Survivorship in dairy cows

Alexander Millar Meek
Iowa State University

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SURVIVORSHIP IN DAIRY COWS

by

Alexander Millar Meek

A Dissertation Submitted to the
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Signature was redacted for privacy.

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Ames, Iowa

1961
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INTRODUCTION

Selection as a force for improving dairy cows depends in part on the number of cows which may be removed voluntarily from the herd. This number depends much on the number which must be removed for reasons other than low production. This justifies studying the reasons for which cows are removed from a herd.

The present study was initiated in order to learn more of the reasons for disposal of dairy cows and also to measure the importance of genetic influences on some of the more common reasons for disposal.

The calving interval was divided into three components namely, calving to first service, first service to the service which resulted in conception, and gestation period. Although variations in these parts, especially the first, are considered largely managemental in nature, studying them separately was thought to be worthwhile because large differences in calving interval had been found between herds in some previous studies. Also, the twelve-month interval, so often advocated, is difficult to attain and determining where-in the difficulty lies and examining the possibilities of circumventing it seemed worthwhile.

Data were obtained from eleven of the registered
Holstein herds maintained at various penal and eleemosynary State Institutions in Iowa under the jurisdiction of the State Board of Control. These herds are generally well managed and data from them should resemble those from pure-bred Holstein herds of similar size in this area of the country.
REVIEW OF LITERATURE

General

Most studies of factors affecting age at first calving have been confined to measuring breeding efficiency, using number of services per conception as a criterion.

Dickerson and Chapman (1940) however used actual age in months at first service for a study of two large purebred Holstein herds. Age at first calving is, of course, completely determined by age at first service and the interval between first service and conception. The proportion of the variance in age at first calving arising from age at first service and interval from first service to conception was approximately equal (44% and 41% respectively, 15% jointly) in Herd No. 1 but in Herd No. 2 the interval from first service to conception accounted for nearly twice as much (61%) of the variation as did age at first service (34%, 5% jointly). In Herd No. 1 the variability in the interval from first service to conception was twice as large as that of Herd No.2.

They conclude that the animal's own reproductive behavior, rather than any deliberate management practice, was responsible for all the variation in age at first calving in these herds. Classifying the cows by age at first calving they found the following results:
Age at 1st calving (mos.) | Number of cows | Age at 1st service (mos.)
--- | --- | ---
24-25 | 34 | 15.4
26-31 | 49 | 17.7
32-46 | 13 | 20.4

In the same study, they show in Herd No. 1 that 152 cows averaged 3 calves with 71 months (2130 days) as the age at disposal and 42 months as the productive life. This shows that the average age at first calving was 29 months. In Herd No. 2 with 106 cows the figures were 2.8 for average calvings per cow, 62 months (1860 days) for age at disposal and 34 months (1020 days) for productive life. This makes average age at first calf 28 months (840 days).

Misner and Dalrymple (1955) in a study of 1111 Holsteins in the New York Institution herds showed 916 days for average age at first calving and 2,541 days for age at disposal giving a productive lifetime of 1,625 days. Their average calving interval in the herd was 13 months but they noted that cows which remained longest in the herd had a calving interval of 14 months.

Davis, Reed and Plum (1953) in a study of the Winterthur herd of Holstein Friesians showed that the average age at first calving was 914.5 days (2.51 years) in a total of 956 calvings.
The average number of calvings per cow in this herd was 3.33. The average time from birth to disposal was 2,187 days (5.99 years) with a productive life of 3.49 years. The average period between calvings (calving interval) was 448 days (1.23 years). The authors point out that this was not a typical herd but was essentially a breeder's herd with sale of surplus stock an important part of the income. This may explain the slightly longer productive life in this herd since producing more surplus stock for sale would be furthered by this. However, interestingly enough, the 41.1% of cows leaving daughters in the herd is the very same as that of the Iowa Institution herds in the present study.

This study is interesting too in that the management was described as outstandingly good and yet among 37 bulls with a total of 956 daughters, only 3 bulls had daughters which averaged under 400 days between calvings. These 21 daughters had the shortest average herd life (1350 days) among all the groups of daughters. Obviously the economics of this herd are not the same as the economics of a herd dependent almost entirely on the sales of milk; yet both types of herd would aim at maximum or nearly maximum production per cow.

Morrison and Erb (1957) in a study of the breeding records of the Holstein Friesian herd of Carnation Milk Farms at
Carnation, Washington, over a 30 year period, found an average calving interval of 424 days in a total of 3342 reproductive periods of normal cows. Among these, the interval after first calving of the heifers averaged 452 days and the mature animals 413 days. The difference they thought due to a herd policy of making the heifers show all the innate milk producing ability they possess in their first lactation by good feeding and late breeding. Still 2 of the State Institution Herds in Iowa show indications of the same policy.

Legates (1954) studied reproductive histories of cows in 12 State-owned dairy herds in North Carolina and obtained a mean of 406 days for 2,443 calving intervals. These herds contained Ayrshire, Guernsey, Jersey and Holstein cows. Only 1 small Ayrshire group, 1 Jersey group, and 1 medium sized Holstein group showed calving intervals of less than 400 days. A heritability estimate of .026 for services per conception and a small negative figure for calving interval, indicate little or no genetic differences between animals for these traits. Repeatability of services per conception was zero, while the value of .133 for calving interval was considered too low to be of practical importance. The conclusion was that the variability in these two measures of reproductive efficiency is nearly all due to temporary things which vary from lactation to lactation for the same cow, although the
calving interval does appear to be slightly more characteristic of the individual cow than is the number of services per conception.

Rennie (1952) studied calving interval in the Iowa State University herd and in the Iowa State Board of Control herds at Mount Pleasant and Cherokee, Iowa. The frequency distribution of the calving intervals was skewed, with a mean of 413 days and the modal class being 360-380 days. Calving intervals ranged from 277-884 days. Differences in the age of the cow at calving accounted for 10.3% of the total variance and 11.7% of the intra-herd, intra-year variance of individual calving intervals. Records on 222 cows from the Iowa State University Holstein herd showed that an average of 26 days elapsed from time of first estrus to first breeding. This indicates some intentional delay in breeding.

Year-to-year differences in calving interval made up only 4.8% of the total variance and 5.1% of the intra-herd variance. Repeatability of calving interval was of the order of .17. Heritability of length of calving interval was .03±.06 from intra-sire regression of daughter on dam and .148 when computed from half-sib correlation. Rennie (1952) concludes that heritability is low and that selection would not be very effective in changing the length of calving interval.
Bohidar (1957) obtained data from 48 herds in the Iowa Cow Testing Association over a period of 12 years from 1920 to 1931. The distribution of the calving intervals was skewed, the mean being 382 days for 1000 cows, with the modal class being 340-360 days. Approximately 90% of the variance came from temporary environmental influences.

Gestation Period

Gestation period in dairy cattle has been studied many times but has been relatively constant, affected slightly by age of cow, sex of calf, and whether a single or multiple birth is involved. Herman, Spalding and Bower (1953) found that 1306 Holsteins in the Missouri Station herd had an average gestation length of 278.8 days with the males being carried 279.4 days and females 278.4 days. Multiple births averaged 272.4 days. The gestation period for mature cows was slightly longer compared to the gestation periods of first and second calvers. Also fall and winter calvers carried their calves an average of 1 to 3 days longer than cows calving during spring and summer.

This last factor of seasonal effect on gestation length may help to explain the lower average gestation interval in the University herd where year-round calving is practiced to a greater extent than in the other Institution Herds. Also,
the lower average age of the University herd may partly cause this difference.

Stallcup, Horton, and Brown (1956) studying the records kept on the Arkansas Agricultural Experiment Station dairy herd, found an average of 276.6 days for the 375 Holstein gestations that ended in a living single calf. The 1.6% twin births averaged 267.0 days. Their data supported the idea that gestation length increases very slightly up to 5 years of age and then, although they theorize a decrease to 9 years of age and an increase in later ages, the variation at ages over 5 years appears essentially random due to the smaller numbers involved. They also found a .9 day increase in gestation length for Holsteins calving in the "cool" months compared to the summer months. Using the intra-sire regression of daughter or dam, they estimate that heritability of gestation length is zero.

DeFries, Touchberry, and Hays (1958) found an average gestation length of 279.6 days for 1054 Holsteins. Male fetuses were carried 1.5 days longer than female fetuses. Without correcting for season of calving or for age of cow, heritability was estimated at .17 from paternal half-sib resemblance and as .64 by the intra-sire regression of daughter or dam.
However Knott (1932) in an investigation of 2,824 births did show differences among bulls in the average length of time the calves they sired, were carried. In his data singles averaged 279.9 days and twins averaged 275.5 days. Male calves were carried 1 day longer than females. An increase of 1.5 days in gestation period from 2 years up to 6 years was indicated, with a slight downward trend after that.

Alexander (1950) showed that Holsteins had a shorter gestation period than the 281 days commonly used in gestation tables. He also found shorter periods for twin calves and for summer calvings. He concluded that gestation length is a heritable factor, because of the distinct differences among breeds and because the grouped offspring of different sires within each breed show marked differences in time spent in utero.

Brakel, Rife, and Salisbury (1952) came to a similar conclusion because of:

a) differences between breed means.

b) smaller variances within the breeds in which line breeding was practiced.

c) inter-sire differences within breeds.

d) decreases in inter-sire differences when sires are closely related.
e) a positive correlation between time the dam and her progeny spent in utero.  
In their data for Holsteins, gestation length averaged 278.6 days.

Livesay and Bee (1945) studied 415 calvings of Holsteins at West Virginia University. They found an average of 278.3 days with females being carried 277.7 days and males 278.7 days.

Non-breeding Period

A portion of the calving interval which has received rather less emphasis in the majority of studies is the period from calving to first breeding. However VanDemark and Salisbury (1950) reported a conception rate of 57.8% for cows serviced 101-120 days after calving as compared with 35% for these bred 20 days after parturition. Breeding efficiency gradually increased with each subsequent 20 day interval up to 120 days, with a slight decline for those bred at later intervals.

Patrick and Herman (1953) examined records on 4,713 breedings and found that maximum breeding efficiency was attained at 106-135 days following calving with a drop before and after that period. However little real variation was present from 53 days up to 165 days. The most frequent period
of breeding was the 53-75 day period where 2395 animals were bred while only 312 were bred in the 106-135 day interval. This study was made on cows in the Louisiana Artificial Breeders Cooperative Inc. and included all breeds.

Hofstad (1941) found that the reproductive system was more susceptible to infection and that breeding difficulties were more common in cows bred 60 days or less after parturition than in those given a longer sexual rest. Conception rate for cows serviced less than 40 days after calving was only 45% compared with 74% for those served 80 to 90 days post partum.

With regard to appearance of estrus, Trimberger and Fincher (1956) showed that on the average, the first estrus after calving occurred 50 days post partum. Fully 67% of the cows showed estrus before 60 days post partum and 93% by 90 days post partum. They state that, in addition to silent heats, the reasons for the prolonged periods of quiescence were retained corpus luteum, non-functional ovaries, and persistent metritis.

Carman (1955) in a study of breeding efficiency in the Iowa State University herd and the Iowa State Board of Control herd at Cherokee found that the period from calving to first estrus averaged 55.4 days in the University herd and 71.0
days in the Cherokee herd. Days from first breeding to conception averaged 28.0 days in the University herd and 42.0 days in the Cherokee herd. Number of services to conception was the same in both herds, indicating that some heat periods were missed in the Cherokee herd. Cows which freshened in March took about 20 days longer to come in heat than cows freshening in September.

Herman and Edmondson (1950) found 57 days for the average length of interval from calving to first heat for 968 calvings in 347 dairy cows. First calf heifers tended to have a longer period (75 days).

McClure (1959) in an investigation on artificially inseminated and naturally bred herds in New Zealand found that cows which were bred less than 60 days after calving were about 25% less fertile than cows bred 60 days or more after calving. However the cows which were mated unsuccessfully less than 60 days after calving were just as fertile as the others at their second mating, if that was more than 60 days after calving. He emphasized that these herds were free of common infectious diseases of the reproductive tract.

Sex Ratio

Ward (1947) in the 23rd Annual Report of the New Zealand Dairy Board includes a summary of births in the various Test-
ing Associations for the 1946-1947 season. In the 25,400 births the sex ratio was 52% bulls to 48% heifers. The twinning percentage was 1.1% and the sex combinations in the twin births were 62 both bulls, 72 both heifers, and 133 mixed. The expectation on a basis of 1:2:1 would be 66.75:133.5:66.75.

Johannson (1932) in a study of 124,000 births of Swedish Red and White, Swedish Friesian, Swedish Landrace, Finnish Ayrshire, and East and West Finnish Landrace breeds, found that the sex ratio was 106 males to 100 females or 51.5 males to 48.5 females.

Knott (1932) among 2,824 single births of Holsteins found 1,441 males and 1,383 females. This is a ratio of 51.0 males to 49.0 females. In 86 sets of twins the sex ratio was 109.7 males to 100 females.

Morgan and Davis (1938) found 730 males and 628 females born from 1,375 conceptions giving a sex ratio of 53.8 males and 46.2 females. No large body of data was found in which females outnumbered males. However Poote and Hall (1954) found percentages of males of 50.8, 51.1, 51.0, 50.3, 50.3, 30.2, and 26.7 in the first seven calvings of an original 50,000 cows. Multiple births were 2.6% of the calvings and 49.3% of these calves were males.
Arnold and Becker (1953) showed a gestation length of 278.9 days for 5,548 Holstein gestations which produced 51.6% male calves and 2.0% twin births.

Longevity Studies

Wilcox, Pfau, and Bartlett (1957) evaluated longevity by the number of apparently normal or successful parturitions. The records studied were from the Overbrook Dairy in New Jersey over the period from 1923 to 1953. They included in the study only those cows which left the herd after passing expected usefulness. They excluded cows which were removed because of obviously environmental causes. The intrasire regression of daughter on dam within six sire groups was .187, thus yielding a heritability estimate of .37. Using the same data the heritability of a breeding efficiency measure was .32. Longevity and breeding efficiency were not significantly correlated.

No animals which left the herd for brucellosis, tuberculosis, kidney infections and other related diseases were included in the data of Wilcox et al. (1957). Also excluded were animals which had to be removed because of accident, hardware, etc. Also the first reproductive cycle and all after the sixth were excluded, as were cycles ending in abortions. From this it seems that much of what was measured
as heritability of longevity was really heritability of low production, as this would probably be the principal remaining cause of disposal. Similarly, removing the first lactations and all subsequent to the sixth would appear to have reduced the value of the conclusions. If the heritability of longevity is to be studied, all forces seem worth more critical scrutiny. Pre-disposition to tuberculosis is an inherited factor in humans according to Pearl (1922) and in guinea pigs according to Wright and Lewis (1921), so that it should be taken into account in a study of longevity in dairy cows. Even accidental death perhaps should be included, as in many cases a factor of awkwardness may be involved which has every appearance of having a heritable basis although no experimental evidence is available. To remove completely all these influences on longevity seems to remove from longevity any value as a statistic to be applied to a dairy cattle population.

Bayley, Parker, Heidhues, Plowman, and Swett (1961) studied longevity on the Beltsville herd where no cows were culled because of either production or type. Excluding disposals for low production seems to reduce automatically the practical applicability of conclusion made from the study, as well as the estimates of heritability obtained. Their values for heritability from intra-sire regression of daughter on dam for 409 Holstein disposals was .008 and on 426 Jerseys
was .050. By paternal half-sib correlation on the same data, values obtained were .188 for Holsteins and .068 for Jerseys. Because of the small numbers these low values are not significantly different from zero. They advocate increasing longevity by improving management, especially as concerns fertility, mastitis, and other disease prevention. They justifiably emphasize that their study indicates the unimportance of genetic influences but they do not comment that what is needed in longevity is not necessarily an increase but a shift of reasons for disposal from the involuntary to the voluntary.

Plowman and Gaalaas (1960) showed heritability estimates of from .028 to .184 on longevity on various Federal, State, and private herds over the country and came up with an average estimate of .148 from daughter-dam regression. Probably the effects of selection for production were a little more prominent in the data used in these calculations than in the previous study.

