A MEASURE OF REPRODUCTIVE EFFICIENCY FOR RANGE BEEF CATTLE BRED IN A RESTRICTED SEASON

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INTRODUCTION

Measures of production which are economically important to beef cattle producers include reproductive performance of the cow herd, weights and grades of calves at weaning, rate and economy of post-weaning gains, and carcass merit. Reproductive performance of the beef cow is important, not only as it affects number of calves produced but also as it affects uniformity in the age of calves.

Measures which beef cattle producers commonly use to describe reproductive regularity in their herds are the calf crop percentage or length of the calving interval. Regularity of reproduction is obviously important to cattlemen since cows which fail to calve will cost approximately the same for maintenance as those cows raising a calf. In a survey of the producers in the American National Cattlemen's Association, it was reported that in 1954 only 79 per cent of the beef cows dropped live calves. This survey also revealed that 30 per cent of the cows which were removed from the herd were culled because they failed to wean a calf. This indicates the importance of the problem to beef cattle producers. It points out a real need for information on the causes of this lowered reproductive performance so that measures of merit might be developed which could improve the situation.

A group of calves which are uniform in age is desirable in the production of beef cattle. In the previously mentioned survey it was indicated that 84 per cent of the commercial herds were bred during a restricted season and 98 per cent of the herds practiced pasture-mating. Generally, the breeding season extended from April to August with the cows calving during a three to four month period in the spring. Cows bred during a restricted breeding season must be very efficient breeders if they are to have as high a percentage calf crop as those cows which are with a bull continuously. Calves which are uniform in age are more desirable because they usually require less labor and demand a higher price when sold as a group. If the interval of time from exposure to a bull until calving is repeatable, then selection could effectively shorten the calving season for the herd.

The purposes of this study were to measure by a practical method the reproductive performance of range beef cows bred during a restricted season and to determine the repeatability of this measure as a basis for selection.

REVIEW OF LITERATURE

During the past 25 years many studies have been conducted on the various aspects of reproduction in farm animals. Many of these studies have dealt with the reproductive efficiency of dairy cattle. This was due to the increased use of artificial insemination for dairy cows and the resulting emphasis on fertility and regularity of breeding. Services per conception, time from first service to conception, time from calving to first estrus, and calving interval are the measures of reproductive efficiency which have been used most often in these studies. There have been very few studies with beef cattle because with a pasture mating system the date of service, number of services per conception and date of conception are usually not known. The measures which can be used for beef cattle under a pasture mating system with a restricted season of breeding are percentage calf crop, calving interval, uniformity in age of the calves, and length of time from exposure to calving. Variable factors, which have a direct or indirect effect on the above measures, include time from calving to first heat, length of the estrous cycle, and length of the gestation period. The use and importance of the above measures will be emphasized in the following review of earlier studies.

Repeatabilities and Heritabilities

Generally, repeatability and heritability estimates of measures of reproductive performance have been low. The following table of estimates of repeatability and heritability as reported by various workers emphasizes the fact that the estimates are near zero for the measures used.

TABLE I

REPEATABILITY AND HERITABILITY ESTIMATES

	Calving Interval		Services Per Conception		First Service to Conception		Calving to First Heat		Regularity of Estrus	
	R[1]	H[2]	R	H	R	H	R	H	R	H
	.02	.01	.00	.00	.11	.07	.06	.32	.18	.05
	neg	.01	.18	.03	.08	.08	.19	.27		
	.13	neg	.12	.00	.02	neg	.15	neg		
		.00	.06	.07			.27	.03		
			.06	neg						
Ave.	.07	.00	.06	.00	.07	.02	.17	.14	.18	.05

1. R = Repeatability
2. H = Heritability

From a study of the records of 257 Angus cows with 927 calving intervals, Brown, et al. (1955) estimated the repeatabilities and heritabilities of calving intervals. The estimates were essentially zero for both repeatability and heritability when the environmental components were not removed. Year of calving accounted for seven per cent of the total variation, while sequence of calving accounted for eighteen per cent of the total variance. These cows were in a herd in Chichuahua, Mexico. This study indicated that genetic and permanent environmental factors had little influence upon calving interval among these cows.

Lasley and Bogart (1943) divided Hereford cows into high and low groups on the basis of the number of inseminations required per calf in their first record. These same cows were checked for the following two years and the difference between the high and low groups was even greater than it was for the first record. This would give an estimate of repeatability greater than one. This large estimate, although not a true value, did indicate that there were permanent differences between cows. The authors found that two-and three-year-old cows required one insemination more per calf and produced a twenty per cent smaller calf crop than five-and six-year-old cows. Also, nine-and ten-year-old cows required .73 more inseminations per calf and had a seventeen per cent smaller calf crop than the five-and six-year-olds. Dry cows required more inseminations per calf than did lactating cows. Also, as the interval from calving to insemination increased, the number of cows which were settled with one insemination became greater.

Repeatability of the interval from parturition to first estrus was estimated at .06 by Warnick (1955). He used records from 50 beef cows covering a three-year period to obtain this estimate. In these records variation in the length of this interval had no effect on fertility. Year and season both had highly significant effects upon this interval. For each ten days later in the season that a cow calved, the interval from parturition to first heat was shortened by six days. Warnick found no line or breed differences in this interval.

Chapman and Casida (1937) estimated the repeatability for the interval, parturition to first estrus, at .19, which was in agreement with the estimate of .15 given by Clapp (1937). Neither of these studies with dairy cattle indicated any change in this interval due to age of cow. Clapp indicated that two of the most important environmental sources of variation were season and level of production. Cows milked four times a day had a 23-day longer interval than those milked twice a day, and repeatability estimates for the two groups were .15 and .09 respectively. Cows calving in December averaged 27 days from parturition to first estrus, while cows calving in September averaged 81 days from parturition to first estrus.

Olds and Seath (1953) analyzed the records from 472 parturitions in dairy cattle. They gave a repeatability estimate of .29 and a heritability estimate of .27 for the interval from calving to first heat. The same workers (1950) studied records from 6,509 cows in 2,403 dairy herds. From these records they concluded that for each additional service which a cow required to conceive the first year an increase of one-tenth of a service was noted the following year. They also found that herds were no more predictable than cows in the number of services per conception which they required.

Olds et al. (1949) found no correlation between daughters and their dams in the number of services required per conception. This work was done with records from 435 dairy heifers and 430 dairy cows with a total of 1,746 pregnancies. They found that only 38 per cent of those cows which failed to conceive had a normal estrous cycle following the infertile service.

