reproductive performance, a regression analysis was made of 402,013 calving intervals. Calving intervals completed in Michigan D.H.I.A. herds were included if they were between 279 and 1000 days in length. The intervals covered a span from 1953 to 1969. In the analysis some differences were obtained for the breeds, but some of these differences were explained by differences in gestation length.

A second analysis within Holsteins was made on 295,355 calving intervals from 1953 through 1966. Each of the variables of service type, age, year, herd size, and herd production resulted in a significant regression estimate. Cows from herds classified as naturally inseminated had a regression effect of 3.1 days longer calving interval. An increase in each of the other variables resulted in an increase in calving interval, except for age and year; here the association was curvilinear. Even age and year had some overall linear increase in the regression model. A seasonal fluctuation was also observed.

The trend for shorter calving intervals in A.I. herds indicates that these herds were able to maintain calving intervals comparable to the naturally bred herds. It

does not seem likely that this difference was due to increased fertility with artificial inseminations, but it was probably due to some related managerial practice. The effect of age is unexplained but was similar to previous observations.

It is obvious that calving interval has not approached the commonly stated goal of 365 days. The practical consequence of the regression increase for year is small since the mean interval for the last year is only 2 days longer than the shortest mean calving interval for any year. What appears to be a gradual decrease in calving interval length is disrupted by a large increase in 1964. Although this result remains unexplained, it may be partly due to changes in aritificial inseminations.

Large herd size was not conducive to shortening calving interval. The effect of increasing herd size apparently did decrease in recent years. Similar effects were noted for increasing herd production. Perhaps reproductive management improved in the large herds and in the higher producing herds, as they became more numerous.

All of the variables tested showed significance but the magnitude was often small and practically unimportant. Obviously calving interval is affected by many things, but none of the variables tested appear to represent significant deterrents to current trends in the dairy industry if proper reproductive management is performed.

BIBLIOGRAPHY

BIBLIOGRAPHY

Andrus, D. F., Freeman, A. E., and Eastwood, B. R. 1970. Age distribution and herd life expectancy in Iowa dairy herds. Jour. Dairy Sci., 53:764-771.

Armstrong, D. V. 1964. Breeding efficiency in a southern California dairy herd. M.S. Thesis. Library, Michigan State University, East Lansing, Michigan.

Bearden, H. J., Hansel, W. M., and Bratton, R. W. 1956. Fertilization and embryonic mortality rates of bulls with histories of either low or high fertility in artificial breeding. Jour. Dairy Sci., 39:312-318.

Boyd, L. J., Seath, D. M., and Olds, D. 1954. Relationship between level of milk production and breeding efficiency in dairy cattle. Jour. Animal Sci., 13:89-93.

Bozworth, R. W., Ward, G., Call, E. P., and Bonewitz, E. R. 1972. Analysis of factors affecting calving intervals of dairy cows. Jour. Dairy Sci., 55:334-337.

Branton, C., Griffith, W. S., Norton, H. W., and Hall, J. G. 1956. The influence of heredity and environment on the fertility of dairy cattle. Jour. Dairy Sci., 39:933 (abstr.).

Branton, C., McDowell, R. E., and Meyerhoeffer, D. C. 1967. Reproductive performance of purebred versus crossbred dairy cattle. Jour. Dairy Sci., 50:611 (abstr.).

Britt, J. H. and Ulberg, L. C. 1970. Changes in reproductive performance in dairy herds using the Herd Reproductive Status System. Jour. Dairy Sci., 53:752-756.

Carman, G. M. 1955. Interrelations of milk production and breeding efficiency in dairy cows. Jour. Animal Sci., 14:753-759.

Casida, L. E. and Chapman, A. B. 1951. Factors affecting the incidence of cystic ovaries in a herd of Holstein cows. Jour. Dairy Sci., 34:1200-1205.

Draper, N. R. and Smith, H. 1966. Applied Regression Analysis. New York: John Wiley & Sons.

Dunbar, R. S. and Henderson, C. R. 1953. Heritability of fertility in dairy cattle. Jour. Dairy Sci., 36: 1063-1071.

Erb, R. E., Wilbur, J. W., and Hilton, J. H. 1940. Some factors affecting breeding efficiency in dairy cattle. Jour. Dairy Sci., 23:549 (abstr.).