Bauer, Bakels, Gall, and Kaiser (1960) in a study of the life-time production of cows of the Allgau Brown Swiss breed showed a simple daughter-dam regression of .18 for length of productive life. This seems high but their data were subject to severe selection, since a requirement for the study was that dam and daughter should both be in the equivalent of the
Advanced Registry roll in this country.

The most complete study of reasons for disposal of dairy cattle is probably Asdell's (1951) where the reasons were divided as is shown in Table 1, along with the results obtained by several other authors. Asdell's data were obtained from 2,792,188 cows in 17 states from 1932 to 1949, inclusive. An average of 20% were lost annually but, as dairy purposes comprised 5.1%, the author states that only 16.8% were actually lost to the industry. Compared to other figures and those of the present study this seems to be a very low figure. The present author prefers to believe that the "dairy purposes" category was larger than it should be, as only animals which had calved were considered. This idea is supported by the figures given for age specific disposals. There the dairy purpose category remained very high up to ages of 9 years and over. The other disposal categories in Asdell's study showed age trends similar to those found in this study except that his "low production" category did not reach a peak of disposals until 6-7 years of age and remained as high as or higher than the 2-3 year and 3-4 year classes. This does not seem plausible where D.H.I.A. testing was being carried out. The cullings for low production were mainly responsible for fluctuations in the year-to-year disposals. Probably this is due mainly to fluctuations in the meat and milk market. Part of Asdell's data was taken from Kansas herds which showed
Table 1. Reasons for disposal as given in five studies

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<td>0.9</td>
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</tr>
<tr>
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<td>2</td>
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<td>3.2</td>
</tr>
<tr>
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<td>9</td>
<td>6</td>
<td>4.6</td>
<td>1.7</td>
</tr>
<tr>
<td>Bang's disease</td>
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<td>15</td>
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<tr>
<td>T.B. reactors</td>
<td></td>
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<td>15.2</td>
<td>25.2</td>
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<tr>
<td>Infections</td>
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<tr>
<td>Poor condition</td>
<td></td>
<td></td>
<td>3.7</td>
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<td></td>
</tr>
<tr>
<td>Foreign Body</td>
<td></td>
<td></td>
<td>1.7</td>
<td>2.5</td>
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</tr>
<tr>
<td>Severe injury</td>
<td></td>
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<td></td>
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<td>Culls</td>
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<td>Bad legs and feet</td>
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<td>Leukosis</td>
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<tr>
<td>Foot and mouth</td>
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<td></td>
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</tr>
<tr>
<td>Rheumatism</td>
<td></td>
<td></td>
<td></td>
<td>0.1</td>
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</tr>
<tr>
<td>Unstated</td>
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<td></td>
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<tr>
<td>Total numbers of cows</td>
<td>2,792,188</td>
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<td>1883</td>
<td>409</td>
<td>1505</td>
</tr>
<tr>
<td></td>
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<td></td>
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much variation because of drought periods in Seath's (1939) data. Asdell (1951) shows a table comparing the percentages disposed of for the various reasons from herds in U.S.A., Scotland, England, and New Zealand. Little difference can be seen between the different countries.

Seath's (1939) figures for causes of disposal are shown in Table 1. His data came from Iowa and Kansas Cow Testing Associations from 1931 to 1935. The surprising feature is again the large proportion of animals listed as sold for dairy purposes. One would wonder if this reason was sufficiently well defined in the forms filled out for disposals. In this study, the average annual turnover was between 28 and 32% which agrees moderately well with results obtained in these present Iowa herds.

Parker, Bayley, Fohrman, and Plowman (1960) give the percentages shown in Table 1 for 409 disposals from the Beltsville Holstein herd. Note that a Tuberculosis outbreak in 1935 and 1936 brought this percentage up to a high level and reduced the value of the comparisons available. Nonbreeders make up a high percentage of the total but the percentage of nonbreeders is of course increased by the lack of production culling.

Birker (1960) gave the reasons for disposal of 1,789 registered German Friesians (Table 1). The breakdown seems
very complete and it differs considerably from the results in this country only in the smaller disposal for mastitis. Perhaps more handmilking is the principal reason for this, as some very high producing cows were included. Also a Tuberculosis clean-up program was under way at the time of this listing.

Becker, Arnold, and Spurlock (1954) analyzed the causes of disposal of 2,182 cows in 14 dairy herds in Florida, excluding the animals sold for dairy purposes.

With a few notable exceptions the five sets of data in Table 1 are very similar. One exception is the 41.3% disposed of for sterility in the Beltsville data but this figure would be increased by the lack of production culling in the data.

Davis (1952) in a study of calf births and losses over 44 years in the Nebraska University herd found that 79% of the 890 Holstein heifer calves born alive entered the milking herd. He listed four main causes of death as digestive, respiratory, infection, and other causes. Of the 111 calf deaths listed, 82 or almost 74% occurred between birth and three months.
Heritability of Causes of Disposal

Probably the earliest work on heritability of mastitis in this country was done by Lush (1950) in a study of New Zealand data obtained from the 21st Annual Report of the New Zealand Dairy Board. A cow was classified by a veterinary officer as "susceptible" if she had mastitis at any age and as "resistant" if she had not developed mastitis by 8 years of age.

The average intra-herd regression of daughter on dam in 27 herds was .19. This yields an estimate of heritability of .38. The method of classification appeared to be rather severe in that many cows which are not considered as particularly susceptible and do not become chronic cases, do show mastitis symptoms at some time or another in their life, possibly because of some injury or perhaps even because some lumps appeared at calving time. However these cows were on year-around pasture so that common sources of injury would be at a minimum. Also this type of dairying does not call for the intensive feeding prior to calving which is often connected with udder abnormalities at calving time. The conclusion, that differences in susceptibility to mastitis have a strong genetic background, seems justified.

Young, Legates, and Lecce (1960) in a study of clinical
mastitis in North Carolina herds gave a quantitative rating to clinical mastitis. This was done by giving each individual a mastitis susceptibility score for each complete lactation. This score was the percentage of months of the lactation during which the individual had one or more cases of clinical mastitis. In a study of 285 cows with 416 complete lactations a heritability figure of .71±.20 was obtained from paternal half-sib correlation. From daughter-dam regression a value of .21±.20 was found.

Possibly year or season effects have inflated the first figure as half-sibs would usually be nearly contemporary and this, in conjunction with the small numbers involved, might explain the large size of the half sib estimate but some degree of genetic causation is indicated.

O'Bleness, Van Vleck, and Henderson (1960) analyzed 842 daughter-dam pairs of the Holstein-Friesian breed within herd and year, with the prime objective of obtaining heritabilities and correlations among type appraisal traits but they also used the data to find a value for the heritability of mastitis. This was .05 which is very close to the daughter-dam regression figure in the present work.

Little other work is available at present on heritability of mastitis. It is hoped that more work can be done in the
near future to remove the lack of real knowledge which the
literature indicates. However the difficulty of removing
properly the effects of management on a trait of this type
is a serious obstacle to further study.

Reduced Fertility Studies

Jones, Dougherty, and Haag (1941) in a study on the
Oregon State College dairy herd over a 25 year period used a
measure of fertility for which they found rather large differ­
ences among cow families within the herd. They concluded that
inheritance is important in obtaining high fertility among
dairy cattle.

Eriksson (1943) studied the effects of ovarian hypoplasia
in Swedish Highland cows and showed definitely that a heredi­
tary factor was responsible. The conclusion reached was that
hypoplasia was conditioned by a recessive, autosomal gene with
incomplete penetrance.

Seath, Staples, and Neasham (1943) showed that cow fami­
lies varied in breeding efficiency from a low of 40.6% of
services resulting in conceptions to a high of 92.3%. No cor­
rections of any kind such as for year effects were applied but
these differences and the sire differences which they found
would seem to justify their statement that breeding efficiency
may be inherited.
Mead, Gregory, and Regan (1946) in a breeding project at the University of California developed a Jersey and Holstein herd in which some deleterious recessive genes appeared to be present. Two different forms of female sterility, which prevented heifers from conceiving or producing offspring, were encountered. The sterility in the Holstein breed was associated with abnormal estrus cycle, usually complete absence of heat. Both forms of sterility are sex limited. These anomalies were of course brought to light by close inbreeding but their presence in the breed indicates possibilities of spread.

Taussig (1946), in a fertility analysis of a herd in New York State, found considerable variation in the fertility of individual lines, indicating that bulls should be selected not only as individuals but also with regard to the fertility of their family. This was probably the strongest statement found in the literature regarding selection for fertility but it was not based on sufficient evidence to be conclusive. Only one herd was included in the study.

On the other hand Olds and Seatn (1950) found a correlation, between the number of services required by cows the first year as compared to the number of services for the second year, of $0.084 \pm 0.012$. This correlation was highly significant but indicated a low degree of predictability. Also Dunbar and Hen-
derson (1953), working with groups of artificially sired paternal half-sibs, calculated an intra-class correlation figure of .027 for non-returns to first service from the components of variance. A similar calculation for cows by different sires in the same herd yielded a figure of .051. The heritability of non-returns to first service was .004. Their conclusion that selection for fertility cannot be very effective seems justified by the results of this study but sterility among heifers is not included in these calculations.

Pou, Henderson, Asdell, Sykes, and Jones (1953) also showed low repeatability and heritability figures of the order of .1 for repeatability and .06 for heritabilities from daughter-dam regressions on corrected data. However in an interesting tabulation they show a trend in which dams with low service needs have daughters with low numbers of services.

<table>
<thead>
<tr>
<th>Mean lifetime services of dams</th>
<th>Mean lifetime services of daughters</th>
<th>No. of daughters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00 - 1.50</td>
<td>2.41</td>
<td>152</td>
</tr>
<tr>
<td>1.51 - 2.00</td>
<td>2.56</td>
<td>156</td>
</tr>
<tr>
<td>2.01 - 2.50</td>
<td>2.57</td>
<td>188</td>
</tr>
<tr>
<td>2.51 - 3.50</td>
<td>2.61</td>
<td>203</td>
</tr>
<tr>
<td>3.51 - 4.50</td>
<td>2.95</td>
<td>87</td>
</tr>
<tr>
<td>Over 4.50</td>
<td>3.11</td>
<td>48</td>
</tr>
</tbody>
</table>
In this table apparently no corrections were made but one would suppose that time trends and seasonal differences would be almost or quite randomized where comparisons of dams and daughters are concerned. The authors commented that this similarity was "not great".

Inchiosa and Pfau (1954), working within a single herd, compared the breeding efficiencies of 338 dam-daughter pairs of 8 Holstein sires, and found significant differences between the mean breeding efficiencies of the 8 groups of daughters. The correlation between the breeding efficiencies of dams and daughters was .203. The correlation between paternal half-sibs was .176 and the correlation between individual reproductive records of one cow was .135. Heritability was calculated to be 41%. These figures seem too high for general application but they indicate the lack of agreement present in animal husbandry circles concerning the proper emphasis on fertility in a breeding program.

Casida and Chapman (1951) have shown that cystic ovaries have a measurable degree of heritability which they calculated from daughter-dam regression to be 43%. Their data covered 1,280 service periods of 341 Holstein cows. As this has been in the past, and to some extent still is, a factor in reproductive failures, it may be of some importance in the overall heritability of disposal for reduced fertility.
Rollinson (1955) sums up the net effects of fertility studies by saying that selection for fertility would be both slow and of doubtful value with present knowledge, for sufficient evidence is not available to suggest the best techniques to be used. He emphasizes that inherited conditions of reduced fertility should be investigated by a team of workers, each of whom can add some special knowledge to the investigation.
SOURCE AND NATURE OF DATA

The data for this study were the records of the Iowa State University herd and ten of the other Iowa State Institution herds for all females born between 1937 and 1957. These dates were chosen as almost complete records were obtainable on the Institution herds for this period. Information on the University herd in earlier years was discarded but this was considered of little importance, particularly as that herd had almost built up to its present size by 1937 and comparisons were therefore less confounded with the effects of an increasing herd size.

One general I. B. M. card was made out in detail for each female born within this period. This card listed the following:

1. Herd number
2. Cow registration number, or eartag number if not registered
3. Dam registration number
4. Sire registration number
5. Sire code number
6. Date of birth
7. Date of disposal
8. Date of first service, when available
9. Date of last calving
10. Reason for disposal

From this card was obtained:
1. Age at first calf
2. Age at first service
3. Age at disposal
4. Length of last lactation

Reasons for disposal were divided into three main groups (A, B, and C) as follows and coded from one to thirty.

A. Disposal due to death from:
   1. Mastitis
   2. Pneumonia
   3. Metritis
   4. Calving trouble
   5. Hardware
   6. Blackleg
   7. Milk fever
   8. Bloat
   9. Calf scours
  10. At birth
  11. Accident
  12. Leukemia
  13. Other causes.

B. Involuntary disposal for:
   14. Pneumonia damage
   15. Reduced fertility
   16. Hardware damage
   17. Bangs reactor
18. Tuberculosis reactor  
19. Abortion  
20. Accident  
21. Other  

C. Voluntary disposal for:  
22. Mastitis damage  
23. Kidney infection  
24. Acetonemia  
25. Low production  
26. Dairy purposes  
27. Old age  
28. Cull, no reason given  
29. Udder injury  
30. Other.  

Included in the voluntary disposals are those animals which could have been returned with treatment. Putting mastitis damage in this classification is perhaps questionable but it was considered that some of these animals could be kept, perhaps with the loss of one quarter, and it was not absolutely necessary to sell all of them. Disposal records were obtained on 4768 females in 11 herds.  

Records consisted of those from 4323 cows in 11 herds for age at first calving, 4242 cows in 9 herds for age at first service, and 3500 cows in 11 herds for length of terminal lactation.
In order to study calving interval, three more cards were made for cows which had complete information on dates of calving, dates of first service after each calving, and date of successful service.

These were in the form:

1. Herd number
2. Cow registration number
3. Dates of 11 calvings, or dates of 11 first services after calvings, or dates of 11 successful services.

From these were obtained the three periods making up the calving interval, where calving interval is defined as the complete period between successive calvings. These are the period from calving to first service, the period from first service to successful service and the gestation interval.

Records on periods from calving to first service were obtained for 2,847 cows in 7 herds, from first service to successful service on 3055 cows in 7 herds and gestation length on 3044 cows in 7 herds. In addition, the number and sex of the calves born were recorded on the cards containing the calving information.

In the course of collecting the data from these herds, which are scattered over Iowa, at least one day was spent at each of the locations, copying the information on the cows
currently in the herd. Then the records of the animals already disposed of, were brought back to Ames for copying. In this way contact was made with the herdsmen and some idea of the managerial facilities and difficulties was obtained. This firsthand knowledge was of value in suggesting explanations of some of the variations found in the data.
ANALYSIS OF DATA AND RESULTS

Age at First Service and at First Calving

These two factors were considered together because they were closely related. The economics of dairying appear to be forcing dairymen to reduce the non-productive period of a cow's life in a herd. Thus, the time of first service should have been decreasing over the years, if the Institution herds had been making a conscious effort to keep up with the national trend with regard to better feeding and earlier breeding of heifers. A slight trend is shown in Figure 1 towards shortening the open period but the comparison, shown between the Institution herds and the University herd, indicates that much earlier breeding would be possible in these Institution herds. The average age at first breeding in the University herd (herd No. 1) is 504 days compared with 629 days in the other herds. This means that on the average a heifer in one of the outside Institution herds is 125 days older than a heifer in the University herd when first bred.

A plausible reason for this is that there is a fixed age level in the University herd after which heifers are to be bred. This is at 15 months of age and, since only a little effort is made to have heifers calve at one period of the year, the herd manager can come close to maintaining this. However
Figure 1. Average ages at first service and first calving by year of birth
in the Institution herds there is a slight tendency towards having heifers calve in the fall. In the Institution herds 44% of the first services of heifers take place in the four month period from November to February while in the same period the University herd breeds 36%. This breeding for fall calving varies somewhat between herds and appears to depend to some extent on the amount of labor available and its quality. Table 2 shows the percentages of first calvings in each month by herds. A comparison of the values for the University herd and for all the Institution herds (1 compared with 2 - 15) shows this tendency for calvings to be bunched a little more closely in the fall in the Institution herds. The differences are not large enough to explain all the difference in age at first service. The herdsmen in the Institution herds must be delaying the breeding of heifers until they reach more advanced ages. The feeding in the early stages of growth is also important as the heifers must be fairly well grown (750 - 800 pounds) to attain a reasonable breeding size by 15 months or shortly after. Some of the herds fed less well, evidently believing that a little less feed and care in the yearling stages fitted into their system better than good feeding and consequent early breeding.