Dunbar and Henderson (1950) studied two measures of fertility: (1) non-returns to first service and (2) calving intervals. A components of variance analysis of non-orthogonal data gave unbiased estimates of genetic differences among dairy bulls. The estimates were essentically zero in both measures of fertility.

Pou et al. (1953) studied records of 834 Holsteins and Jerseys which were collected during a 30-year period. Three measures of breeding efficiency were investigated: (1) number of services per conception with estimates of .08 and .02 and heritability estimates of .08 and -.09; and (3) number of services per conception, for which he obtained repeatability estimates of .06 and .06 and heritability estimates of .08 and -.15. The two herds differed significantly in the first two characters. Age of cow differences accounted for less than two per cent of the variance. Years accounted for less than four per cent of the variance, except in one herd, for the interval from parturition to first estrus in which years accounted for 15 per cent of the total variance. Days from calving to first estrus varied markedly by season with cows calving in March averaging 65 days to first heat while those calving in September averaged 45 days to first heat.

Lush and Molln (1942) obtained information on litter size and weight from 2,560 sows with 7,415 litters. Repeatability estimates were: .15 from an intra-block analysis; .13 for contemporary sows not having litters in all of the same seasons; and .17 for non-contemporary sows of the same breed at the same station. They stated that repeatability measures the fraction of the difference found between two sows in one season which was most likely to be found between them in the future. They also commented that where the reach in selection was one pig then the change in the herd average would be about .15 pigs per litter. They stated; "While this average amount of progress may seem disappointingly small, and of course, will be attended by many individual surprises and exceptions, yet it is not zero and if extended over many years would ultimately lead to large changes in the herd or breed average." Under these conditions selection based on two litters would give a 50 per cent increase over selection based upon a single litter. A sow's own record should receive three times the weight of her dam or full sister when selecting for traits with this size repeatability.

Traits Related to Breeding Efficiency

Brown et al. (1955) from a study of 927 calving intervals of range beef cows reported that the average calving interval was fourteen months. The standard deviation was three months and the range was from 9 to 28 months.

Warnick (1955) reported that the average intervals from parturition to first estrus were 59 days for Angus and 63 days for Herefords. These were derived from the records of 151 cows during a three-year period. An interval of this length indicates that the shortest average calving interval would be 11 months if all cows conceived at their first heat.

Lasley and Bogart (1943) found the length of the average estrous cycle to be 20 days with a range of 10-29 days. Interval from calving to first estrus averaged 80 days with a range of 10-200 days. Two- and three-year-old cows required 2.37 inseminations per calf and had a 66 per cent calf crop, while five-and six-year-old cows required 1.36 inseminations per calf and had an 86 per cent calf crop. Nine-and ten-year-old cows required 2.09 inseminations per calf and had a 69 per cent calf crop.

Rhoad (1944) from a study of 832 pasture matings in beef cattle found that 563 of them culminated in normal births, 62 were terminated by abortions and 207 were apparently infertile matings. The average number of heat periods from exposure to conception for all cows was 1.81. The date of conception and the number of heat periods were calculated using a 282-day gestation period and an estrous cycle length of 20 days. He studied the effect of the length of time which cows remained open on the per cent conceptions corrected to represent a 100 per cent fertile herd with the following results: (1) at the end of the first estrous cycle period of twenty days 52 per cent of the cows had conceived; (2) in the second period 28 per cent of the cows conceived; (3) only 11 per cent of the cows conceived in the third twenty day period, (4) the remaining nine per cent of the cows had conceived by the end of the sixth period.

Warren (1950) analyzed 402 conceptions and found an average of 1.69 services per conception with no significant breed differences among Herefords, Angus and Shorthorns. Age of dam affected conception rate significantly, with 2.04 services per conception being required for two-year-olds and with 1.20 services per conception as the average number required for eight-and nine-year-old cows. The greatest number of services per conception was required during the summer and the smallest number was required during the fall. Gestation lengths were found to be as follows: 284 days for Angus, 286 days for Herefords, 282 days for Shorthorns. Age of dam had no effect on gestation length in this study. Gestation length for cows dropping bull calves was 2.1 days longer than for cows dropping heifer calves.

Burns et al. (1954) bred 44 beef cows, which had previously failed to calve, to a fertile bull. One half of the cows were killed three days after breeding and the other half were killed 34 days following mating. The time from first exposure to estrus averaged 45 days for 22 cows of Brahman breeding and 12 days for 22 cows of English breeding. At three days 40 per cent of the cows of Brahman breeding had live embryos. Embryo losses between three and 34 days were 18 per cent for the Brahmans and 100 per cent for the English breeds.

Knapp et al. (1940) studied 164 parturitions in Shorthorns and found an average gestation length of 280 days with a range of 260 to 322 days. Male calves were carried two days longer than females in these data.

Piam (1944) reported that Herefords had a gestation period of 279 days with a range of 243 to 316 days. Weight at birth had no significant effect upon length of gestation. The gestation length for male calves was only .77 of a day longer than for female calves.

Johnson (1944) found that the average gestation length for 39 Shorthorns was 284 days; for 98 Herefords it was 283 days; and for 112 Angus it was 281 days.

Livesay and Bee (1945) in studying Aberdeen-Angus found that 173 gestations averaged 282 days, with 79 male gestations averaging 283 days while 94 female gestations averaged 282 days. Herefords with 174 calves had a gestation length of 285 days with no sex difference. A significant difference between breeds was found.

Long et al. (1948) reported data from a nine-year crossbreeding project conducted at the Ohio Agricultural Experiment Station. Four types of calves in approximately equal numbers were produced each year: purebred Herefords, crossbreds with Angus sires and Hereford dams, purebred Angus and crossbreds with Hereford sires and Angus dams. In this study 101 purebred Hereford calves had an average gestation length of 286 days, while 99 purebred Angus calves averaged 276 days. The average length of gestation for the crossbreds was 282 days. A high correlation was found between length of gestation and birth weight. Male calves were carried 1.3 days longer than females and weighed 1.3 pounds more at birth.

Gerlaugh et al. (1951) found the gestation length for 101 purebred Angus cows to be 276 days, for 102 purebred Hereford cows to be 286 days, for Hereford bulls by 94 Angus cows to be 282 days and for Angus bulls by 102 Hereford cows to be 283 days.

Burris et al. (1952) at the Nebraska Agricultural Experiment Station obtained data from four lines of cattle containing 188 Herefords, 184 Angus and 130 Shorthorns. The gestation periods were: Angus, 282 days; Herefords, 286 days; and Shorthorns, 284 days. No significant differences due to age of dam or sex of calf were found. Year, sire, and sex-breed interaction had no effect on gestation length. Birth weights were correlated with gestation length. The regression of birth weight on gestation length was .38. This was illustrated by the fact that when the gestation length of Herefords increased from 276 days to 285 days the birth weight increased from 60 to 66 pounds.