Everett, R. W., Armstrong, D. V., and Boyd, L. J. 1966. Genetic relationship between production and breeding efficiency. Jour. Dairy Sci., 49:879-886.

Foley, R. C., Bath, D. L., Dickinson, F. N., and Tucker, H. A. 1972. Dairy Cattle: Principles, Practices, Problems, Profits. Lea and Febiger, Philadelphia.

Foote, R. H. 1970. Inheritance of fertility-facts, opinions, and speculations. Jour. Dairy Sci., 53:936-944.

Foote, R. H. and Hall, A. C. 1954. Relationship between number of services and percent nonreturns, calving rate and sex ratio in artificial breeding. Jour. Dairy Sci., 37:673 (abstr.).

Gaines, W. L. 1927. Milk yield in relation to recurrence of conception. Jour. Dairy Sci., 10:117-125.

Gangwar, P. C., Branton, C., and Evans, D. L. 1965. Reproductive and physiological responses of Holstein heifers to controlled and natural climatic conditions. Jour. Dairy Sci., 48:222-227.

Hafs, H. and Boyd, L. J. 1964. Sterility. Hoard's Dairyman, 109:257.

Hall, J. G., Branton, C., and Stone, E. J. 1959. Estrus, estrous cycles, ovulation time, time of service, and fertility of dairy cattle in Louisiana. Jour. Dairy Sci., 42:1086-1093.

Johnson, A. D. and Ulberg, L. C. 1967. Heat detection pays big dividends. Hoard's Dairyman, 112:1167.

Kucker, W. L. 1970. Adoption of production testing and artificial insemination by Michigan dairy farmers. Ph.D. Dissertation. Library, Michigan State University, East Lansing, Michigan.

Labhsetwar, A. P., Tyler, W. J., and Casida, L. E. 1963. Genetic and environmental factors affecting quiet ovulations in Holstein cattle. Jour. Dairy Sci., 46:843-845.

Lasley, J. F. and Bogart, R. 1943. Some factors influencing reproductive efficiency of range cattle under artificial and natural breeding conditions. Missouri Agr. Exp. Sta. Res. Bull. 376.

Legates, J. E. 1954. Genetic variation in services per conception and calving interval in dairy cattle. Jour. Animal Sci., 13:81-88.

Louca, A. and Legates, J. E. 1968. Production losses in dairy cattle due to days open. Jour. Dairy Sci., 51:573-583.

Mercier, E. and Salisbury, G. W. 1947. Seasonal variations in hours of daylight associated with fertility level of cattle under natural breeding conditions. Jour. Dairy Sci., 30:747-756.

Miller, P., VanVleck, L. D., and Henderson, C. B. 1967. Relationships among herd life, milk production, and calving interval. Jour. Dairy Sci., 50:1283-1287.

Morrow, D. A., Roberts, S. J., McEntes, K., and Gray, H. G. 1966. Postpartum ovarian activity and uterine involution in dairy cattle. Jorn. Amer. Vet. Med. Assoc., 149:1596.

Norman, H. D. and Thoele, H. W. 1967. Effects of calving interval upon 305-day milk and fat production. Jour. Dairy Sci., 50:975 (abstr.).

Olds, D. 1969. An objective consideration of dairy herd fertility. Journ. Amer. Vet. Med. Assoc., 154:253.

Olds, D., Colvin, L. D., Cooper, T. and Deaton, O. W. 1966. Sources of variance affecting dairy herd fertility and delayed returns to service. Jour. Dairy Sci., 49:1004-1005.

Olds, D., and Cooper, T. 1970. Effect of postpartum rest period in dairy cattle on the occurence of breeding abnormalities and on calving interval. Jour. Amer. Vet. Med. Assoc., 157:92.

Olds, D. and Seath, D. M. 1953. Repeatability, heritability, and the effect of level of milk production on the occurrence of first estrus after calving in dairy cattle. Jour. Animal Sci., 12:10-14.

Olds, D., and Seath, D. M. 1965. Evaluation of time to breed cows after calving. Jour. Dairy Sci., 48: 841 (abstr.).

Pelissier, C. L. 1970. Factors contributing to low breeding efficiency in dairy herds. Jour. Dairy Sci., 53:684 (abstr.).