Table 3 shows the yearly averages for all herds with data available on first service. Age at first service is still far
Table 2. Percentage of first calvings in each month (by herds)

<table>
<thead>
<tr>
<th>Months</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>11</th>
<th>12</th>
<th>15 (2-15)</th>
</tr>
</thead>
<tbody>
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<td>January</td>
<td>8.1</td>
<td>15.9</td>
<td>10.5</td>
<td>14.6</td>
<td>12.0</td>
<td>9.8</td>
<td>9.8</td>
<td>9.3</td>
<td>8.4</td>
<td>12.5</td>
<td>7.2</td>
</tr>
<tr>
<td>February</td>
<td>8.8</td>
<td>4.3</td>
<td>7.9</td>
<td>8.6</td>
<td>3.8</td>
<td>3.4</td>
<td>7.1</td>
<td>9.3</td>
<td>6.5</td>
<td>5.6</td>
<td>8.4</td>
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<td>March</td>
<td>9.8</td>
<td>2.3</td>
<td>6.7</td>
<td>9.3</td>
<td>3.0</td>
<td>6.3</td>
<td>8.2</td>
<td>7.8</td>
<td>8.2</td>
<td>5.3</td>
<td>4.9</td>
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<td>April</td>
<td>7.0</td>
<td>2.6</td>
<td>3.9</td>
<td>4.6</td>
<td>6.0</td>
<td>6.8</td>
<td>6.2</td>
<td>6.5</td>
<td>11.2</td>
<td>5.3</td>
<td>4.1</td>
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<td>May</td>
<td>6.0</td>
<td>4.0</td>
<td>6.0</td>
<td>5.3</td>
<td>6.0</td>
<td>8.8</td>
<td>4.1</td>
<td>6.9</td>
<td>7.4</td>
<td>5.3</td>
<td>6.3</td>
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<td>2.8</td>
<td>4.1</td>
<td>6.0</td>
<td>7.5</td>
<td>7.8</td>
<td>5.8</td>
<td>8.0</td>
<td>6.5</td>
<td>5.0</td>
<td>6.1</td>
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<td>July</td>
<td>8.9</td>
<td>3.4</td>
<td>5.7</td>
<td>8.6</td>
<td>9.0</td>
<td>9.8</td>
<td>9.6</td>
<td>7.4</td>
<td>8.7</td>
<td>5.0</td>
<td>13.7</td>
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<tr>
<td>August</td>
<td>8.6</td>
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<td>12.8</td>
<td>9.9</td>
<td>7.5</td>
<td>7.3</td>
<td>8.9</td>
<td>8.6</td>
<td>11.7</td>
<td>10.0</td>
<td>10.8</td>
</tr>
<tr>
<td>September</td>
<td>8.1</td>
<td>20.5</td>
<td>11.1</td>
<td>6.6</td>
<td>17.3</td>
<td>7.3</td>
<td>7.7</td>
<td>9.3</td>
<td>11.2</td>
<td>13.4</td>
<td>10.8</td>
</tr>
<tr>
<td>October</td>
<td>11.0</td>
<td>12.8</td>
<td>9.7</td>
<td>6.0</td>
<td>17.3</td>
<td>10.7</td>
<td>12.0</td>
<td>8.0</td>
<td>8.4</td>
<td>11.6</td>
<td>11.1</td>
</tr>
<tr>
<td>November</td>
<td>9.8</td>
<td>10.3</td>
<td>11.8</td>
<td>10.6</td>
<td>5.3</td>
<td>8.8</td>
<td>9.8</td>
<td>10.0</td>
<td>5.4</td>
<td>14.1</td>
<td>7.8</td>
</tr>
<tr>
<td>December</td>
<td>8.2</td>
<td>11.7</td>
<td>9.8</td>
<td>9.9</td>
<td>5.3</td>
<td>13.2</td>
<td>10.8</td>
<td>8.9</td>
<td>6.3</td>
<td>6.9</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Total numbers: 570 351 611 151 133 205 674 461 367 320 489 3762

Total: 4332
Table 3. Year means for age at first service in each herd (in days)

<table>
<thead>
<tr>
<th>Years</th>
<th>Herds</th>
<th>Overall mean</th>
<th>No. in means</th>
</tr>
</thead>
<tbody>
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<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1937</td>
<td>498</td>
<td>619</td>
<td>592</td>
</tr>
<tr>
<td>1938</td>
<td>489</td>
<td>635</td>
<td>586</td>
</tr>
<tr>
<td>1939</td>
<td>483</td>
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<td>1940</td>
<td>512</td>
<td>630</td>
<td>644</td>
</tr>
<tr>
<td>1941</td>
<td>525</td>
<td>720</td>
<td>671</td>
</tr>
<tr>
<td>1942</td>
<td>512</td>
<td>682</td>
<td>620</td>
</tr>
<tr>
<td>1943</td>
<td>555</td>
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<td>750</td>
</tr>
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<td>517</td>
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</tr>
<tr>
<td>1957</td>
<td>474</td>
<td>503</td>
<td>707</td>
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</table>

Mean over all years 504 586 676 586 642 616 644 643 595 612
from the present recommendations of most extension men and
dairy specialists that heifers be fed so as to be bred at 450 -
460 days. The table shows also considerable year-to-year
variation, probably due in part to varying requirements for re-
placement purposes. This would be particularly true in the many
herds where sale for dairy purposes was only a small propor-
tion of total sales. Herd Number 2 which had the most sales
of dairy stock also had the lowest average age at first service
among the Institution herds, but even this was 82 days longer
than the University figure.

Table 4 shows the average ages at first calving by years
and herds. Here the 10 Institution herds show an average of
943 days compared with the 814 days of the University herd.
This gives a difference of 129 days or just a fraction longer
than the 125 days difference in age at first service.

Obviously, first service and first calving are closely re-
lated. To measure this the correlation between the two was
computed on 3971 paired observations, first as a single popu-
lation, then on an intrayear, intraherd basis. This analysis
is shown in Table 5. The overall correlation was .738; that
within herds was .728; and that within years within herds was
.696 with 95% confidence limits of .679 to .712. The weighted
correlations between herd means was .913 and that between yearly
means within herds was .877. Thus the relation between herd
Table 4. Year means for age at first calving in each herd (in days)

<table>
<thead>
<tr>
<th>Years</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>11</th>
<th>12</th>
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No. in means 572 348 608 152 133 204 673 461 367 318 487 4323
Mean overall years 814 893 995 996 845 968 982 929 952 915 887 926
Table 5. Analysis of variance and covariance of age at first service and age at first calving

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean square calving</th>
<th>Mean square Service</th>
<th>Covariance Serv. and calv.</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
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<td>Total</td>
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<td></td>
<td></td>
<td></td>
<td>.738</td>
</tr>
<tr>
<td>Between herds</td>
<td>8</td>
<td>1,762,921</td>
<td>1,332,459</td>
<td>1,399,671</td>
<td>.913</td>
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<td>Between years/herds</td>
<td>159</td>
<td>83,854</td>
<td>56,700</td>
<td>60,460</td>
<td>.728</td>
</tr>
<tr>
<td>Within years</td>
<td>3803</td>
<td>16,630</td>
<td>11,194</td>
<td>9,497</td>
<td>.696</td>
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</table>
means and between yearly means was slightly closer than that on individual cows, as might have been expected if the general causes of the correlation had been much the same in all three cases but much of the individual variation had been extinguished by the averaging in the correlations (.913 and .877) between the averages.

Using the square of the correlation coefficient (.696) indicates that about 52% of the intrayear intraherd variance in age at first calving is caused by things other than age at first breeding. In other words, the variation among heifers in time taken to conceive after breeding begins is about half of the total variance in calving age. Besides actual difficulties in conception, this would, of course, include the occurrence of undetected early abortions.

Table 6 shows the components of variance for herds and for year and month of birth within herds. The important features of Table 6 are the relative sizes of the components. The variance in age at first calving is larger than the variance in age at first service. This is to be expected because additional factors may cause conception to be prompt or delayed after service begins. In both cases the herd mean of the University herd (Herd No. 1) was, statistically, highly significantly lower than the means of the other herds. The differences between years within herds are affected possibly by
Table 6. Analyses of variance for age at first service and age at first calving

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean squares</th>
<th>Expected mean squares</th>
<th>Value of components</th>
<th>% age of variance</th>
</tr>
</thead>
<tbody>
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<td>(Age at first calving)</td>
<td></td>
<td>(Age at first service)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between herds</td>
<td>10</td>
<td>1,556,877</td>
<td>$\sigma_e^2+3.22\sigma_m^2+24.00\sigma_y^2+385.14\sigma_h^2$</td>
<td>3,756</td>
<td>15.0</td>
</tr>
<tr>
<td>Between years/herds</td>
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<td>96,485</td>
<td>$\sigma_e^2+2.93\sigma_m^2+20.38\sigma_y^2$</td>
<td>3,546</td>
<td>14.2</td>
</tr>
<tr>
<td>Between months/years/herds</td>
<td>1519</td>
<td>22,572</td>
<td>$\sigma_e^2+2.44\sigma_m^2$</td>
<td>3,363</td>
<td>13.4</td>
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<tr>
<td>Within months</td>
<td>2594</td>
<td>14,365</td>
<td>$\sigma_e^2$</td>
<td>14,365</td>
<td>57.4</td>
</tr>
<tr>
<td>Total</td>
<td>4322</td>
<td></td>
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<td>25,030</td>
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</table>

(44)
year to year differences in replacement requirements in the Institution herds, while the component between months is affected by the time of year and the effects associated with time of year in which the animal is born. Time of birth affects whether they will be bred young to freshen in the fall or be held over to calve in the following year. This last effect is shown in the high percentage (44%) of first services of heifers taking place in the months of November, December, January, and February in the Institution herds.

It would appear that factors other than those removed in the analysis are of importance, both on age at first service and on age at first calving. All normal heifers will be showing heat symptoms by the age at which breeding is normally commenced in the herds studied. Biological differences between heifers are probably important only in the time taken from first breeding to conception. On heifers where both age at first service and at first calving were available on the same animal, the period from first breeding to calving was 315 days indicating a breeding period of 37 days or about 2.8 services per conception if normal intervals occurred and the heifer was bred at each heat.

Age at Disposal and Length of Terminal Lactation

In any study involving age at disposal it is important to establish the fact that all or almost all cows, of any co-
hort of animals studied, have left the herd. If this is not so, then the averages for those born in the later years of study are hopelessly biased towards the younger ages. For this reason all studies on these two factors were carried out on animals born between 1937 and 1950. Less than 1% of animals born within that period remained alive in the herds at the end of 1957. These would have a slight tendency to bias downwards the average age at disposal for those born in 1950 and just earlier. However, it was considered that this effect would be more than counterbalanced by the additional information to be gained from the animals born in those years and already gone.

The presence in the herd of animals of the same cohort as animals already culled may not affect importantly the length of terminal lactation but these older animals are kept slightly longer in their last lactation. For this reason length of terminal lactation was investigated over the shortened period.

Figure 2 shows the average ages at disposal obtained over the complete period. Obviously the curve is biased in the later years by the absence of death records on the older cows still in the herd. As in the previous graph, the University herd is shown separately from the Institution herds in order to illustrate the difference and the variation possible between herds.
Figure 2. Average age at disposal by year of birth
Table 7 shows that the University Herd (Herd No. 1) is turning over its cows faster than the other herds. Probably this is due mainly to the herd policy of calving all heifers possible. If the herd size stays constant, when a heifer calves an older cow must leave the herd to make room for her. However, as is shown in the age specific death rates, the mere fact of the earlier calving increases the probability of disposal due to the additional stress of calving and rebreeding. Table 7 shows also that some size increase occurred in the herds during the early part of the period. The conspicuous decline in age at disposal after 1951 is partly due to the fact that the members of the cohorts born in that period who will finally have high ages at disposal are still in the herds and their eventual high ages cannot now be in the average.

Table 8 shows an analysis of variance for age at disposal. Several herds contribute largely to the component between herds of 10%. Herd No. 1 shows a 536 day deviation from the overall mean, Herd No. 5 (Davenport) shows a 526 day deviation, Herd No. 11 (Mt. Pleasant) 569 days, and Herd No. 2 (Anamosa) a 463 day difference. The other herds approach more closely the overall average value.

An examination of Table 7 will show how the differences of the yearly means within herds have produced the component for years in Table 8. As the herds have increased in size from
Table 7. Year means for age at disposal in each herd (in days)

<table>
<thead>
<tr>
<th>Years</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>7</th>
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No. in means 672 588 515 129 137 363 689

1937-57 mean 1303 1321 2079 2089 1674 1642 1842

1937-50 mean 1377 1450 2223 2439 2260 1977 1988

No. in 1937-50 mean 465 410 360 84 67 226 516
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<td>4190</td>
<td>2595</td>
<td>2014</td>
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<td>1867</td>
<td>1837</td>
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<td>1827</td>
<td>1749</td>
<td>1507</td>
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<td>1535</td>
<td>1841</td>
<td>2021</td>
<td>1601</td>
<td>299</td>
</tr>
<tr>
<td>1952</td>
<td>1553</td>
<td>1554</td>
<td>1522</td>
<td>1460</td>
<td>1456</td>
<td>333</td>
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<tr>
<td>1953</td>
<td>1485</td>
<td>1499</td>
<td>1414</td>
<td>1340</td>
<td>1399</td>
<td>287</td>
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<td>1383</td>
<td>1188</td>
<td>1267</td>
<td>1270</td>
<td>264</td>
</tr>
<tr>
<td>1955</td>
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<td>1349</td>
<td>1260</td>
<td>701</td>
<td>1049</td>
<td>222</td>
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<tr>
<td>1956</td>
<td>1092</td>
<td>1104</td>
<td>638</td>
<td>612</td>
<td>922</td>
<td>160</td>
</tr>
<tr>
<td>1957</td>
<td>497</td>
<td>998</td>
<td>--</td>
<td>733</td>
<td>724</td>
<td>89</td>
</tr>
</tbody>
</table>

No. in means | 490 | 347 | 271 | 475 | 4676

1937-57 mean | 1764 | 1928 | 2136 | 1535 | 1696

1937-50 mean | 2059 | 2482 | 2316 | 1836 | 1913

No. in 1937-50 mean | 285 | 173 | 209 | 229 | 3024
Table 8. Analysis of variance for age at disposal

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean squares</th>
<th>Expected mean squares</th>
<th>Value of components</th>
<th>Variance % age of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between herds</td>
<td>10</td>
<td>38,870,310</td>
<td>$\sigma_e^2 + 3.41\sigma_m^2 + 25.86\sigma_y^2 + 267.68\sigma_h^2$</td>
<td>125,662</td>
<td>10.0</td>
</tr>
<tr>
<td>Between years/herds</td>
<td>130</td>
<td>4,521,138</td>
<td>$\sigma_e^2 + 2.98\sigma_m^2 + 21.04\sigma_y^2$</td>
<td>163,991</td>
<td>13.0</td>
</tr>
<tr>
<td>Between months/years/herds</td>
<td>995</td>
<td>1,052,311</td>
<td>$\sigma_e^2 + 2.61\sigma_m^2$</td>
<td>49,860</td>
<td>3.9</td>
</tr>
<tr>
<td>Within months</td>
<td>1888</td>
<td>922,176</td>
<td>$\sigma_e^2$</td>
<td>922,176</td>
<td>73.1</td>
</tr>
<tr>
<td>Total</td>
<td>3023</td>
<td></td>
<td></td>
<td>1,261,690</td>
<td>100.0</td>
</tr>
</tbody>
</table>
an average of 714 cows in the early 1940's up to 825 cows in 1957 there has been a slight decrease in average age at disposal. This decrease is complicated in the later years by the older cows still being in the herd but the decrease can be seen in all except the University herd by comparing the 1940 and 1941 means with those of 1948 and 1949. The component of 4% for months merely shows that some variance is present depending on month born. The component of 73% within months indicates large effects not common to cows born in a certain herd, year, and month.