Wheat and Riggs (1952) analyzed data from 551 gestation periods from purebred Herefords, Aberdeen-Angus, Shorthorns and Hereford X Brahman crossbreds. Herefords had a gestation length of 285 days, while Aberdeen-Angus had a gestation length of 279 days. There were significant differences in gestation length between breeds and between sires within a breed, but there were no significant differences between age of dam groups within sires and breeds or between sexes.

Chapman and Casida (1934) analyzed 169 records and found that the average length of time from parturition to first estrus was 69 days with a standard deviation of 39 days. Only 52 per cent of the normal cows had as many as 63 per cent of their estrous cycles falling between

17 and 27 days. The estrous cycle range was from two to 201 days with a mode of 21 days. Chapman and Casida (1935) found that during the period from parturition to first estrus 50 per cent of the cows had intervals less than 61 days, while 40 per cent had intervals between 61 and 120 days, and only ten per cent had intervals over 120 days. The same workers (1937) found no seasonal effects on estrous cycle length of cattle and sheep. The differences between individuals were the source of significantly more variation than the differences between the cycles of the same individual.

Clapp (1937) studied the records of 159 Holstein cows to determine the interval from calving to first heat. Cows which were milked four times a day averaged 69 days, while those milked two times a day averaged 46 days, and those nursing calves averaged 72 days from calving to first heat. Cows calving in December and January with 27-and 37-day intervals respectively, had the shortest intervals, while those calving in July and September with 72 and 81 days, respectively, had the longest intervals. The age of cow had no effect on the interval from calving to first heat.

Spielman et al. (1939) analyzed the records of 368 cows of four dairy breeds collected from 1913-38. They assumed that twelve months (called 100 per cent months) was the desired calving interval. Total reproductive months were the months the animal remained in the breeding herd. They let reproductive efficiency equal the number of 100 per cent months divided by the total number of reproductive months. Reproductive efficiency of breeds ranged from 67 per cent to 81 per cent. A correlation of .55 was found between foundation cows and the mean of their female descendants. There were marked differences between cow families and breeds.

Hull et al. (1940) studied data collected from 1900 through 1939 on 482 breeding age females from three breeds of dairy cattle. Seventeen months was the average calving interval. Bangs and trichomoniasis were given as the probable causes for this long interval. Reproductive efficiency (100 per cent months divided by the total reproductive months) was 72 per cent.

Jones et al. (1941) stated that delayed service after calving had no effect on the number of services per conception. They believed that selection should be based on generations of highly fertile ancestors. This was checked by following the records of female descendants of foundation cows to find the differences in numbers culled for reproductive performance.

Tanabe and Salisbury (1946) studied data from matings of 12,621 cows with 41 bulls from 1940-1944. They found that 2.07 services were required per conception giving a breeding efficiency of 48 per cent. The age of cow had an effect on breeding efficiency with the rate of conception steadily increasing for cows until four years of age and starting to decline at eight years. Bulls two years of age were the most efficient.

Chance and Mather (1949) analyzed records of 1,168 cows collected from six herds over a 13-to 21-year period. All cows descending in the female line from a foundation cow were included as a family. An analysis of variance of 882 cows in 89 families indicated that only two of the families differed significantly in reproductive efficiency or longevity.

Boyd et al. (1954) reported that the average number of services per conception for 519 cows located in 29 different herds of three dairy breeds was 1.68. There was no significant correlation between milk production and services per conception.

Gowen and Dove (1931) in a study of 7,679 cows found that 64 per cent of the cows bred became pregnant at the first service. Fifty-three per cent of the cows exposed a second time became pregnant at that service. Forty-nine per cent of those bred a third time became pregnant as a result of that service. A decreasing percentage of the individuals conceived at later services until only nine per cent of those bred a seventh time conceived at that service. No seasonal differences were found in conception rates. The age of cow had no marked effect on conception rate until 14 years.

Erb et al. (1940) in a study of 1,440 services resulting in 922 conceptions for dairy cows found that 72 per cent of the conceptions resulted from a single service, 19 per cent of the conceptions resulted from the second service, 6 per cent of the conceptions resulted from the third service, two per cent of the conceptions resulted from the fourth service, and one per cent of the conceptions resulted from later services. May, with 74 per cent conceptions, and August, with 58 per cent conceptions, were the extreme months in breeding efficiency. Some cow families were found to have a higher breeding efficiency than others.

Trimberger and Davis (1945) found definite differences in conception rate among a few cow families and daughter groups but stated that these differences were not repeatable. They thought it was not possible to predict future individual performance either from the past performance of the individual or from the performance of its ancestors.

Olds et al. (1949) reported that 52 per cent of the heifers conceived at first service, while only 48 per cent of the cows conceived at first service. Seventy-eight per cent of the cows had conceived by the third service. Five per cent of the cows were classified as non-breeders. The highest conception rate occurred between 50 and 75 days after calving. The first heat occurred approximately 30 days after calving. Of 121 cows which came in heat between one and 18 days after calving, 44 of the cows had another heat about 13 days later. Only 38 per cent of the cows and heifers failing to conceive came back in heat between 18 and 24 days later. Highest conception rate occurred for cows going into their fourth or fifth pregnancy.

Olds and Seath (1953) studied 472 parturitions in dairy cattle and found an average interval of 32 days from calving to first estrus. The average length of the estrous cycle was 22 days.

Herman and Edmondson (1950) concluded that the interval from parturition to estrus for 367 cows with 968 parturitions was 57 days. No relation was found between season and this interval. Very young and old cows had a longer interval than cows between two and one-half and seven years of age.

Käb (1937) checked the records kept from 1898 to 1934 in three herds including 136 bulls and 1,475 cows with 7,104 calves. Fertility was measured by the number of viable calves produced at a given age. An analysis of the fertility of the daughters of 22 bulls was made. The variation between families suggested a genetic cause of fertility.

Koch (1938) used the ratio of a cow's age to the number of live calves produced to measure reproductive performance. Data on Spotted Cattle in Baden indicated that the most widespread cause for culling cows was poor fertility. In 13 families with good records only one out of 72 cows was culled. In this study 37 of the 87 daughters by three bulls were culled for sterility while only eight of the 140 daughters by other bulls were culled.