Pou, J. W., Henderson, C. R., Asdell, S. A., Sykes, J. F., and Jones, R. C. 1953. A study of the inheritance of breeding efficiency in the Beltsville dairy herd. Jour. Dairy Sci., 36:909-915.

Schaeffer, L. R. and Henderson, C. R. 1972. Effects of days dry and days open on Holstein milk production. Jour. Dairy Sci., 55:107-112.

Shannon, F. P., Salisbury, G. W. and VanDemark, N. L. 1952. The fertility of cows inseminated at various intervals after calving. Jour. Animal Sci., 11:355-360.

Shannon, F. P. and Searle, S. R. 1962. Heritability and repeatability of conception rate of bulls in aritificial breeding. Jour. Dairy Sci., 45:86-90.

Smith, J. W., and Legates, J. E. 1962. Relation of days open and days to lactation milk and fat yields. Jour. Dairy Sci., 45:1192-1198.

Spears, J. R., Olds, D., and Cooper, T. 1965. Evaluation of sources of variance in dairy herd fertility. Jour. Dairy Sci., 48:90-92.

Speicher, J. A. and Meadows, C. E. 1967. Milk production and costs associated with length of calving interval of Holstein cows. Jour. Dairy Sci., 50:975 (abstr.).

Tanabe, T. and Salisbury, G. W. 1946. The influence of age on breeding efficiency of dairy cattle in artificial insemination. Jour. Dairy Sci., 29:337-344.

Trimberger, G. 1954. Conception rates in dairy cattle from services at various intervals after parturition. Jour. Dairy Sci., 37:1042-1049.

Touchberry, R. W., Rottersten, K., and Andersen, H. 1959. Associations between service interval, interval from first service to conception, number of services per conception, and level of butterfat production. Jour. Dairy Sci., 42:1157-1170.

VanDemark, N. L. and Salisbury, G. W. 1950. The relation of the postpartum breeding interval to reproductive efficiency in the dairy cow. Jour. Animal Sci., 9:307-313.

Wilcox, C. J., Pfau, K. O., and Bartlett, J. W. 1957. An investigation of the inheritance of female reproductive performance and longevity, and their interrelationships within a Holstein-Freisian herd. Journ. Dairy Sci., 40:942-947.

Wunder, W, W. and McGilliard, L. D. 1971. Season of calving: age, management, and genetic differences for milk. Jour. Dairy Sci., 54:1652-1661.

APPENDIX

APPENDIX

Table 9. Calving interval by herd size for Michigan Holsteins.

Year	Herd Size				
	<25	25-50	51-100	>100	All
1953	409.9				409.9
1954	401.4	398.4			400.4
1955	404.2	402.0	384.8	481.5	405.7
1956	412.1	404.3	418.1	430.4	409.6
1957	400.9	394.3	398.2	473.2	399.0
1958	395.4	394.9	395.1	435.9	395.6
1959	401.5	396.0	393.2	425.0	397.2
1960	393.2	389.0	389.0	405.7	390.2
1961	393.0	391.6	389.0	404.3	391.9
1962	392.0	388.2	386.6	397.6	388.9
1963	394.7	388.8	388.4	395.1	389.7
1964	407.3	411.1	408.8	412.4	410.0
1965	415.1	393.5	388.8	400.6	395.0
1966	404.3	392.5	388.8	390.0	391.3
All	400.7	394.0	392.1	400.9	395.2

APPENDIX

Table 10. Calving interval by level of production for Michigan Holsteins.

Year	Level of production				
	<10,000	10,000-12,000	12,000-14,000	14,000-16,000	>16,000
1953		416.6			
1954	387.1	399.3	399.6	417.2	
1955	403.3	397.7	400.3	428.2	428.5
1956	395.6	408.7	410.1	414.3	435.9
1957	394.2	396.4	397.2	410.8	415.5
1958	390.4	394.7	393.8	399.6	411.3
1959	398.0	391.8	398.1	402.3	410.4
1960	383.5	387.0	390.1	397.2	398.1
1961	391.2	387.3	391.6	395.4	394.3
1962	380.0	384.8	388.9	390.6	393.0
1963	385.7	383.9	387.8	392.9	392.5
1964	412.8	396.7	404.2	415.8	414.2
1965	407.2	392.8	391.4	394.5	404.9
1966	392.6	387.9	390.1	393.1	392.0
All	391.6	391.1	393.4	398.8	400.5