Table 9 shows an analysis of the variance in length of the last lactation. This shows that nearly all of the variation (92.2%) is independent of factors common to herd, year, and month. Table 10 shows the herd and year averages for the whole period and for the 1937 - 1950 period. The University herd has a somewhat lower figure, due to their faster turnover policy but on the whole this table merely shows that the effects of years and herds on the length of terminal lactation is very small.

Figure 3 shows graphically the average length of last lactation by years, again showing the University herd separately. Here again the causes of variation appear to be almost wholly things that vary even among cows born in the same month. Little here seems of use to the animal breeder except perhaps,
Table 9. Analysis of variance for length of terminal lactation

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean squares</th>
<th>Expected mean squares</th>
<th>Value of components</th>
<th>%age of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between herds</td>
<td>10</td>
<td>357,426</td>
<td>$\sigma_e^2 + 2.91 \sigma_m^2 + 20.55 \sigma_y^2 + 201.83 \sigma_h^2$</td>
<td>1,510</td>
<td>4.5</td>
</tr>
<tr>
<td>Between years/herds</td>
<td>121</td>
<td>49,024</td>
<td>$\sigma_e^2 + 2.61 \sigma_m^2 + 17.07 \sigma_y^2$</td>
<td>1,044</td>
<td>3.1</td>
</tr>
<tr>
<td>Between months/years/herds</td>
<td>849</td>
<td>31,183</td>
<td>$\sigma_e^2 + 2.29 \sigma_m^2$</td>
<td>61</td>
<td>0.2</td>
</tr>
<tr>
<td>Within months</td>
<td>1315</td>
<td>31,044</td>
<td>$\sigma_e^2$</td>
<td>31,044</td>
<td>92.2</td>
</tr>
<tr>
<td>Total</td>
<td>2295</td>
<td>33,659</td>
<td></td>
<td></td>
<td>100.0</td>
</tr>
</tbody>
</table>
### Table 10. Year means for length of last lactation in each herd (in days)

<table>
<thead>
<tr>
<th>Years</th>
<th>Years</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1937</td>
<td></td>
<td>278.8</td>
<td>296.8</td>
<td>182.7</td>
<td>273.0</td>
<td></td>
<td></td>
<td>321.9</td>
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<tr>
<td>1938</td>
<td></td>
<td>244.4</td>
<td>276.5</td>
<td>390.1</td>
<td>787.5</td>
<td></td>
<td></td>
<td>350.5</td>
</tr>
<tr>
<td>1939</td>
<td></td>
<td>234.8</td>
<td>402.9</td>
<td>308.1</td>
<td>308.0</td>
<td></td>
<td></td>
<td>580.5</td>
</tr>
<tr>
<td>1940</td>
<td></td>
<td>185.4</td>
<td>341.2</td>
<td>327.2</td>
<td>376.0</td>
<td>741.0</td>
<td></td>
<td>348.1</td>
</tr>
<tr>
<td>1941</td>
<td></td>
<td>229.6</td>
<td>346.8</td>
<td>376.5</td>
<td>264.0</td>
<td>370.0</td>
<td></td>
<td>337.5</td>
</tr>
<tr>
<td>1942</td>
<td></td>
<td>223.5</td>
<td>240.7</td>
<td>288.8</td>
<td>230.4</td>
<td>320.8</td>
<td></td>
<td>349.1</td>
</tr>
<tr>
<td>1943</td>
<td></td>
<td>202.9</td>
<td>242.1</td>
<td>359.9</td>
<td>180.7</td>
<td>320.8</td>
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<td>304.2</td>
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<tr>
<td>1944</td>
<td></td>
<td>188.1</td>
<td>391.4</td>
<td>366.0</td>
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<td>236.8</td>
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<td>371.3</td>
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<td>298.5</td>
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<td>255.6</td>
<td>260.1</td>
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<td></td>
<td></td>
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<td>235.6</td>
<td>199.5</td>
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<td></td>
<td>236.2</td>
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<td></td>
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<td>159.8</td>
<td>204.5</td>
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<td>477.3</td>
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<td>174.9</td>
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<td>181.7</td>
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<tr>
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<td>113.0</td>
<td>187.3</td>
<td></td>
<td></td>
<td></td>
<td>197.0</td>
</tr>
</tbody>
</table>

| No. in means | 506 | 278 | 500 | 125 | 95 | 140 | 567 |
| 1937-57 mean | 222.3 | 258.8 | 286.7 | 260.2 | 319.8 | 218.6 | 302.3 |
| 1937-50 mean | 220.6 | 283.0 | 314.2 | 273.7 | 335.0 | 255.9 | 325.5 |
| No. in 1937-50 mean | 351 | 182 | 347 | 84 | 52 | 57 | 432 |
Table 10. (Continued)

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<th>Years</th>
<th>9</th>
<th>11</th>
<th>12</th>
<th>15</th>
<th>Overall mean</th>
<th>No. in means</th>
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<td>178.5</td>
<td>214.6</td>
<td>280.2</td>
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<td>129</td>
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<tr>
<td>1942</td>
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<td>325.7</td>
<td>212.6</td>
<td></td>
<td>290.9</td>
<td>144</td>
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<td>234.7</td>
<td>179.5</td>
<td>287.3</td>
<td></td>
<td>263.4</td>
<td>138</td>
</tr>
<tr>
<td>1944</td>
<td>311.0</td>
<td>307.8</td>
<td>265.9</td>
<td>272.1</td>
<td>289.5</td>
<td>160</td>
</tr>
<tr>
<td>1945</td>
<td>302.4</td>
<td>272.7</td>
<td>200.6</td>
<td>196.6</td>
<td>267.9</td>
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<tr>
<td>1946</td>
<td>219.7</td>
<td>339.7</td>
<td>229.7</td>
<td>174.4</td>
<td>264.4</td>
<td>183</td>
</tr>
<tr>
<td>1947</td>
<td>266.3</td>
<td>241.2</td>
<td>251.1</td>
<td>243.7</td>
<td>266.5</td>
<td>263</td>
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<tr>
<td>1948</td>
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<td>233.9</td>
<td>291.3</td>
<td>249.0</td>
<td>266.3</td>
<td>240</td>
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<tr>
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<td>224.8</td>
<td>209.0</td>
<td>203.8</td>
<td>252.9</td>
<td>242</td>
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<tr>
<td>1950</td>
<td>292.2</td>
<td>294.2</td>
<td>216.8</td>
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<td>266.0</td>
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<td>214.3</td>
<td>291.1</td>
<td>257.2</td>
<td>253.5</td>
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<tr>
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<td>234.2</td>
<td>291.2</td>
<td>248.1</td>
<td>259</td>
</tr>
<tr>
<td>1953</td>
<td>232.6</td>
<td>200.9</td>
<td>240.5</td>
<td>264.8</td>
<td>230.3</td>
<td>231</td>
</tr>
<tr>
<td>1954</td>
<td>302.5</td>
<td>214.4</td>
<td>148.0</td>
<td>255.8</td>
<td>224.3</td>
<td>208</td>
</tr>
<tr>
<td>1955</td>
<td>306.1</td>
<td>189.5</td>
<td>282.3</td>
<td>226.8</td>
<td>229.2</td>
<td>129</td>
</tr>
<tr>
<td>1956</td>
<td>241.0</td>
<td>173.5</td>
<td>--</td>
<td>172.1</td>
<td>199.3</td>
<td>94</td>
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<tr>
<td>1957</td>
<td>3.0</td>
<td>177.5</td>
<td>--</td>
<td>108.0</td>
<td>150.0</td>
<td>37</td>
</tr>
</tbody>
</table>

No. in means

1937-57 mean: 378 277 261 373 3500
1937-50 mean: 281.1 235.6 250.1 238.3 262.4

No. in 1937-50 mean:

240 141 201 209 2296
Figure 3. Average length of terminal lactation by year of birth
to know that the average length of terminal lactation is in the region of 270 days.

**Calving Interval**

Calving interval has been studied intensively by Rennie (1952) on three of the herds used in the present study over the period 1940 - 1951. However, considering the variation in length found in a previous study by Meek (1960), it was thought worthwhile to find where the variation existed and try to explain it.

For this reason the three cards for first service after each calving, successful service after each calving, and calving dates were used to obtain the following intervals:

1. First service to successful service
2. Successful service to calving (gestation interval)
3. Calving to first service.

These intervals are shown in a line diagram similar to that used by Rennie (1952).

<table>
<thead>
<tr>
<th>Breeding Period</th>
<th>Gestation</th>
<th>Non-breeding period</th>
</tr>
</thead>
<tbody>
<tr>
<td>First service</td>
<td>Successful service</td>
<td>first</td>
</tr>
<tr>
<td></td>
<td></td>
<td>First</td>
</tr>
<tr>
<td></td>
<td></td>
<td>service</td>
</tr>
</tbody>
</table>

The periods of importance are, of course, the breeding period, and the period from calving to first service or non-
breeding period since the gestation interval is more nearly constant having a standard deviation of 5 days. However the gestation interval was determined up to the eleventh calving.

Information on these factors was obtained on only 7 out of the 11 herds as this information was missing from the other 4. Generally the information missing was only the first service date, as often only the service date which was successful was copied from the barn book on to the individual cow's permanent record sheet.

Period from first service to successful service

Table 11 shows the averages obtained for breeding periods 1 to 11 along with the herd averages by herds and by breeding period. Probably the most surprising figure is that of herd 7 in the first breeding period. The value of 106.5 days obtained from 197 records requires some explanation. From examination of the data it was apparent that the heifers were being exposed to the bull for a short time, probably not over two heat periods, and then the bull was removed. Any heifers which had not been settled were not bred again until the following fall or winter. Thus the average of 106.5 days includes quite a few heifers which were not being exposed for almost a year between first and successful services. This resulted in an average age at first calving in this herd of 2.76 years, with 30% of these calvings being by animals 3 years old or older. This is
Table 11. Mean period from first service to successful service (in days)

<table>
<thead>
<tr>
<th>Breeding periods</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>11</th>
<th>No. of records</th>
</tr>
</thead>
<tbody>
<tr>
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<td>32.1</td>
<td>20.2</td>
<td>39.0</td>
<td>106.5</td>
<td>54.6</td>
<td>37.7</td>
<td>28.9</td>
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<tr>
<td>2</td>
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<td>41.0</td>
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<td>42.8</td>
<td>26.1</td>
<td>32.8</td>
</tr>
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<td>25.8</td>
<td>21.5</td>
<td>24.3</td>
<td>33.0</td>
<td>51.1</td>
<td>30.9</td>
<td>31.3</td>
<td>32.2</td>
</tr>
<tr>
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<td>34.5</td>
<td>29.5</td>
<td>29.2</td>
<td>40.0</td>
<td>49.0</td>
<td>44.2</td>
<td>32.1</td>
<td>37.1</td>
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<td>43.5</td>
<td>41.4</td>
<td>44.4</td>
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<td>52.1</td>
<td>38.8</td>
<td>40.4</td>
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<td>30.2</td>
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<td>31.0</td>
<td>46.2</td>
<td>45.1</td>
<td>37.8</td>
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<td>26.6</td>
<td>16.5</td>
<td>47.5</td>
<td>81.5</td>
<td>68.9</td>
<td>35.7</td>
<td>39.1</td>
</tr>
<tr>
<td>9</td>
<td>15.9</td>
<td>67.3</td>
<td>6.3</td>
<td>0.0</td>
<td>11.4</td>
<td>21.5</td>
<td>60.4</td>
<td>40.6</td>
</tr>
<tr>
<td>10</td>
<td>13.8</td>
<td>35.7</td>
<td>21.0</td>
<td>63.2</td>
<td>0.0</td>
<td>0.0</td>
<td>78.5</td>
<td>39.1</td>
</tr>
<tr>
<td>11</td>
<td>104.0</td>
<td>34.2</td>
<td>-</td>
<td>-</td>
<td>64.0</td>
<td>-</td>
<td>103.0</td>
<td>58.3</td>
</tr>
</tbody>
</table>

Herd mean         | 32.6 | 25.8 | 35.3 | 58.7 | 54.4 | 43.0 | 30.9 | 39.6 |
No. in mean        | 574  | 291  | 564  | 197  | 642  | 433  | 354  | 3055 |
the herd maintained at Fort Madison. Their later breeding periods are all average or a little below.

The large herd at Glenwood, number 8, shows the next longest average breeding period of all the herds. The second period is considerably longer than any of the others with large enough numbers included to be reliable. This helps make the interval between first and second calving longer than between any other calvings. Breeding periods may have been prolonged by missed heat periods. This factor would also increase the non-breeding period which in this herd is also close to the longest of all herds. No severe disease-caused breeding troubles were indicated by the disposal records of this herd.

Herd number 2 kept at Anamosa showed the shortest breeding period of 25.8 days. This would average about 2.23 breedings using 21 days as the normal cycle and adding 1 for the first service. This is to be compared with an overall average of 2.89 breedings. These figures for the average number of breedings are higher than most estimates but they involve the doubtful assumption that every cow was bred on every heat period so they probably are a bit too high. On the other hand they include only cows which did eventually conceive.

The herds tend to increase in breeding period with an increase in size of the herd, if the enlarged figure for the
first period in herd 7 is ignored. A plausible reason for this is that the one cow-man in charge of each of these herds does not have the time for as close supervision in the larger herds as does the man in charge of the smaller herds. The University herd is somewhat of an exception, but two of the smaller Institution herds actually have a shorter breeding period than does the University herd.

*Gestation interval*

Most estimates of gestation length give 278 - 280 days for Holstein-Friesians and the results shown in Table 12 support this. The principal exception lies in the University herd with the low average of 275.6 days. Several investigators have shown that female calves are normally carried about a day shorter than males. The University herd was the only one in which more female calves than males were born but this could have only a tiny effect on its average length of gestation. Also, in this study a normal calving was counted as being one which was followed by a normal lactation. In the University herd with an important function being to produce genetic data, greater effort may have been put into obtaining lactations from early calving animals. This factor is shown in the 36 calvings (2.7%) at under 250 days in the University herd compared with 109 calvings (1.47%) at under 250 days in the Institution herds. This again would have a very small ef-
Table 12. Mean length of gestation interval (in days)

<table>
<thead>
<tr>
<th>Intervals</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>11</th>
<th>All herds</th>
<th>No. in mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>276.1</td>
<td>279.1</td>
<td>278.6</td>
<td>283.8</td>
<td>280.9</td>
<td>279.4</td>
<td>279.2</td>
<td>279.2</td>
<td>3044</td>
</tr>
<tr>
<td>2</td>
<td>273.3</td>
<td>285.6</td>
<td>276.8</td>
<td>280.3</td>
<td>278.0</td>
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<td>278.6</td>
<td>278.2</td>
<td>2149</td>
</tr>
<tr>
<td>3</td>
<td>278.2</td>
<td>277.8</td>
<td>279.2</td>
<td>277.7</td>
<td>279.8</td>
<td>282.0</td>
<td>278.8</td>
<td>279.4</td>
<td>1382</td>
</tr>
<tr>
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<td>275.8</td>
<td>279.5</td>
<td>283.6</td>
<td>281.8</td>
<td>278.2</td>
<td>281.7</td>
<td>281.0</td>
<td>280.2</td>
<td>905</td>
</tr>
<tr>
<td>5</td>
<td>274.3</td>
<td>276.6</td>
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<td>279.0</td>
<td>284.1</td>
<td>282.2</td>
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<td>275.3</td>
<td>274.4</td>
<td>277.2</td>
<td>276.8</td>
<td>286.7</td>
<td>278.5</td>
<td>336</td>
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<td>7</td>
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<td>264.8</td>
<td>283.2</td>
<td>280.6</td>
<td>275.9</td>
<td>280.5</td>
<td>277.9</td>
<td>118</td>
</tr>
<tr>
<td>9</td>
<td>277.8</td>
<td>280.6</td>
<td>275.0</td>
<td>280.6</td>
<td>279.6</td>
<td>279.3</td>
<td>281.5</td>
<td>280.0</td>
<td>69</td>
</tr>
<tr>
<td>10</td>
<td>294.2</td>
<td>279.1</td>
<td>275.0</td>
<td>282.4</td>
<td>277.0</td>
<td>275.0</td>
<td>273.4</td>
<td>280.2</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>279.0</td>
<td>295.2</td>
<td>-</td>
<td>-</td>
<td>286.0</td>
<td>-</td>
<td>-</td>
<td>290.0</td>
<td>6</td>
</tr>
</tbody>
</table>

Herd means  | 275.6| 280.0| 278.7| 281.1| 279.5| 280.4| 279.9| 279.1

No. in means | 571  | 289  | 562  | 197  | 641  | 430  | 354  | 3044
fect on average length of gestation.