Casida (1953), in a review article stated that fertility depends on three things: female fecundity, fertilization rate and prenatal death rate. It was estimated that the largest number of repeat breeding cattle was caused not by failure to conceive but by prenatal death of the embryo. Bulls with a non-return of 67 per cent or over had a fertilization rate of 100 per cent. Heifers which were apparently sterile were found to have conception rates of approximately 70 per cent.

DESCRIPTION OF THE DATA

The data for this study included the breeding and calving records for 325 cows which were maintained in four experimental beef herds located at three different stations in Oklahoma. Table II shows the number of records within each of the experimental projects.

TABLE II

NUMBER OF RECORDS USED IN THIS STUDY

Projects	No. of Years	Calving Intervals[1] No. of Cows	No. of Intervals	Successful Exposures[2] No. of Cows	No. of Calves
670	5	61	175	99	351
650	6	94	411	109	558
526-S	9	42	238	58	372
526-W	4	54	157	59	211
Total		251	981	325	1,492

1 A calving interval is the length of time between consecutive calves for a cow.
2 A successful exposure is the exposure of a cow to a bull which results in a calf.

The cows were pasture mated within a limited breeding season. A bull was put with 15 to 20 cows each year near the first of May and he was usually removed from the group in early August. Cows which failed to conceive during this period were usually not exposed again until the following year. The records of these skip-breeding cows were removed from the data used in the analysis of calving intervals because it was thought that these long intervals were not indicative of the cow's ability to conceive.

Six per cent of the cows failed to calve each year on the average. Only twelve per cent of the cows which failed to calve once failed a second time. These high calf crop percentages were probably due to several factors. Only those cows which were pregnant at the beginning of two of the projects(526-S and 526-W) were included in the experiments. Only those cows which had two or more calves were included in this study since repeatability estimates were to be made and they cannot be calculated with fewer than two records for each cow. Also cows were usually culled from the herds if they failed to calve during two consecutive years.

Project 670 was an experimental herd which included four lines of registered beef cows kept at the Fort Reno Station for the purpose of studying the heritability of several economically important traits. The four lines contained cattle of two breeds with three of the lines within one breed. Line 1 was an Angus line which was being developed as a closed herd with selection for economically important traits. Line 2 was a Hereford line which was also developed as a closed herd with selection for the same traits. Lines 3 and 4 were large-and small-type Herefords being compared as non-inbred lines. Some of the cows in this project were bred at the time of purchase, and changing them from year-long to spring calving caused some long calving intervals for the first few years in Lines 1 and 2. These early records, therefore, were not used in the repeatability estimates for calving intervals.

Project 650 was a herd of grade Hereford cows at the Fort Reno Station which were used to study the effects of the age at first calving and various levels of supplemental feeding on the cows' productivity. When the experiment was started, 120 heifers were allotted at random into eight treatment groups. Four of the lots were calved first at two years of age, while the other lots were calved first at three years of age. The winter feeding phase began about November 1 each year and ended about April 15. Three different levels of supplemental winter feeding were fed to each of the groups bred to calve at different ages. Two of the groups received supplemental summer feed in addition to the winter phase. All lots remained intact except for those on supplemental summer feed in one year, with no cows being removed except for sterility and by death losses. There were very few cows in this experiment that failed to calve each year and few remained open for longer than ninety days.

The cows in Project 526-S were 60 grade Herefords of varying ages kept at the Lake Carl Blackwell range area. They were divided into four lots of 15 cows each for the purpose of studying various levels of mineral supplementation. The cows assigned to this herd in 1946 were pregnancy tested before purchase and no open cows were included. As the daughters of these animals reached maturity, some of them were put into the breeding herd.

The data in Project 526-W were from a herd of 60 grade Hereford cows at the Oklahoma Range Cattle Minerals Station near Wilburton. They were in a study of the effects of various mineral supplements on the performance of beef cows. Pregnant heifers were selected for the initiation of this study which included six different treatments. They remained on the same treatments throughout the period covered by this study.

The distribution of the intervals of time between the dates upon which the cows calved and the dates upon which they were put into the breeding pastures is given in Figure 1. The average number of days from calving until exposure to a bull was 56 days. Since cows could not have an interval shorter than zero days and because few cows calved earlier than 90 days before exposure, the skewness of this distribution was expected.

The distribution of the intervals of time between the dates upon which the cows were exposed to a bull and the dates upon which they calved the following year is given in Figure 2. The average number of days from exposure to calving was 309 days. Again the skewness of this distribution was expected since previous literature indicated that the large percentage of cows would conceive at either their first or second heat.

It was expected that cows which were open for the longer period of time before exposure to a bull would conceive earlier and calve earlier the next year. The relationship of these two intervals is presented graphically in Figure 3.

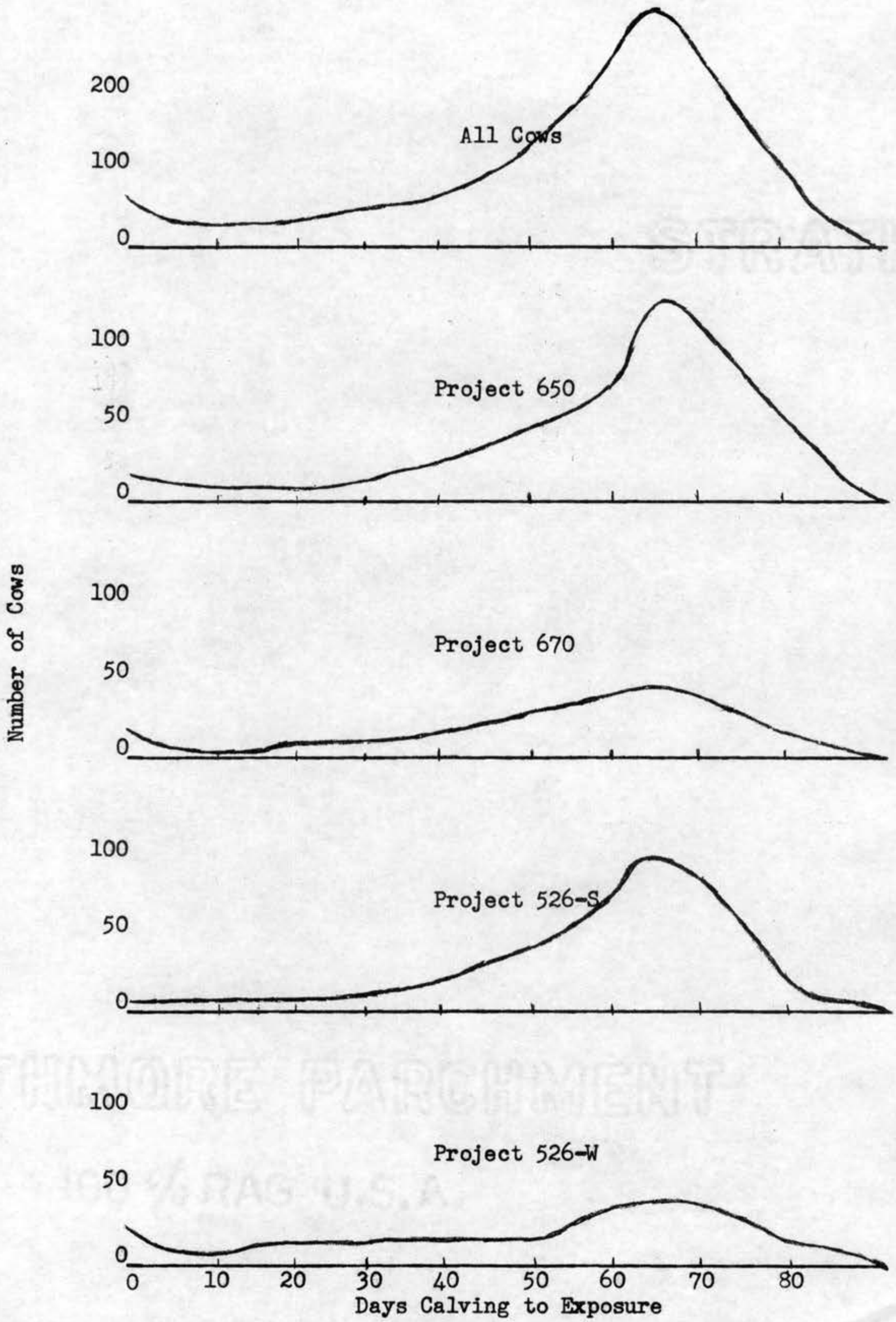

FIGURE 1. DISTRIBUTION OF DAYS FROM CALVING TO EXPOSURE

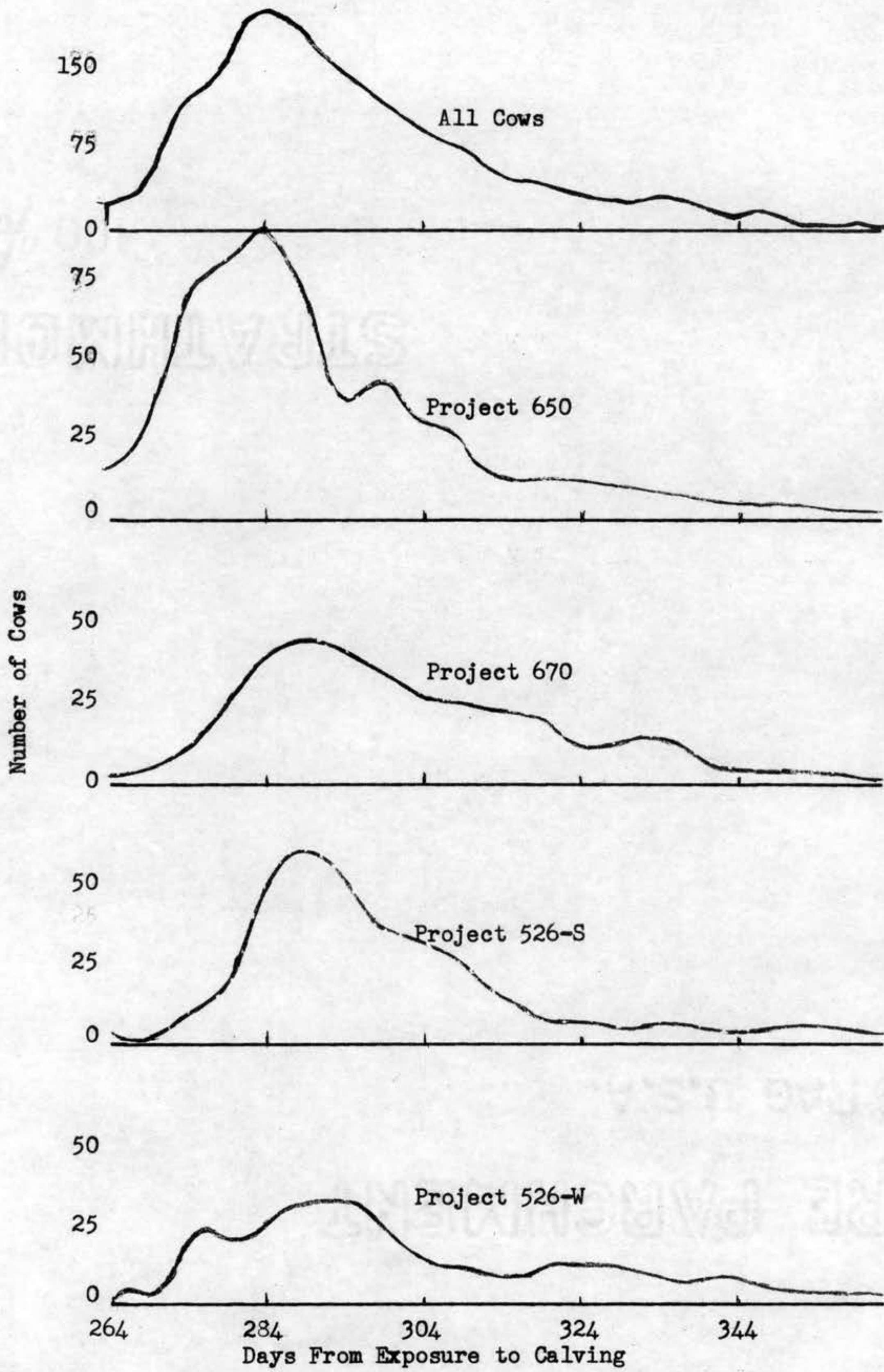

FIGURE 2. DISTRIBUTION OF DAYS FROM EXPOSURE TO CALVING

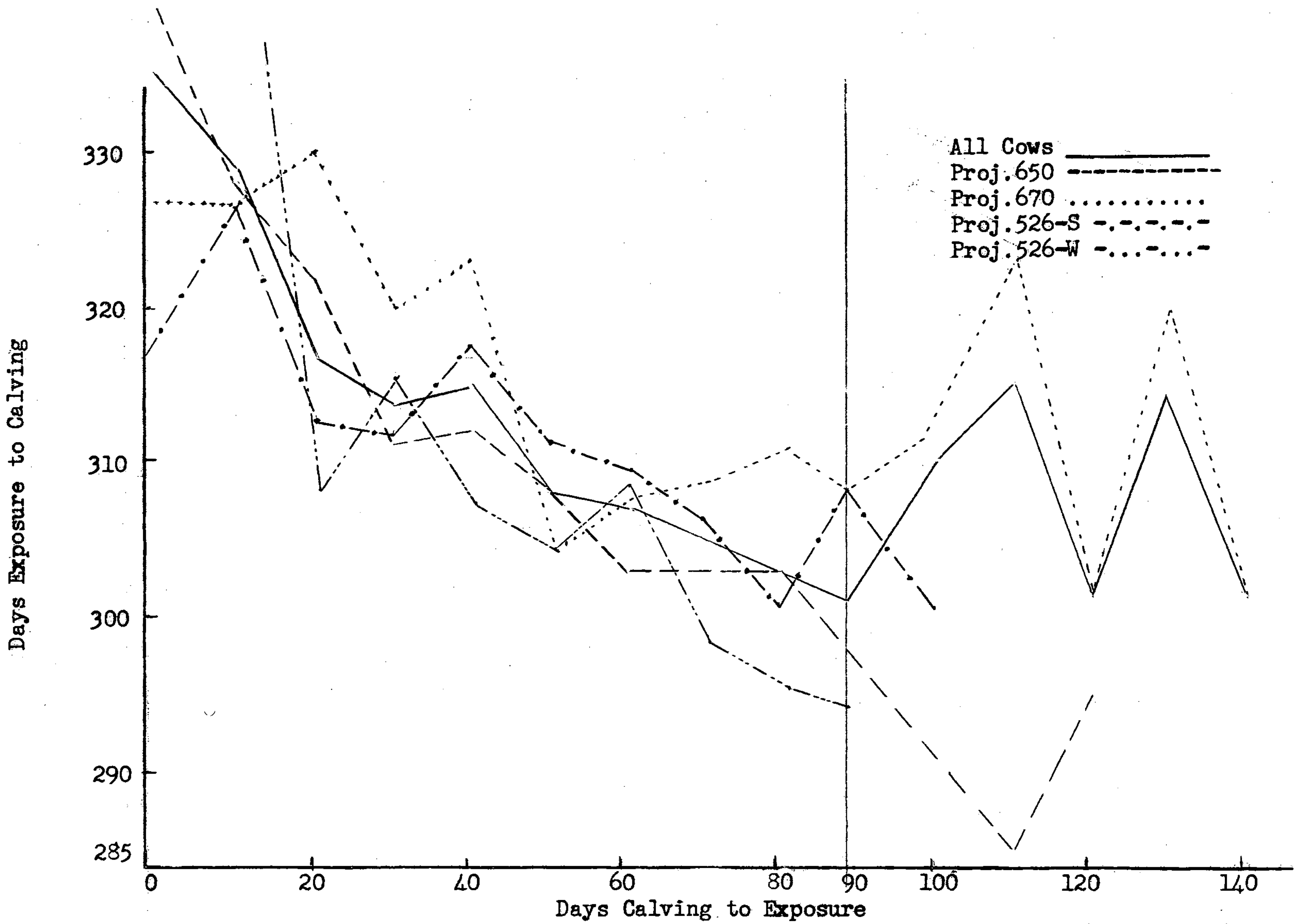

FIGURE 3. REGRESSION OF DAYS FROM EXPOSURE TO CALVING ON DAYS FROM CALVING TO EXPOSURE

METHODS OF ANALYSIS

The data in this study were analyzed to determine the repeatability of several different measures of reproductive efficiency. The average differences due to treatment, location, season and breeding group were removed by an analysis of variance. It was thought that the length of time a cow had been open before being exposed to a bull would have an effect upon the length of time it would take her to conceive. This would cause unwanted variation in calving dates. To measure this effect an analysis of covariance was computed for these two variables.

Calving intervals and days from time of exposure to time of calving were analyzed to obtain estimates of the variance components and repeatabilities. The variances between cows and within cows were taken from the analysis of variance table and an intra-class correlation was computed using the method described by Snedecor (1946). Intra-class correlation is the ratio of the variance between cows to the variance between cows plus the variance of the repeated records within a cow. This ratio is an estimate of the repeatability of the trait. Confidence limits were calculated for each repeatability estimate by determining the least significant variance between cows and computing an intra-class correlation from this value. The data were analyzed separately for each project to see if differences existed. These analyses were then pooled to obtain a more reliable estimate of intra-class correlation.

The regression coefficient for days from exposure to calving (Y) on days from calving to exposure (X) was computed from an analysis of covariance table. In the covariance analysis the average effects of subclass differences were removed from the within cow variance, subclasses being the year and treatment in which each record was made. The regression coefficient, calculated by dividing the within-cow sum of cross-products by the sum of squares of x, estimates the average slope of the regression line for each cow's individual records. The covariance and regression methods explained by Snedecor (1946) were used to compute the regression coefficients.