Perhaps a more important factor is the earlier average age at calving in the University where 37.7% of the lactations are made by heifers compared with 25.6% in the Institution herds. It has been reported by Stallcup et al. (1956) and Herman et al. (1953) that there is a significant tendency for younger cows to have shorter gestation lengths. Probably a combination of these and other factors was responsible for the shortened period. Little else of value was found in the gestation data.

Non-breeding period

An interesting and variable managemental time period is that between calving and first breeding. As can be seen in the review of literature, many varying estimates have been given of the time which elapses between calving and the showing of heat symptoms. Survey data are probably highly inaccurate in this respect, as few herdsmen bother to record heats on cows which have not had time to recover from the stress of calving. The average estimate is somewhere between 30 and 40 days but high-producing cows tend to show less evident symptoms than lower-producing cows. This may be due to the additional stress of high production in this period. However from experience and from the literature, most cows seem to show
symptoms of heat by 60 days after calving. Reasoning from this premise the figures in Table 13 indicate that some conscious effort was involved in postponing breeding past several heat periods after calving. Perhaps the herdsmen were adhering to a recommendation used in the early 1930's in these herds that 3 months elapse before breeding after calving. This would help explain the rather long calving interval in these herds.

However the optimum economic length of calving interval seems never to have been demonstrated satisfactorily. Possibly the longer intervals are justified in these herds of rather high producing cows. At any rate the calving interval cannot approach the 12 months often suggested unless non-breeding period averages far less than those shown in Table 13 are achieved.

Table 13 shows the herd and period (calving to first service) averages for the 7 herds in this study. In all except herds 1 and 2, the period from first calving to service is longer than that from second calving to service although the average differences are very small (1.5 days). The overall average of 97.8 days is much longer than is generally advised particularly as the 60 day non-breeding period is advocated in the present management guide provided to the herdsmen of the Institution herds. The 60 day period has been extensive-
Table 13. Mean period from calving to first service

<table>
<thead>
<tr>
<th>Intervals</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>All herds</th>
<th>No. in means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>2</td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>86.1</td>
<td>88.8</td>
<td>107.9</td>
<td>91.7</td>
<td>104.6</td>
<td>108.1</td>
<td>91.2</td>
<td>98.5</td>
</tr>
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<td>86.2</td>
<td>90.5</td>
<td>104.5</td>
<td>87.6</td>
<td>103.9</td>
<td>103.8</td>
<td>86.6</td>
<td>97.0</td>
</tr>
<tr>
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<td>89.6</td>
<td>103.2</td>
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<td>101.7</td>
<td>113.2</td>
<td>86.0</td>
<td>98.0</td>
</tr>
<tr>
<td>4</td>
<td>86.9</td>
<td>92.6</td>
<td>99.9</td>
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<td>91.5</td>
<td>96.2</td>
</tr>
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<td>96.0</td>
<td>110.5</td>
<td>86.7</td>
<td>118.9</td>
<td>105.9</td>
<td>86.1</td>
<td>100.8</td>
</tr>
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<td>107.7</td>
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<td>100.2</td>
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<td>106.1</td>
<td>87.0</td>
<td>79.0</td>
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<td>89.6</td>
<td>127.5</td>
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<td>158.0</td>
<td>83.1</td>
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<td>101.7</td>
<td>74.0</td>
<td>86.5</td>
<td>82.0</td>
<td>-</td>
<td>83.5</td>
<td>93.9</td>
</tr>
</tbody>
</table>

Herd means: 87.5 90.3 105.2 89.8 104.8 106.7 89.8 97.8

No. in mean: 538 269 546 168 591 419 316 2847
ly advised in recent years most recently by Asdell (1957) in the Northeast Regional Publication on breeding difficulties in dairy cattle. The University herd is very little (10 days) below average, where the recommendation of 60 days, from calving to commencing breeding, is used. One would expect that the average of a herd run on that basis would be 70 - 71 days if heats were normally distributed over a 21 day heat cycle and all cows showed heat symptoms as soon as 60 days after calving. The older rule of a 90-day open period following calvings should not have affected the University herd over this 1940-1957 period since that rule was rescinded there shortly before 1940.

Trimberger and Fincher (1956) showed that 81.5% of the 200 cow Cornell University experimental herd came into heat before 60 days postpartum and that 93% showed definite symptoms by 90 days postpartum. These results indicate that lack of external heat symptoms was not entirely responsible for the long open period. Some conscious effort to delay breeding following calving must have been practiced among some of the Institution herds.

Here, too, the length of time appears to be correlated positively with the size of the herd. At least the trend is in that direction with the larger herds showing the longer intervals. This may emphasize again that one man cannot control the lives of the animals in the larger herds as completely
as in the smaller herds. However herds 3, 8, and 9 show much consistency in the various intervals, so it may be that the herdsmen concerned are strongly of the opinion that a 90-day open period is advisable.

Sex Ratio of Calves

In six herds where complete information on the sex of calves was available, the overall ratio was 51.7% males and 48.3% females. This is within the range found by previous investigators. Only one herd, the University herd, showed a slight (50.9%) predominance of females. The lowest estimate of females was 47.0% in Herd 7. These sex ratios were from 7,189 calvings by 2,482 cows or 2.9 calvings per cow.

These 7,189 calvings produced 7,372 calves thus indicating a twinning percentage of 2.54%. This also falls within the range of the results of prior investigators such as Meadows and Lush (1957) who showed an average of 3.08% twin births for Holsteins, 2.58% for five dairy breeds. The herds showed a range from 0.38% (Herd no. 8) up to 4.53% (Herd no. 2). The average age at calving in the high-twinning herd was 5.37 years as against 4.41 years in the low-twinning herd. Doubtless more of the calvings in the low herd would be by first calf heifers, which have long been known to produce twins less frequently than older cows.

Twinning has little or no effect on rate of increase in
herd size as the number of normal heifer calves expected from 100 normally distributed twin births (25 M.M. : 50 M.F. : 25 F.F.) is the same (50) as from 100 single births, even if all of the heifers twin to a bull are barren. A few of them will not be barren but, on the other hand calf mortality seems to be slightly higher among twin calves. Meadows and Lush (1957) found a total death loss of 5.4% up to 30 days among single calves while the death loss to 30 days in twin births was 10.1%.

Heritability of Length of Herd-Life

Plowman and Gaalaas (1960) presented heritability figures for longevity in Holstein-Friesian cattle in groups of herds in various parts of the country. They showed an overall average heritability of 15% based on the intra-sire regression of daughter on dam. In the present study length of herd-life is used instead of longevity as the disposal ages were not always a measure of total lifetime.

Two methods were used to calculate heritability of length of herd-life. The first was based on the average correlation between paternal half-sibs within groups born in the same year in the same herd. Unfortunately the fact that the correlation between genic values of half-sibs is 1/4 requires the multiplication of the correlation between half-sibs by 4 to estimate heritability. This tends to magnify any sampling errors which
may be in the estimate, or any errors involved in the "sire component" containing some effects of environment common to paternal half-sibs. Lush (1948) states that the sampling disadvantage of the half-sib method as compared with offspring-parent regression would be cancelled if four times as many degrees of freedom were available in the data for measuring half-sib correlations as there are for parent-offspring resemblance. However, increased numbers do not compensate for environmental effects common to half-sibs. The increase in degrees of freedom is not quite satisfied in the present study but, as more degrees of freedom are available for analysis among half-sibs than for the daughter-dam regression, the half-sib correlation analysis was given some attention. The second method used was the intra-sire regression of daughter or dam.

The half-sib data used were those from the period 1937-1950, to avoid the bias of having a part of the cohort still alive.

Table 14 shows the analysis and the heritability value which was obtained by multiplying the intra-class correlation by four. The value of .32 indicates that 32% of the variance in length of herd-life is caused by additive effects of genes. This value is higher than any found by Plowman and Gaalaas (1960) from daughter-dam regressions.

Another estimate of this value was obtained by using
Table 14. Analysis of variance in length of herd life

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean squares</th>
<th>Expected mean squares</th>
<th>Value of components variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between herds</td>
<td>10</td>
<td>38,870,310</td>
<td>$\sigma_e^2 + 9.97\sigma_s^2 + 25.86\sigma_y^2 + 267.68\sigma_h^2$</td>
<td>125,577</td>
</tr>
<tr>
<td>Between years/herds</td>
<td>130</td>
<td>4,521,138</td>
<td>$\sigma_e^2 + 9.04\sigma_s^2 + 21.04\sigma_y^2$</td>
<td>137,078</td>
</tr>
<tr>
<td>Between sires/years/herds</td>
<td>404</td>
<td>1,263,588</td>
<td>$\sigma_e^2 + 4.34\sigma_s^2$</td>
<td>79,451</td>
</tr>
<tr>
<td>Within sires</td>
<td>2479</td>
<td>918,769</td>
<td>$\sigma_e^2$</td>
<td>918,769</td>
</tr>
<tr>
<td>Total</td>
<td>3023</td>
<td>1,260,875</td>
<td></td>
<td>1,260,875</td>
</tr>
</tbody>
</table>

$$h^2 = \frac{4\sigma_s^2}{\sigma_s^2 + \sigma_e^2} = 0.32$$
daughter-dam comparisons repeating the dam’s record as considered by Kempthorne and Tandon (1953). Heritability is estimated by multiplying this regression of daughter on dam by two.

Table 15 shows the analysis of 3,363 daughter-dam pairs where both members of the pair have left the herd. This value for heritability (.06) is much lower than that obtained from the half-sib analysis. Daughter-dam regression on an intra-sire basis should be largely free of environmental differences which exist between herds or between animals separated by many years and in this case, should give a good estimate of heritability.

In the half-sib analysis a possible source of bias is the inclusion of some environmental effects in the resemblance between half-sibs. Also, as sires were used entirely within herds and daughters were contemporary in herds, some additional correlation could have been introduced in the half-sib analysis.

Table 14 shows also the variance components associated with length of herd life. A comparison with Table 8 shows that the operations have attributed to $\sigma_s^2$ more than they did to $\sigma_m^2$. The difference in their coefficients leaves less to be apportioned to $\sigma_y^2$ when the data are classified by sire. Making the division intra-sire or intra-month makes little difference in $\sigma_e^2$. The component within sires shows little change from that of Table 8 indicating that
Table 15. Daughter-dam regression for length of herd life

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean square</th>
<th>Cross products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between sires</td>
<td>278</td>
<td>3,478,549</td>
<td>860,289</td>
</tr>
<tr>
<td>Within sires</td>
<td>3084</td>
<td>948,269</td>
<td>27,224</td>
</tr>
<tr>
<td>Total</td>
<td>3362</td>
<td></td>
<td>27,224</td>
</tr>
</tbody>
</table>

\[
\hat{b}_{\text{dau-dam}} = \frac{27,224}{948,269} = .03
\]

\[h^2 = .06\]

much of the variance in length of herd life is due to factors other than differences between herds, between years, and between paternal half-sibs. The intra-class correlation of .08 in Table 14 shows that the tendency for daughters of one bull to leave the herd at the same age is small but is measurable.

Reasons for Disposal

A rather detailed list of reasons for disposal was used in this study. Many of the categories could have been put together, particularly in the death classes. However, it was considered important to know the average ages of the animals which left for each reason and also to obtain age-specific death rates, and heritabilities on certain of the reasons where the data were numerous and some genetic effect seemed
to be involved.

Table 16 shows the numbers involved in each of the reasons and the average ages at disposal. Death makes up 13.53% of all disposals, with pneumonia being the commonest cause of death and amounting to 2.24% of the total disposals and 16.59% of all deaths. Leukemia and blackleg were considered as separate reasons but might have been included in the number 13 reason without loss. This number 13 reason for non-classified deaths included such occasional happenings as forage poisoning, and a few rare diseases such as Johne's disease, Red water fever and others.

The death classification shows the shortest average total lifetime, mainly because it includes the calfhood diseases such as calf scours, pneumonia and those dead at birth. The small number (15) of cows dying from milk fever (number 7) indicates that management was reasonably good, since many cases of milk fever must have occurred in this many calvings.

The total percentage of deaths (13.53%) is high. Most studies show 6 - 7% as in Seath (1939). However most studies, including Seath's, were confined to cows which had calved at least once. Subtracting from the death total the predominantly calfhood losses of pneumonia, calf scours, and the at birth class gives 8.03% for death among animals from first calving onward.
Table 16. Ages at disposal, separately by reasons

<table>
<thead>
<tr>
<th>Subclass</th>
<th>Reason</th>
<th>No. of disposals</th>
<th>Av. age at disposal</th>
<th>% age of total</th>
<th>% age in subclass</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Death</td>
<td>Mastitis</td>
<td>1</td>
<td>2223.8</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pneumonia</td>
<td>2</td>
<td>187.9</td>
<td>2.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Metritis</td>
<td>3</td>
<td>1947.8</td>
<td>0.88</td>
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</tr>
<tr>
<td></td>
<td>Calving trouble</td>
<td>4</td>
<td>2122.4</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hardware</td>
<td>5</td>
<td>1967.9</td>
<td>1.34</td>
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The involuntary disposals (reasons 14 to 21) include 33.26% of all disposals. These were all considered to be forced culls. The largest subgroup here is, of course, those who went because of reduced fertility (No. 15). This has been true in most other studies. Many herdsmen may have used this as a kind of catch-all classification but, in this study, the breeding records were examined wherever sterility was claimed as a reason for disposal. Any cases which seemed doubtful were reclassified. Even with this careful screening almost one quarter of all disposals were due to some degree of infertility. Abortion (No. 19) is the only other category of any size in the "involuntary" grouping. The smallness of this class indicates that these herds were relatively free from Bang's disease, vibrio fetus, trichomoniasis, and other diseases causing abortion. Testing for brucellosis was apparently done all through this period. The 4.80% disposal for abortion (No. 19) plus Bang's reaction (No. 17) compares very favorably with the 10 - 15% which Seath (1939) found in D.H.I.A. records in Iowa and Kansas.

Most of the animals in the No. 21 classification were listed as injured during calving, with ruptured pelvic girdles or eversion of the uterus being the most common occurrences. A few younger animals listed as ruptured were included in this classification.
The main category of "voluntary" disposals (reasons 22 to 30) contains 53.21% of all disposals. This, however, is a little high as probably half of the mastitis damage reason (No. 22) could well have been included in the involuntary class. These would be cases where the mastitis was thought incurable or where the cow was not good enough to justify drying up one quarter and keeping her as a breeding animal. The proportion of animals in the mastitis damage category which should be included in the voluntary or involuntary disposals would vary depending on whether the herd was made up of grade or pedigreed animals. In the grade herd a larger proportion would be included in the involuntary class while registered herds, such as these, have more reason to try to maintain the cows in the herd. Even if the mastitis classification (No. 22) was shifted entirely to the "involuntary" group, 37% of all disposals would remain in the "voluntary" classification and almost 20% of all disposals were listed as being for low production (No. 25). Again it might be said that this classification was used as a catch-all for animals whose production had been much reduced by some other conditions, such as mastitis, acetonemia, etc. The previous records on these animals were studied for any such happening before they were put definitely in this class. Also the low average age of the cows which went for "low production" indicates that the majority of these were in early productive life. This is addi-
tional evidence that their classification was correct.

Obviously the category for acetonemia need not have been included in this breakdown, as it was either a very rare occurrence in these herds or it was recognized and treated successfully.

Of the animals sold for dairy purposes (No. 26), 254 out of the total of 569 came from the herd at Anamosa. Its sales were mainly of calves and bred heifers.

In classification number 28, where no reason was given for culling the animals, many were animals which for some reason did not get classified at the time of their disposal and the herdsman could not recall the true reason when he was completing their life-history sheets. This group could also include animals with some anatomical defect, or poor in type, or simply some animal with a disease or condition which the herdsman could not spell. In the number 29 classification were included mashed teats, barbed wire cuts, and the common and uncommon factors which can be responsible for udder damage without disease. Into number 30 went those with bad feet and legs, poor type, chronic kickers, etc.

Tables 17 and 18 show separately for each herd the reasons for disposal. It is rather speculative to estimate the extent to which these differences were really biological and how much
Table 17. Reasons for disposal, separately by herds (reasons 1-15)

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<td>517</td>
<td>14  1  10  12  7  -  2  1  -  -  3  -  3  -  174</td>
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<td>137</td>
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<tr>
<td>7</td>
<td>365</td>
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<td>504</td>
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they were due to the herdsmen having different preferences in the reasons they assigned. Presumably the major differences, and those in reasons which could be defined clearly and objectively, were mainly biological. This is not so sure for the reasons which were defined more subjectively. Perhaps herdsmen preference played a large part in those, probably many, cases where disposal was decided because of the joint presence of two or more reasons, no one of which would by itself have brought disposal at that time.

Age-Specific Death Rates

Some scrutiny of the age-specific death rates seemed advisable before attempting heritability estimates for individual reasons for disposal. Table 19 shows the number of animals involved at each age level in each of the reasons for disposal which were to be investigated and also shows the broad groupings of death, voluntary, and involuntary losses. The reasons used were:

1. Death from mastitis
2. Death from pneumonia
4. Death from calving trouble
8. Death from bloat
9. Death from calf scours
14. Disposal for pneumonia damage
15. Disposal for reduced fertility
22. Disposal for mastitis damage
Table 19. Number leaving the herd at each age for each of the stated reasons

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25. Disposal for low production
1-13. All losses from death
14-21. All other involuntary disposals
22-30. All voluntary disposals
1-30. All reasons.

Table 20 shows for each cause or group of causes the death rates during each age interval per 1000 living at the beginning of that age interval. As would be expected, large differences appear in the probability for disposal at different age levels. These figures are simply the proportion which would be expected to be disposed of during each age interval for every thousand living. Obviously the results can vary considerably in the ages with very small numbers but in the younger ages the numbers are larger and the estimates of the disposal rates from various reasons should be fairly good.

In the number 1 classification (death from mastitis) only 37 animals are included. There are, of course, no deaths up to 2 years of age, because the disease would not normally appear before first calving. Then the rate rises gradually, apparently reaching a maximum at about 9 - 10 years, although the evidence after 7 years is too scanty to make that at all certain. This disease seems to be distributed rather evenly over ages past 4 years old, although it seems inclined to in-
Table 20. Death or disposal rates per 1000 living of the same age for each cause or group of causes

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Table 20. (Continued)

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crease a bit with age.

The number 2 class (death from pneumonia) is obviously a disease of young stock. Calf losses were over 20 per 1000 calves raised, and in the next age group (1 to 2 years) this falls to 1.6 per 1000. Probably the losses in ages 1 to 2 and 2 to 3 occurred mostly in the fall of the year when the change from pasture to barn or feed lot puts more stress on the animals and pneumonia is not uncommon. The 10 year old animal might have been a true pneumonia condition or a toxemia caused by a foreign body in the lungs. Pneumonia is a condition normally easily cured by modern antibiotics but was sometimes fatal before their discovery or general use.

Number 4 (death from trouble at calving) shows a rather level distribution after calving age is reached, with probably some tendency to increase with increasing age. This would be expected but the small numbers leave the actual evidence a bit indecisive.

In number 8 (death from bloat) the highest death rates occur in the youngest age groups, presumably because they are less closely supervised. Heifers on pasture are generally maintained at some distance from the barn and often are seen only once a day. Thus, any trouble which they may have with bloat can be quite advanced or even fatal before it is noticed.
Also some of the cases called bloat could have been caused by other diseases or poisoning and be called bloat because the animal was already in a swollen condition when found. Some of the older animals may have been dry cows also on distant pasture.

The 16 calves per 1000 which died of calf scours is a reasonable figure probably a little lower than the national average in this respect.

Figure 4 shows these curves of death rates per 1000 living at each age level. It emphasizes that the death rate increases with number 1 and 4 and decreases with number 8 as age advances. Semi-logarithmic graph paper was used in an effort to smooth out the curves and as it is generally more meaningful with death rates.

Number 14 (pneumonia damage) with only 15 animals represented in it shows very little except that pneumonia is most common with younger animals. Most of those listed as being sold for pneumonia damage were animals which never again attained normal growth and condition possibly due to cysts in the lungs. Because numbers were small, this classification was not shown graphically.

Number 15 (reduced fertility or some degree of sterility) was the largest single classification in the list of reasons. The rate increases fairly steadily to 7 - 8 years of age.
Figure 4. Death rates per 1000 living for no. 1 (mastitis), no. 2 (pneumonia), no. 4 (calving trouble), and no. 8 (bloat)
AGE-SPECIFIC DEATH RATES PER 1000 LIVING OF THE SAME AGE

AGE CLASSES

1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12
Then it plateaus for three years and then climbs again until the data are too few to be meaningful. If the breedings had been commenced earlier in the Institution herds probably more 1-2 year olds would have been in this class but the later breeding ages throws most of the disposals of barren heifers into the 2-3 year old class. However the low figures in both these classifications indicate that heifer infertility is not as important as is infertility at later ages. Metritis, cystic ovaries, and other conditions following calving may well be more important causes of infertility losses than are such conditions as vaginitis, infantile organs, double cervix, hormone imbalance, etc. which may prevent heifers from ever calving at all. Since almost all of the breeding in these herds was done by natural service, probably repeat breedings were not considered as much of an economic loss as they would be in a herd bred artificially. At any rate more of the older cows were removed for impaired fertility and age is obviously important. The graph of No. 15 in Figure 5 shows this sharp early increase in rate subsequently becoming nearly level but still showing some increase with age.

Number 22 (disposal because of mastitis damage) follows a similar pattern with low rates in early age groups and a leveling off from about 5 years up until the numbers become too small for any conclusions to be drawn. This would indicate
Figure 5. Disposal rates per 1000 living for no. 15 (reduced fertility), no. 22 (mastitis damage), and no. 25 (low production)
that young cows are relatively free of mastitis or that, if mastitis does occur, the herdsman is willing to treat it rather than cull the animal. If it is true that less mastitis occurs in younger animals, as experience and the results of this study indicate, then some unknown changes associated with age may be related to mastitis infection. Plastridge (1958) showed an increase in occurrence of mastitis from 14% to 100% from the first up to the eighth lactation. He pointed out that infections and reinfections could be the cause but also cited evidence of a lower degree of susceptibility in younger animals. Legates and Grinnells (1952) showed that, out of 11 herds of 1,174 cows, 215 heifers had an average incidence of mastitis of 16.7% as compared to 51.1% for the 959 older cows. From these figures it would seem that milking younger animals, with a faster turnover of cows, would be the best way to combat mastitis.

The curve of number 25 (low production) is markedly different from most of the others. The rate is very low in the 1 - 2 year old class where probably only animals bred by mistake would appear. The rate reaches its peak in the 3 - 4 year old class and then falls off rapidly as age increases. This is as would be expected if the really low-producing animals were mostly weeded out in the first to third lactations. This would be a natural plan where much culling on low production is intended. The later disposals could be caused by
giving mediocre producers another chance or, as so often happens, by keeping a below-average producer because she will be calving next at a season when the milk requirement is heavy. In these Institution herds the milk requirement appears to be fairly constant throughout the year so that the necessity of an even supply may at times have had an even more important influence on disposal of cows than price would have in a commercial dairy. Probably some additional factors were involved when older cows were sold for low production. Thus a cow with some benign hardware case or with a mild kidney infection or declining in production because of age would be recorded as sold for low production but of course would not necessarily be genetically a low-producing cow. That this disposal rate is much higher among the younger animals than among the old or middle-aged warrants considerable faith in the disposal records and the figure of 20% for disposal because of low production.

Figure 6 shows the causes grouped into: death losses, involuntary disposal, and an overall curve of disposal. Also shown is the human death rate curve taken from Pearl (1922) for the United States Registration Area in 1910.

All curves except the "involuntary" show a higher mortality rate at the very youngest age. The rates are generally low prior to reproduction. The human curve has been given a
Figure 6. Death and disposal rates for nos. 1-13 (all deaths), nos. 14-21 (involuntary disposal), nos. 22-30 (voluntary disposal), nos. 1-30 (all causes), and a human all cause death curve
scale of 5 years to 1 for the cows in order to make them more directly comparable. A 7:1 ratio would probably have been better but such a grouping of human data was unavailable. The disposal of cows because of death follows most closely the human death curve. Where man's interference is involved, the probability of disposal in the younger periods is increased considerably. The human death curve shows a higher infant or under 1 year of life mortality (143.3 per 1000) than any of the curves for cows. This may merely show that the human infant is more dependent on others than is the calf which is prepared better for an almost independent existence at birth.

As would be expected death is the largest of the three main categories for calves, being 47.93 per 1000. Although high, this is close to average. Figure 6 shows that the death rate then falls sharply below either of the other curves and gradually returns towards the other two as the increased age of the animal increases the stresses to which she is exposed.

The involuntary (14-21) group starts at a very low figure and increases sharply up to 5 years where it becomes nearly level, at least until 11 years. After that it becomes very irregular, presumably because the numbers are small.

The voluntary (22-30) classification starts low but not as low as the involuntary class. This is due mainly to the sale of heifer calves for dairy purposes mainly from one herd.
rather than to any disposals caused by disease, Mastitis damage and low production then combine to keep the "voluntary" rate higher than either of the other classifications. In later years the old age class takes over to maintain this group rate at a high level.

The comparison of human and bovine female curves indicates that a natural population of cows would follow rather closely the human mortality curve if 1 year of bovine life is equivalent to 5 - 7 years of human life. However, with the culling done by man, the probability of disposal for cattle is increased much more sharply by the onset of the stresses of reproduction and production and is maintained at a much higher, but more constant level than the human curve. It is to be hoped that improved medical knowledge in both fields will, in the human curve, decrease the high death rate in the early age groups, while in the bovine curve, improvement will be aimed at throwing more of the disposals into the voluntary classification so that selection may be more intense.

These figures indicate that control of reduced fertility and mastitis is the most pressing problem in the industry today.

Heritability Estimates on Certain Reasons for Disposal

Table 21 shows, by years and by the reasons on which heritability estimates were made, the numbers leaving the
Table 21. Disposal numbers by years and major causes or groups of causes

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<th>9 calf scours</th>
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<td>1</td>
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<td>87</td>
<td>76</td>
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</tr>
<tr>
<td>1950</td>
<td>41</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>75</td>
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<td>5</td>
<td>2</td>
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<td>6</td>
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<td>38</td>
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<tr>
<td>57</td>
<td>4</td>
<td>8</td>
<td>-</td>
<td>6</td>
<td>3</td>
<td>10</td>
<td>18</td>
<td>49</td>
</tr>
</tbody>
</table>

Reason totals 731 122 50 48 75 1146 932 3103
population. A Row by Column Chi Square test showed significant year deviations. The higher values occurred mainly in those years where the records were not complete. These years were 1937 - 1940 and in the late 1950's. The main thing shown by this table is that in no instance is there any indication of epidemic-like dis­posals or extremely large deviations from year averages. This fact is important as in the half-sib analysis for the heritability estimates the numbers in the sub-classes become small enough that removal of year effects could introduce more error, of a random nature, than is removed by doing the analysis within years of birth or disposal. The bulls used in this study averaged 12.5 daughters but they were used an average of 1.5 years.

In both the half-sib correlation and daughter-dam regression analyses, disposal records were used over the entire period of 21 years in order to obtain large enough numbers. Because of this, bulls used in the last few years would not have all their daughters included yet in the list of dis­posals. As disposal records were completed up through 1960 on animals born up until 1957, this meant that about 130 cows would still be in the herds out of the group studied. These would of course be sired by several bulls and it was considered that the additional numbers of disposal records from contemporaries of these animals would justify any possible bias involved.
For the analysis of variance and covariance, each animal was coded 0 or 1 depending on whether it was or was not culled for the reason under study.

Heritabilities were estimated by intra-sire regression of daughter on dam and by paternal half-sib correlations. The herd effects were removed and, where indicated, the year effects (birth or disposal). Death from bloat and death from calf scour could be investigated only by half-sib analyses as they are, in the first case mainly and the second case entirely, diseases of young heifers below calving age.

Using the intra-sire regression of daughter on dam as a measure of heritability removes much or all of the environmental term because usually a set of paternal half-sibs are nearly contemporary at birth and, in this case, they were maintained entirely within herds. Dams would not be as closely contemporary but would not differ much. This is true too of the paternal half-sib analysis when the year effects are removed, but not when the analysis is merely intraherd.

In the half-sib analysis several models were used, based on slightly different assumptions. In the first case all the disposal records were treated as a single large population and the analysis was simply within and between sires.

The analysis was:
<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Expected mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between sires</td>
<td>378</td>
<td>( \sigma_e^2 + 12.52 \sigma_s^2 )</td>
</tr>
<tr>
<td>Within sires</td>
<td>4,389</td>
<td>( \sigma_e^2 )</td>
</tr>
<tr>
<td>Total</td>
<td>4,767</td>
<td></td>
</tr>
</tbody>
</table>

In the second analysis the population was first divided into herds and then into groups of paternal sibs within herds.

The analysis was:

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Expected mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between herds</td>
<td>10</td>
<td>( \sigma_e^2 + 31.99 \sigma_s^2 + 425.06 \sigma_h^2 )</td>
</tr>
<tr>
<td>Between sires within herds</td>
<td>368</td>
<td>( \sigma_e^2 + 11.99 \sigma_s^2 )</td>
</tr>
<tr>
<td>Within sires</td>
<td>4,389</td>
<td>( \sigma_e^2 )</td>
</tr>
<tr>
<td>Total</td>
<td>4,767</td>
<td></td>
</tr>
</tbody>
</table>

The third analysis was also hierarchal but the intraherd differences between years of disposal of the cows were removed before computing the intrayear differences between groups of paternal sibs. This would be importantly different from the preceding if some factors, other than sires, which varied from year to year had a marked effect on the reasons for disposal.

The analysis here was:

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Expected mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between herds</td>
<td>10</td>
<td>( \sigma_e^2 + 5.37 \sigma_s^2 + 29.28 \sigma_y^2 + 425.06 \sigma_h^2 )</td>
</tr>
</tbody>
</table>
Another analysis was run using the same model but classifying the cows on year of birth rather than by year of disposal.

The analysis then became:

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Expected mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between herds</td>
<td>10</td>
<td>$\sigma_e^2 + 8.81 \sigma_s^2 + 26.28 \sigma_y^2 + 425.06 \sigma_h^2$</td>
</tr>
<tr>
<td>Between years of birth/herds</td>
<td>207</td>
<td>$\sigma_e^2 + 7.35 \sigma_s^2 + 21.61 \sigma_y^2$</td>
</tr>
<tr>
<td>Between sires/years/herds</td>
<td>638</td>
<td>$\sigma_e^2 + 6.50 \sigma_s^2$</td>
</tr>
<tr>
<td>Within sires</td>
<td>3,912</td>
<td>$\sigma_e^2$</td>
</tr>
<tr>
<td>Total</td>
<td>4,767</td>
<td></td>
</tr>
</tbody>
</table>

In this last analysis the subclass numbers in the sire component are almost three times as large as in the previous one. This follows naturally from the fact that the daughters of a sire were usually all born within one or two years but their disposal usually extended over many years.