Intra-class correlation coefficients were computed from the errors of estimate mean squares of the covariance analyses, using the method previously described.

RESULTS AND DISCUSSION

Calving Interval

The calving interval is the number of days between two consecutive calves produced by a given cow. The repeatability of this measure of reproductive efficiency cannot be calculated with fewer than three calves. Because of this factor several cows had to be removed from the data in the analysis of calving intervals. This measure can be used to the best advantage for cows handled under a system where breeding is not seasonally restricted. The purpose of estimating the repeatability of calving interval in this study was to determine the effect of seasonal breeding on the repeatability and to compare this estimate with the repeatability estimates for other measures.

The mean calving interval in this study was 364 days with a standard deviation of 28 days. This relatively short and consistent interval is due to several factors. Only those cows which calved in consecutive years were included in the data. The cows were handled under a restricted breeding season, with the season starting approximately the same time each year. Also, there was some selection for efficiency since cows which failed to calve for two consecutive years were usually culled. If the cows had been exposed to the bull continuously or if the two-year and over intervals had been included in the study, the average interval would have been longer, and would have been more variable.

TABLE III

ANALYSES OF VARIANCE FOR CALVING INTERVAL

Pooled From Analyses in Which Temporary Environmental Components Were Present

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Between Cows	247	142,579	577	841+3.79(-70)
Within Cows	732	615,808	841	841

The Confidence Interval for "R" at the 95% Prob. level is -.02 to -.16

Pooled From Analyses in Which Temporary Environmental Components Were Removed

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Between Cows	247	142,579	577	824+3.78(-66)
Within Cows	629	518,405	824	824

The Confidence Interval for "R" at the 95% Prob. level is -.02 to -.16

TABLE IV

REPEATABILITY ESTIMATES FOR CALVING INTERVAL

Method[1]	Proj. 670	Proj. 650	Proj. 526-S	Proj. 526-W	Pooled
(a)	-.08	-.21	.04	-.16	-.09
(b)	-.09	-.22	.10	-.17	-.09

1 (a) Analysis of variance without removing temporary environmental components associated with season, line of breeding and experimental treatment.