For the intrasire regression of daughter on dam, 3,363 daughter-dam pairs were available. The dam's record was repeated with each daughter, if she had two or more daughters, as was demonstrated by Kempthorne and Tandon (1953). This gave
278 degrees of freedom between sires and 3,084 within sires.

Table 22 shows the heritability values and the herd, year, and sire components for the 9 different kinds of disposals studied. Each will be discussed separately as the heritabilities seem to differ genuinely from one analysis to another or from one classification to another.

No. 1. Death from mastitis

Death from mastitis appeared to have no particular pattern in its occurrence. However 23 of the 37 deaths ascribed to this disease were in just 2 of the 11 herds. The deaths were scattered over the years of the study but there was a tendency for several cows to go from one herd in one year. This fact could bring about an additional correlation among contemporaries which would reduce the value of any heritability values obtained. Heritability is surely very low, perhaps zero.

No. 22 and Nos. (1+22). Mastitis disposal and mastitis death and disposal

These categories were examined separately and then combined but they will be discussed together as the much larger numbers in the disposal category (No. 22) and the greater range in death-rate makes it much more important than death (No. 1) in its effect on the values obtained. Disposal rate for mastitis increases from less than 23 per 1000 at 2 years of age up
Table 22. Heritability estimates and components for herds, years, and sires

<table>
<thead>
<tr>
<th>Trait</th>
<th>Intra-sire regression of daughter on dam</th>
<th>Between and within sires</th>
<th>Between sires within herds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$h^2$</td>
<td>$h^2$ Sire comp.</td>
<td>$h^2$ herd comp. sire comp.</td>
</tr>
<tr>
<td>No. 1 Mastitis death</td>
<td>0</td>
<td>.16 .0003</td>
<td>.10 .0001 .0002</td>
</tr>
<tr>
<td>Nos.(1+22) Mastitis death and disposal</td>
<td>.001±0 .25 .0080</td>
<td>.25 0 .0080</td>
<td></td>
</tr>
<tr>
<td>No. 22 Mastitis disposal</td>
<td>.06 .24 .0075</td>
<td>.17 .0004 .0051</td>
<td></td>
</tr>
<tr>
<td>Nos.(2+14) Pneumonia death and disposal</td>
<td>.38 .03 .0002</td>
<td>0 .0004 0</td>
<td></td>
</tr>
<tr>
<td>No. 4 Calving trouble</td>
<td>.06 .09 .0002</td>
<td>.10 0 .0002</td>
<td></td>
</tr>
<tr>
<td>No. 8 Bloat</td>
<td>- .12 .0003</td>
<td>.11 0 .0003</td>
<td></td>
</tr>
<tr>
<td>No. 9 Calf scours</td>
<td>- 0 0</td>
<td>0 .0001 0</td>
<td></td>
</tr>
<tr>
<td>No. 15 Reduced fertility</td>
<td>.05 .24 .0108</td>
<td>.10 .0071 .0045</td>
<td></td>
</tr>
<tr>
<td>No. 25 Low production</td>
<td>.08 .35 .0139</td>
<td>.28 .0030 .0112</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trait</th>
<th>Between sires within year of disposal within herds</th>
<th>Between sires within year of birth within herds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$h^2$ Herd Year Sire comp. comp. comp.</td>
<td>$h^2$ Herd Year Sire comp. comp. comp.</td>
</tr>
<tr>
<td>No. 1</td>
<td>0 .0001 0 0 .16 .0001 0 .0003</td>
<td></td>
</tr>
<tr>
<td>Nos.(1+22)</td>
<td>.50 0 .0051 .0165 .10 .0001 .0059 .0032</td>
<td></td>
</tr>
<tr>
<td>No. 22</td>
<td>.43 .0024 .0027 .0134 .10 .0027 .0033 .0031</td>
<td></td>
</tr>
<tr>
<td>Nos.(2+14)</td>
<td>.77 .0002 .0021 .0048 0 .0004 .0004 0</td>
<td></td>
</tr>
<tr>
<td>No. 4</td>
<td>.32 0 0 .0084 .05 0 .0004 .0001</td>
<td></td>
</tr>
<tr>
<td>No. 8</td>
<td>.78 0 .0036 .0027 0 0 .0005 0</td>
<td></td>
</tr>
<tr>
<td>No. 9</td>
<td>.73 0 .0006 .0028 .21 .0001 0 .0008</td>
<td></td>
</tr>
<tr>
<td>No. 15</td>
<td>.23 .0065 .0085 .0107 .10 .0069 .0030 .0047</td>
<td></td>
</tr>
<tr>
<td>No. 25</td>
<td>.40 .0032 .0068 .0156 .14 .0032 .0084 .0057</td>
<td></td>
</tr>
</tbody>
</table>
to 114 per 1000 at 10 years. The combined value for daughter-dam regression will be lower than that obtained from No. 22 alone because among 37 death victims, there was no dam and daughter combination in which both died from mastitis. Even so a small positive heritability was obtained. In the half-sib analysis of both the disposal and combined classification it is assumed in the case of the analysis between and within sires that equal probability of disposal exists for all cows in the population which is not true because of herd and year differences. Thus bias has probably been introduced by this assumption. Similarly, in the analysis within herds bias is introduced by the fact that there are considerable differences within time intervals in herds which could affect the sire component.

In the analysis within year of disposal the sire component is automatically inflated whenever the probability of disposal varies according to age. Within the year of disposal, the daughters of one sire will be older than the daughters of another sire and will have different probabilities of disposal for different reasons. This automatic effect seems to have increased the sire component and consequently tended to have made the heritability value too high in all analyses where probabilities of disposal vary according to the age of the animals. For this reason, the "sire components" from the analyses within year of disposal contain much besides 1/4 of the genic variance
and heritability estimated from 4 times that component is heavily biased upward. The daughter-dam regression, which is a nearly independent estimate is 6% which agrees fairly well with the 10% from half-sibs within year of birth.

It should be emphasized that this category of mastitis disposal and/or death will never be used as a catchall category for disposals for other reasons. With any herdsman mastitis severe enough to cause death or disposal is something for which he probably feels a bit ashamed. It is an admission of defeat on his part in fighting a disease which has been, and is, a scourge of the dairy industry. Thus it would appear that both analyses show a minimum value for heritability of mastitis. Lush (1950) and Legates and Grinnells (1952) have shown that much higher estimates of heritability are obtained by using incidence of mastitis instead of death or disposal for mastitis. This rather supports the idea that the present estimates are minimum.

In all cases the component for herd differences was only 2% or less of the variance. This indicates that the occurrence of mastitis disposals was rather evenly spread out over the herds. Differences between years included only 4-5% of the variance thus showing some variation from year to year. Probably this year-to-year variation would have two main causes. One would be the level of production which, in turn, is af-
fected by roughage available. Second would be the quality of labor available. A year of high production would probably show some increase in mastitis while the milker efficiency would rise and fall irregularly from year to year with the changing labor force.

(No. 2+14). Pneumonia losses

The high figure (.38) from the regression analysis of pneumonia death and disposal suggests merely that drawing conclusions from very small numbers is dangerous. In the figures for the regression $\Sigma x^2$ was only 6 while $\Sigma xy$ was 1. The reason for this was simply that few of the animals leaving because of pneumonia ever attained calving age where they could appear as dams. Pneumonia is a disease primarily of young heifers. Thus no reliability need be attributed to the regression value.

The other values concerning pneumonia are essentially zero except that within year of disposal. Here again the component between sires has been inflated by the differing probabilities of disposal of animals of different ages within the year of disposal.

The tentative conclusion is that the heritability of pneumonia is close to zero which is biologically plausible.

No. 4. Calving trouble

The values obtained for this show a surprising consistency
except that the analysis within year of disposal again gives too high a figure for the same reason as before. That the range of heritability of from .05 to .10 should cover the possibilities seems reasonable since calving trouble is closely connected with anatomical peculiarities, particularly of the neck or outlet of the pelvis and possibly of the cervix. Most such anatomical peculiarities which were hereditary would probably show their effects in the losses in the early age groups. Later losses would more likely be from causes such as hydrops amnii, unusually large calves, twin calves, abnormal presentations, or even recurring lethals. Presumably the heritable part tends to be partially self-limiting in that few live calves will be born. This idea is supported by the fact that in only 2 cases did both dam and daughter go out of the herd for this reason.

No. 8. Bloat

As bloat is almost entirely a disease of young cattle below calving age no attempt was made to get a daughter-dam regression although the age-specific death rates show that losses are spread over about 7 years. The year-of-loss effect was obviously important as Table 21 shows that 12 of the cases occurred in just 2 years while the average should have been a little over 2 per year. In the analysis by year of birth, the component of variance among years was 5% while the component
among years of disposal was over 25%.

These data suggest the conclusion that the heritability of bloat is probably close to zero despite the differences seen among herds in susceptibility to bloat. Apparently some factor other than genetic is involved possibly due to some difference in the development of the rumen.

No. 9. Calf scours

This disease, of course, only lends itself to half-sib analysis because deaths are all within the first year of life. It indicates clearly the danger involved in data where the probabilities of occurrence differ so widely. The effects of sires and of years are confounded by the seasonal effects of this disease. Year of birth and year of disposal are almost always the same or adjacent. The best estimate is probably zero or very close to that. This seems reasonable despite the fact that many people think of cow families where calf-raising was a problem and every cow man professes to know that Guernsey calves are harder to raise than any other breed. However this last is thought to be a function of the vitamin content of the milk rather than any heritable factor in the anatomy or physiology of the calf itself.

No. 15. Reduced fertility

No obvious source of bias would be involved in the estimate of heritability obtained from daughter-dam regression in
this trait. The value of 5% should be a reasonable estimate affected only by the fact that this reason for disposal is not as clearly defined as some of the other reasons. The fact that complete infertility cannot be measured in the dams should not affect the value of the regression coefficient as the covariance term will be reduced to the same extent as the variance of the parent.

The half-sib estimates show that herd effects and effects of year of disposal are obviously important (3-4% of the variance) so that the analysis should be within herds and probably not within year of disposal. Making it within year of birth takes out only 1.64% of the variance. These facts seem natural, as some herds might really have more trouble with infertility than others, presumably due to local differences in management or in the incidence of infectious troubles. Then, too, it would be natural for such conditions to vary within a herd more from year to year of disposal than among years of birth. Table 21 indicates small but real differences in numbers of disposals by years. Also Table 20 shows that the death-rates are spread out over a long period and do not show as large a variation as do some of the other traits. Thus the heritability value based on year of disposal is slightly biased upwards because age-differences in this cause of disposal are partly included in the sire component although not as much so
as for some of the other traits.

The conclusion to be drawn is that at least 5% and perhaps 10% of the differences in fertility among cows are due to additively genetic factors. However this classification is certainly not as clear as is mastitis. "Reduced fertility" falls in a class with low production as a catch-all category for disposal which, in many cases, are partly decided for other reasons. For example, if two cows are equally suspected of infertility but one is a mediocre producer or poor in type, while the other had produced well and is of good type, the first is likely to be discarded forthwith but the second will be retained longer and treated more to overcome her suspected infertility. Often the treatment will be successful.

No. 25. Low production

This category is somewhat similar to that of reduced fertility in that selection is definitely involved among the cows which become dams. This is not, of course, because they do not have any opportunity to reproduce, but that most disposals for low production occur in the early years of life when fewer of them will yet have produced a daughter than would be the case with cows which stayed in the herd for several calvings. Also some cows sold early in life for low production may have had their daughters marked for removal before they calved at all. This would be of no importance in the Univer-
sity herd where the policy was to keep all heifers through at least their first lactation but it could have some effect in the other herds, particularly in the Anamosa herd where many were sold for dairy purposes.

Also, the low production category would be affected most by the changes in herd size. When herd size was being increased standards would be lowered, while a herd stable in size could keep higher standards of production and thus could sell more cows for "low production". Year of birth seems more dependable as a basis for estimating heritability, since it does not suffer so much from the year-to-year changes in culling standards as does year of disposal. Herd differences accounted for 2% and year of birth differences for 5% of the variance in the "low production" classification.

The low production class could have contained cows which were being disposed of mainly for other reasons which contributed to low production. This may explain, at least partly, why its heritability seems lower than that of milk production (20-30%) or fat production (20-30%). However, the fact that most of these really did go for low production is indicated by the age-specific rate for this kind of disposal being high in the early ages at and after first calving and tapering off to a rather low level in later years. Changing herd size could have been a factor in the presence of older animals, as many
of these must have been kept during the expansion period un­
til enough replacement heifers were available.

It is concluded then that the heritability of disposal
because of low production lies in the region of 14% from these
data but that not as much faith can be placed in this figure
as in the better defined groupings.
DISCUSSION

The findings concerning age at first service and age at first calving do not conform closely to the recommendations of dairy specialists. However, these herds have been operating with considerable success for many years. Apparently the later ages at service and calving fit the conditions under which they are maintained in the Institution herds. The average age at first calving (31 months) appears high but in the herds where the calvings of heifers are concentrated to some extent in a fall calving season little reduction is possible. If they do not calve before 27 or 28 months they would have to be held over until 32 to 36 months. The 612-day (20 months) age at first service simply measures the average age of the heifers when first bred. To reduce this much would require a system, such as is used in the University herd, where a definite age is set for breeding and little or no attention is paid to season of calving. Such a system has been recommended in the Institution herds but apparently the herdsmen have not been conforming closely to it. Perhaps greater emphasis on artificial breeding will encourage earlier calving as in some of the herds the heifers are formed into breeding groups running with the bull so that often the age or size of the youngest heifer will control the time at which the bull is allowed to run with the heifers.
Perhaps better conditions of feeding in the young heifers would be helpful in bringing them up to breeding size at an earlier age, thus encouraging the herdsmen to permit earlier breeding. For maximum genetic improvement the preference is obviously for early calving, so that a faster turnover can be obtained with a consequent decrease in the generation interval.

Length of the terminal lactation shows very little except that on the average the terminal lactation lasts about 270 days.

Age at disposal has an effect on possible rates of increase in herd size and (a little only) on selection pressure possible. Theoretically in a herd of constant size the cows must average, with 75% of the heifer calves later attaining calving, 2.7 calves in order to replace themselves. The minimum average age at disposal is in reality fixed by the age at first calving, the calving interval, and the rearing percentage. Thus, any increase in rearing percentage, reduction in calving age, or decrease in calving interval would reduce the length of time a cow must stay in the herd in order to replace herself. To increase this average age at disposal seems important under only two circumstances. These are where the average age attained by the better cows can be increased by reducing disposals for disease among the higher producing cows. This, however would be balanced by more chance to discard the
lower producers at younger ages so that the net effect on the average age at disposal (but not on its distribution) would probably be very small or zero. The other is in countries where beef from heifers born in dairy herds is an important part of the food supply. To increase the lifetime of the better cows seems always desirable, but, unless the herd is being increased in size, this will lower automatically the age of disposal of the cows which are culled intentionally. Increasing the actual milk produced per day of life by improved hygiene is important but increasing it by small increments in average length of life in the herd is unimportant.

Gestation interval conforms closely to other reports in the literature.

In the case of the breeding period the herd which shows the low average breeding period of 25.8 days shows what is at least possible in this population. Presumably some problems of low conception rates were involved in herds 7 and 8 and to a lesser degree in herd 9. Yet no disease problems were apparent in the disposals from these herds. They have been Bang-tested over the whole period of study. Presumably the main factor involved in the prolonged average periods in these herds was the human factor involved in finding cows in heat and in breeding them.
The same factor is probably involved to a greater or lesser degree in determining the period from calving to first service, although herd policy concerning whether a 60-day or 90-day period after parturition would play some part. In the management of these herds, 60 days is stipulated but apparently not all the herdsmen follow this with equal diligence.

The number of animals which one man can oversee may limit importantly the development of dairies extremely large in size or such establishments as milking pools. The success of these places may depend partly on dividing the animals into units small enough to be overseen efficiently by one cow-man.

A reduction in length of the open period at least down to 90 days which, at present conception rates, would mean starting to breed not later than 60 days after parturition, is the most economic means of maintaining peak flow from a good-producing dairy herd. Perhaps the breeding period could be reduced in length. If cows were all bred at 90 days after calving and all conceived on the first breeding, then a 380 day calving interval could be maintained. With normal conception rates calving interval should approach 400 days which would be a very worthwhile goal.

The sex ratio of the calves supported reasonably well the idea that little bias will be introduced by using a 50:50
ratio as the expectation. Twinning percentage was similar to that found in other herds. The occurrence of twins does not affect the actual number of normal heifer calves expected from a group of calvings, as the occurrence of freemartins reduces the expectation to about the same as among single calvings.

Heritability of Length of Herd Life

The present study of this heritability value differed from previous studies by Bayley et al. (1961) and Wilcox et al. (1957) in that no restrictions of any kind were placed on the data and length of herd-life was measured as the actual age in days at disposal. The daughter-dam comparisons included 3,363 pairs. The sire groups within year of birth of daughters were 404 and the total disposals were 3,024. The daughter-dam regression method yielded the lower value of .06 or 6%. The half-sib correlation obtained from sire groups within year of birth of daughters yielded a figure of .32 or 32% heritable.

The conclusion from the present study of large numbers of disposals is that heritability of length of life in the herd is possibly more than .06 but probably distinctly less than .32 because the correlation from the half-sib analysis is probably biased upward by the fact that there is variation
in age-specific death rates which could materially increase the sire component within year of birth. This would be particularly true where a sire had a large number of daughters leaving the herd for a cause such as low production which has a high death-rate in the early years of life.

Even with heritability this high, it would seem that in herds where voluntary removals constituted 36 or more per cent of all disposals there would be a very high correlation between length of life and productive ability. Thus much of any attention which might be paid to length of life would simply duplicate selection for productive traits. In other words selecting for longevity would closely approximate selecting for production and its use would change only a little the actual choice of cows to be kept.

Results from other workers support the idea that heritability of this trait is large enough to be measurable but does not change the conclusion that selection for production will automatically select also for long herd life in that high producers will be maintained longer and have more opportunity to raise more heifers to join the herd.

Reasons for Disposal

Obviously the most desirable change in the reasons for disposal would be to reduce the deaths and involuntary dis-
posals and thus to increase the disposals which would be made for voluntary reasons. There is little point to trying to increase the average life of all cows, as that can hardly be done except by decreasing the rearing percentage or lengthening the calving interval. Efforts should be directed toward increasing the lifetime of the better animals so that their inheritance may be passed on to more progeny.

Mastitis disposals and infertility problems are the two most important factors in disposals. Some idea of any time trend in these over the period studied should be of value. Drury and Murray (1961) have reported a considerable increase in the occurrence of mastitis in 25 herds in the Lansing milk shed area in Michigan. Table 23 shows by years the disposals for the three principal causes, mastitis, reduced fertility, and low production. Figure 7 shows on semi-logarithmic paper the percentages of each, so that any trends or differences in trends can be compared visually. In Figure 7 the data are only for the birth years 1940-1954 where the data are most complete and do not extend into the most recent years where they could be biased much by the presence of many contemporary animals which have not yet reached disposal.

The total disposals for these three reasons are rather constant over the period. The low is 51% and the high is 66% except for the last years (in the table but not on the graph).
Table 23. Yearly disposals for mastitis, reduced fertility, and low production

<table>
<thead>
<tr>
<th>Years</th>
<th>(1+22) Mastitis</th>
<th>15 Reduced Fertility</th>
<th>25 Low Production</th>
<th>Total Disposals</th>
<th>(1+22) Mastitis</th>
<th>15 Reduced Fertility</th>
<th>25 Low Production</th>
<th>All Three Reasons</th>
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<tr>
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<td>7</td>
<td>23</td>
<td>8</td>
<td>95</td>
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<td>24.2</td>
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<td>13</td>
<td>36</td>
<td>12</td>
<td>123</td>
<td>10.6</td>
<td>29.3</td>
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<tr>
<td>1939</td>
<td>25</td>
<td>34</td>
<td>9</td>
<td>127</td>
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<td>26.8</td>
<td>7.1</td>
<td>53.6</td>
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<td>34</td>
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<td>158</td>
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<td>26.6</td>
<td>13.3</td>
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<tr>
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<td>51</td>
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<td>177</td>
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<td>28.8</td>
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<tr>
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<td>37</td>
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<td>25</td>
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<td>12.8</td>
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<td>37</td>
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<td>21.6</td>
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<tr>
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<td>22.6</td>
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</tr>
<tr>
<td>1954</td>
<td>44</td>
<td>63</td>
<td>72</td>
<td>274</td>
<td>16.1</td>
<td>23.0</td>
<td>26.3</td>
<td>65.4</td>
</tr>
<tr>
<td>1955</td>
<td>21</td>
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<td>58</td>
<td>225</td>
<td>9.3</td>
<td>22.2</td>
<td>25.8</td>
<td>57.3</td>
</tr>
<tr>
<td>1956</td>
<td>16</td>
<td>33</td>
<td>38</td>
<td>172</td>
<td>9.3</td>
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<td>22.1</td>
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<td>4</td>
<td>10</td>
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<td>4.3</td>
<td>10.9</td>
<td>19.6</td>
<td>34.8</td>
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Figure 7. Yearly disposals shown as percentages of all disposals for no. 15 (reduced fertility), no. (1+22) (all mastitis), no. 25 (low production), and these three causes together
PERCENTAGE OF TOTAL DISPOSALS

YEAR OF BIRTH

ALL 3 CAUSES

[Graph showing percentage of total disposals over time, with specific years and causes indicated.]

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where disposals were still very incomplete and diseases of youth predominated. Reduced fertility varied only between 21% and 29% and probably the low period from 1943-1945 covers the period of most rapid expansion in herd size. The mastitis curve is highest at the start but drops slightly and then is nearly constant until after 1947 when it is generally much lower. The low production line shows the strongest and steadiest trend, beginning at around 13 to 17% and rising to around 25 or 26% with one year actually above 29%. The mastitis disposals seem to have been replaced partly by disposals for low production. However this is by no means the full story as the disposals for low production were fewer in the early 1940's partly because the numbers in the herds were expanding then.

As a general conclusion, disposals for mastitis have decreased slightly while reduced fertility has remained essentially constant and low production disposals have increased definitely.

The decrease in mastitis disposals might be due, to some extent, to improved methods of treatment rather than to any reduction in incidence. However experience suggests that, although the treatments may delay the disposals, the end result is the same. Increasing the herd life of a chronic mas-
titis case naturally allows more opportunity for disposal for other reasons. No clear-cut conclusion appears possible.

Heritability Estimates on Reasons for Disposal

The different methods of estimating heritability in this type of data indicate clearly that knowing the biological factors involved in the case is necessary before deciding on a method of estimating heritability.

Taking sire groups within the year of disposal seemed at first to be a reasonable form of analysis but more careful consideration showed that the daughters of a sire within a year of disposal will be approximately the same age and will differ widely in average age from daughters of other sires leaving within that year. When the probability of disposal for a given reason varies distinctly with age, such a grouping puts many of the effects of age differences into the "sire component", thus inflating heritability when estimated from that component. Even using only the sire component within year of birth is not quite a clean procedure as animals which all die within the first year of life will have somewhat the same effect. Also, the average ages of the daughters of various sires will not be quite the same, even within year of birth, as often the last daughters of one sire will have been born early in that year and the first daughters of another sire late in that year.
With the intra-sire regression of daughter on dam no systematic source of bias would appear to be involved as herd and year effects should be largely removed by this method. Little or no environmental correlation should be present between daughter and dam in these traits.

The estimates obtained by regression and by half-sib analysis agree most closely for causes such as calving trouble where the differences between years are small and the rate is at no time very high.

Young et al. (1960) found that mastitis occurrence showed a heritability of .79 with a paternal half-sib analysis which perhaps suffered from an age-probability bias as did the present estimates when derived from sire differences within year of disposal. Their daughter-dam regression method yielded .06 or exactly the same value as in the present study. Lush (1950) obtained values of .38 and .19 from New Zealand data, using the intra-herd regression of daughter on dam. Despite wide fiducial limits he thought the evidence good that heredity plays a moderately large part in whether a cow develops mastitis or not.

These earlier results and the present study make it almost certain that differences in susceptibility to mastitis have a moderately strong genetic background. The proper procedure for using this information is complicated by the gen-
eral experience that cows producing at high levels appear to be more liable to have mastitis than lower producing cows. This factor is not always supported in the literature as in Plastridge (1958) but some relationship seems to be present. Also cows which milk faster seem to have an increased susceptibility.

Frank and Pounden (1961) have shown that the occurrence of mastitis is correlated with estrous cycles and possibly also with the feeding of legume forages high in estrogens. Mastitis occurred most frequently in the period from postpartum day 31 to post-conception day 30, but this period is, of course, that of highest production and hence may be a time of high probability of attack, even without the presence of estrogens. However observation indicates that attacks in chronic cases occur most frequently 2 to 3 days after a heat period. The present author is inclined to blame this on general over-activity during estrus but other biologically significant factors may be involved.

Many farmers and herdsmen talk of mastitis bulls which they remember having used in their herds with bad results. The present heritability values are high enough to justify some belief in these tales.

Among the other causes of disposal, the pneumonia, calving trouble, bloat, and calf scour classifications are to a
large extent self-limiting, somewhat as partial or complete lethals are, in that all of them except calving trouble generally cause death at an early age. Even with calving trouble an anatomical abnormality which might be inherited would in most cases be present at first calving and cause the death of both heifer and calf.

Reduced fertility has been found in most studies, to have low heritability values not far removed from zero. However most of the work reported used a value such as number of breedings per conception and little work has been done on the basis of disposals, particularly where heifers which never did calve are included in the data. The presence of sterile heifers in the data could increase heritability estimates if single gene effects were important in complete sterility in heifers. Differences between years of birth were very small as the sire component estimates within herds and within year of birth are identical. They are both slightly higher than the daughter-dam estimate. Table 23 shows very well how small is the year-to-year variation in the percentage of disposals.

Hereditary differences might affect reproduction in three main ways. First would be the true anatomical abnormalities such as double cervix, and other tubal abnormalities. These would affect animals being bred for the first time. Secondly,
Casida and Chapman (1951) have shown that the character, cystic ovaries, is rather highly heritable. They estimate .43 in a herd of 341 cows. This tended to affect the older, higher producing animals more frequently. Its importance in disposal would depend to some extent on the alertness of the herdsman and the availability of veterinary aid. Where the cystic condition of the ovary is not allowed to remain too long, the cysts can generally be removed readily either by manual expression or by hormonal treatment. However lack of such attention will lead eventually to complete sterility. Another form of small hard cysts, which occurs in older cows, is probably a kind of disease of age and is not commonly accompanied by nymphomaniacal manifestations. Other hormonal disturbances may be involved.

A third possibility is the actual presence of genes which cause sterility in other ways, as reported by Mead, Gregory, and Regan (1946) who hypothesized a specific gene for sterility with a gene frequency of .1 or less. In this case also, all the effect would be on non-calving heifers and, like lethal genes, could not be measured by the daughter-dam regression but could be manifest in the half-sib analysis.

The evidence is sufficient to indicate that if a bull is to be used on a large scale and his sons may also be used, making an attempt to find out how many of his daughters failed
to calve would be worth while. If they were removed for lack of fertility, the reason for that infertility should be sought.

The heritability of low production seems rather low as compared with the 20-30% most generally ascribed to milk and fat production. But the figure shown here is based on the coarse all-or-none classification of disposal for low production, rather than on the continuous variable, low production itself. Also, when the herds were expanding in size disposals for low production were fewer, while in the period of stable herd size the percentage greatly increased. The value of .28 shown where only herd effects were removed might be a good estimate in this case but it will still contain some of the effects of any time trend. The heritability of removal for low production is of little practical use as the traits presumably measured crudely by it are measurable more precisely in the live animals prior to disposal.

Longevity is presumably subject to sufficient natural selection that it does not merit additional selection pressure. However, mastitis and reduced fertility seem definitely worth studying on large-scale data such as can be obtained from daughters of bulls widely used in large bull studs.

Dairy cattle breeders cannot give much attention to breeding for disease resistance, on a scale such as is done by many plant breeders and even by some poultry breeders, be-
cause of the high values of the individual animals and the long generation interval; yet some recognition should be given to the possibility of reducing the incidence of certain diseases by careful scrutiny of records of bulls chosen for wide use.
SUMMARY

This study covered a period of 21 years in 11 herds of Holstein-Friesian dairy cows which numbered an average of 714 cows per year. At least 3,000 observations were involved in most of the averages and analyses. Hence sampling errors in the results were small.

Age at first service averaged 612 days. Average age at first calving was 926 days or just 36 days longer than the gestation interval (279.1 days) from average age at first service. Considerable variation between herds was obvious in age at first calving. The correlation between age at first service and age at first calving was between .70 and .74 depending on the grouping of the data. In age at first calving, the variance components for herds removed 15%, years within herds 14%, and months within years 13%, with the remainder being 57%. In age at first service the values were 17% for herds, 9% for years within herds, 5% for months of birth and 69% in the remainder. Total variance in age at first service was only 67% as large as variance in age at first calving. No genetical significance in these two factors was indicated.

The average age at disposal was 1,696 days over the whole 21 year period and 1,913 days for the period (1937-1950) far enough back that almost all of the cows born in those years
had been removed. The herd component of variance was 10%, the year of birth component 13% and the month of birth 4% with 73% of the variance due to other factors.

The terminal lactations averaged 262 days over the complete 21-year period and 278 days in the period in which disposal was almost complete. Over 92% of the variance was from factors other than herd or year or month of birth.

Breeding periods, the time from first service to successful service, were studied on 3,055 cows in 7 of the herds and covering a possible 11 lactations. No significant differences in breeding periods were found between the different lactations. Gestation interval showed a slight trend towards a longer interval as number of lactations advanced. The average time from calving to first service following this calving was between 90 and 100 days. Individual herds varied widely in this.

Variance in length of herd life among half-sibs gave an estimate of heritability of .32 while an intra sire regression of daughter on dam gave a value of .06. The regression analysis is considered the more reliable due to its comparative freedom from bias from environmental effects which can increase the correlation found in half-sib estimates even when herd and year effects are removed.
Age at disposal is divided into 30 reasons for disposal. Ages and percentages of total disposal are shown for all reasons (Table 16). The reasons for disposal are subdivided by herds and age classes. Age-specific death rates are shown in Table 20.

Heritability estimates are made by daughter-dam regressions and also by 4 types of half-sib analysis on the following reasons for disposal:

<table>
<thead>
<tr>
<th>Reason</th>
<th>Heritability</th>
<th>Best estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1 Mastitis death</td>
<td>0 - .16</td>
<td>0</td>
</tr>
<tr>
<td>(No.1+22) All mastitis</td>
<td>.001 - .50</td>
<td>= .10</td>
</tr>
<tr>
<td>No. 22 Mastitis disposal</td>
<td>.06 - .43</td>
<td>= .10</td>
</tr>
<tr>
<td>(No.2+14) Pneumonia death and disposal</td>
<td>0 - .77</td>
<td>= 0</td>
</tr>
<tr>
<td>No. 4 Calving trouble</td>
<td>.05 - .32</td>
<td>= .05</td>
</tr>
<tr>
<td>No. 8 Bloat</td>
<td>0 - .78</td>
<td>= 0</td>
</tr>
<tr>
<td>No. 9 Calf scours</td>
<td>0 - .73</td>
<td>= 0</td>
</tr>
<tr>
<td>No. 15 Reduced fertility</td>
<td>.05 - .24</td>
<td>= .10</td>
</tr>
<tr>
<td>No. 25 Low production</td>
<td>.08 - .40</td>
<td>= .14</td>
</tr>
</tbody>
</table>

Biases involved in the different analyses are discussed.

Year effects on the disposals for mastitis, reduced fertility, and low production are shown graphically and the usefulness of these estimates to dairy cattle breeding plans are discussed.
Some attention to mastitis and reduced fertility in young heifers seems worth while in any large-scale breeding plan which involves the possibility of a bull being followed by his sons in an artificial insemination stud.
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