(b) Analysis of the components of variance removing temporary environmental components including season, line of breeding and experimental treatment.

The pooled repeatability estimate for calving interval which is given in Table IV is negative. This would indicate that the true repeatability must be near zero. This estimate is in agreement with those of Brown, et al. (1954) and Legates (1954). The estimates for the individual projects are probably different since the 95 per cent confidence intervals for projects 650 and 526-S did not over-lap as can be seen in Appendix A. Even though two of the projects may have been different, it was thought that pooling the project analyses as shown in Table III would give a more reliable estimate of repeatability. This estimate would apply to regularly producing beef cattle herds using restricted breeding. Under this system of management, if a cow conceives at the first of the breeding season, she will not have a chance to have a calving interval shorter than twelve months the following year but can have one as long as nineteen months. The opposite would be true of a cow conceiving at the last of the breeding season, as she could not have an interval longer than fifteen months the following year but could possibly have one as short as her gestation period. This means that seasonal breeding forces those cows with a long interval one year to have a shorter interval in the following year and those cows with a short interval to either remain early breeders or have a longer interval the following year. This would automatically reduce the repeatability estimate and could cause it to be negative, as it would make the records by the same cow more variable without necessarily changing the cow averages. Cows that would have an interval longer than sixteen months and less than two years would be automatically eliminated from this study. This could be another factor in reducing the repeatability. Probably because of the above factors, removing the differences due to years, breeding and environment did not increase the repeatability, as can be seen in Table IV. These components were not significantly different from zero in the components of variance analyses given in Appendix A.

When cows which skipped a year were included in the analysis the repeatability estimate became positive. This was because the variance between cows was increased more by these long intervals than the variance of repeated records within cows. The estimate made by this method would not be applicable as it is possible that the cow which had an interval of two years would have had an interval of fourteen to twenty months if she had not been subjected to seasonal breeding. For this reason the repeatability estimates computed from the data including skip-breeders were not used in the study.

The results of the study indicate that the use of calving interval as a basis for selection would be of very little practical value. Among the reasons leading to this conclusion are: (1) the fact that with seasonal breeding the length of the calving interval could be decreased very little even if selection were effective, (2) the repeatability of the trait is too small for progress by selection to be effective, and (3) it requires the records of two consecutive calves to get a measure of calving interval.

Interval From Calving to Exposure

This interval is the number of days from the time a cow calves until she is exposed to a bull. The purpose of studying this interval was to determine its effect upon the interval from time of exposure to calving. From the reports of Olds, et al. (1949), Lasley and Bogart (1943), it was determined that the highest conception rate occurred between 75 and 80 days following parturition. This meant that on the average a cow which calved ten days before exposure did not conceive as soon as one which calved 75 days before exposure. If this is true, then the longer the period of time cows were open before exposure to a bull the shorter would be the average time from exposure to calving. Cows bred during a restricted season vary in the length of time during which they are open before exposure. This would increase the variability of the interval from exposure to calving. Because of this it was felt that a correction of the interval from exposure to calving for the effect of the length of the interval from calving to exposure might be helpful. To make this correction an intra-class covariance analysis was computed. The correction was made on an intra-cow basis with the differences due to years, nutritional treatments and breeding groups removed. The covariance tables are given in Appendix B for the individual projects, while the pooled analysis is given in Table V.

TABLE V

POOLED COVARIANCE ANALYSIS FOR DAYS FROM EXPOSURE TO CALVING WITH DAYS FROM CALVING TO EXPOSURE

Source	d f	Sum x^2	Sum xy	Sum y^2
Total	1,118	533,807	-112,105	600,883
Between Cows	308	213,187	-198,660	300,005
Within Cows	714	239,177	41,070	218,779
B Plus W[1]	1,022	452,364	-157,590	518,784

1 Between cows plus within cows

The average number of days from calving to exposure was 56 days with a standard deviation of 22 days. The pooled regression coefficient as shown in Table VI on an intra-cow basis was .17. This would indicate that, on the average, the longer an individual cow had been open before exposure, the longer it took her to calve following exposure. This would probably not be true for cows which were exposed continuously. The restricted breeding season forced a cow with a short interval from calving to exposure to conceive rather quickly after calving, or not at all. A cow which calved in January had no chance to conceive quickly after calving because the bulls were not put with the herd until May. The fact that cows which calved early one year could not calve earlier and cows which calved late could not calve later probably caused the regression on an intra-cow basis to be positive.

TABLE VI

REGRESSION OF DAYS EXPOSURE TO CALVING ON DAYS CALVING TO EXPOSURE

Method	Proj. 670	Proj. 650	Proj. 526-S	Proj. 526-W	Pooled
Intra-Cow	.16	.17**	.19*	.15	.17*
Between Cows	-.33**	-.35**	-.22*	-.47**	-.35**
Total	-.24*	-.38**	-.26*	-.37*	-.34**

* Probability of chance occurrence less than .05
** Probability of chance occurrence less than .01

The between cows regression was -.35 as shown in Table VI. This regression did not include variation due to year, breeding group, and nutritional treatment. Physiologically this negative regression is what would be expected. Figure 3 shows this overall regression to be negative. The negative regression was obviously the result of between cow covariance. Any adjustment of the records which would remove variance between cows would obviously lower estimates of repeatability. Adjustment of the data using the intra-cow regression coefficient, which was positive, actually lowered the repeatability of the interval from exposure to calving, slightly. This may have been due to bias introduced into the covariance by unequal numbers.

Interval From Exposure to Calving

The interval from exposure to calving is the number of days from the time the cow is exposed to a bull until she calves the following year. This interval includes the time from exposure to first estrus the number of estrous cycles before conception and the length of gestation. Using this measure of reproductive efficiency was considered practical because it is the most easily applied measure for cows which are pasture-mated for a restricted period of time. It had already been determined that calving interval was not a repeatable measure of breeding efficiency in range cattle which were bred in a restricted season if skip-breeders were removed from the data. It was felt that if an appraisal of breeding efficiency could be made, that would by-pass the effect of seasonal breeding, then repeatable differences among cows might be found. The date on which the bull is turned with the cows as well as the date the cow calves are records which would require very little extra record keeping for ranchers. In a herd in which all cows are in the same breeding group, selection for a shorter interval from exposure to calving would be a practical procedure for cattlemen.

The average interval from exposure to calving was 309 days with a standard deviation of 23 days. The average interval for cows which were not regular breeders was two days longer than that for cows which were regular breeders, if the year during which a skip occurred was not included. In this study, only 24 of the 325 cows were irregular breeders. The difference might have been greater or less if there had been more irregular breeders on which to base a comparison.

There were seasonal, breed, line of breeding, and nutritional treatment differences in these data. Generally, a producer will select his cows on the basis of the records made the preceding year. Most producers have only one breed of cattle and one line of breeding within that breed. The cattle of a single herd are usually fed alike and exposed to similar environmental and management factors each year. For these reasons the variance components of these temporary environmental differences were removed in the analysis. The analyses of the variance components are shown in Appendix C for the individual projects. The analyses indicated that there were significant differences among years in three of the four projects. Nutritional treatments also caused significant differences in this interval in one project. This could have been caused by the nutritional differences being confounded with years in the three projects in which treatment differences were not apparent, due to climatic and feeding practice changes. In project 650 the level of nutrition may have been high enough in six of the treatments to cancel the climatic differences; also the feeding practices in this project were held constant. Interactions between years and breeding group and years and nutritional treatment did not appear to be significant in any of the projects. The sex of the calf did not cause any appreciable difference in the length of the interval.

The purpose of determining the repeatability of a measure is to obtain an indication of the progress which can be made by selection. Within a group progress by selection depends on repeatability of the measure, and variability usually expressed as the standard deviation of the measure. If a measure is highly repeatable and the herd is variable, then considerable progress can be made by selecting for the measure. Repeatability is the ratio of the genetic variance plus the permanent environmental variance to the genetic variance plus the permanent environmental variance plus the temporary environmental variance. The permanent environmental variance is due to any factor that is not genetic which remains the same for that cow in every record, while the temporary environmental variance is due to changing environmental conditions, such as climate, nutrition, disease, and any random errors in measurement. The smaller the effect of temporary environment and the more of it which can be removed from the data, the higher will be the repeatability estimate. This fact is emphasized in Table VIII and in the discussion which follows.

The repeatability of the interval from exposure to calving varied from project to project and according to the methods of analysis used for its estimation. The analyses used in computing these estimates are given in Table VII. In table VIII are the estimates of repeatability which vary from -.02 to .65. This variability is caused by the amount of temporary environment which was removed in the analysis, the differences in the data which were used, the method used in computing the estimate, and random errors in measurement.

TABLE VII

ANALYSES OF VARIANCE FOR DAYS FROM EXPOSURE TO CALVING

Pooled From Analyses in Which Temporary Environmental Components Were Present

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Between Cows	321	299,681	934*	525+4.62(89)
Within Cows	1,167	612,439	525	525

The Confidence Interval for "R" at the 95% Prob. level is .11 to .18

Pooled From Analyses in Which Temporary Environmental Components were Removed

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Between Cows	321	300,131	935**	374+4.58(123)
Within Cows	1,049	392,635	374	374

The Confidence Interval for "R" at the 95% Prob. level is .21 to .28

Pooled From Analyses in Which Temporary Environmental Components and The First Record Were Removed

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Between Cows	308	300,005	974**	306+3.53(189)
Within Cows	714	218,779	306	306

The Confidence Interval for "R" at the 95% Prob. level is .33 to .43

TABLE VII (Continued)

Pooled From Errors of Estimate of the Covariance Analyses in Which Temporary Environmental Components and the First Record Were Removed

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Between Cows	308	249,587	810**	298+3.53(145)
Within Cows	710	211,690	298	298

The Confidence Interval for "R" at the 95% Prob. level is .28 to .38

* Probability of chance occurrence less than .05.
** Probability of chance occurrence less than .01.

The repeatability of the interval from exposure to calving, uncorrected for differences among years or treatment, was found to be .14 with 95 per cent confidence intervals of .11 and .18.

The repeatability of this interval was .25 after removing the variance due to years, breeding groups and experimental treatments by an analysis of variance. The removal of these sources of variation increased the repeatability estimates in all projects. The increase was most noticeable in project 650 as was to be expected. The projects were not different in these estimates because their 95 per cent confidence intervals overlapped. These analyses are shown in Appendix C. Adjustment for differences in years accounted for the increased repeatability in all projects except 650, where adjustment for nutritional treatment differences caused the increase. The repeatability of .25 would be more nearly applicable than .14 for a herd in which selection would be based on records made within the same year, breed, and feeding regime. The progress to be expected by selection according to Lush (1945) could be increased approximately 26 per cent by using the average of two records rather than a single record when repeatability is 25 per cent.

TABLE VIII

REPEATABILITY ESTIMATES OF THE INTERVAL FROM EXPOSURE TO CALVING

Method[1]	Proj. 670	Proj. 650	Proj. 526-S	Proj. 526-W	Pooled
(a)	.20	.12	.06	.22	.14
(b)	.25	.30	.10	.27	.25
(c)	.44	.26	.26	.65	.38
(d)	.40	.20	.20	.59	.33
(e)	.36	.01	-.01	-.02	.06
(f)	.14	.26	.19	.54	.28

1 (a) Intra-class correlation uncorrected for temporary environmental variance.
(b) Intra-class correlation corrected for temporary environmental variance.
(c) Intra-class correlation corrected for temporary environmental variance, omitting the first record.
(d) Intra-class correlation corrected for temporary environmental variance, omitting the first record and corrected for days calving to exposure.
(e) Regression of subsequent records on the first record.
(f) Regression of subsequent records on the second record.

By removing the first record of each cow from the analysis, the repeatability estimate was increased from .25 to .38. In three of the projects the cow's first calf was her first record, but this was not true for all cows in project 670. In project 650 the cows calved first at different ages, and this may have caused the reduction in its estimate of repeatability as the cows which calved first at two years of age appeared to be more variable. The increased repeatability of records after the first indicates that the first record of a cow is not as reliable for predicting future performance as is the second record.

With a repeatability of .38 the gain in rate of progress by selection would be only 20 per cent by using the average of two records.

There was a slight reduction in size of the repeatability estimate, from .38 to .33, as a result of the adjustment of the records for the intra-cow regression of days from exposure to calving on the days from previous calving to exposure. This correction was made by covariance analyses shown in Appendix B and the repeatability estimate was calculated from the errors of estimate mean squares as shown in Appendix D and Table VII.

The regression of subsequent records on the first record of the same cow gave rise to an estimate of repeatability of only six per cent. When subsequent records were regressed on the second record, repeatability was increased to 28 per cent. Project 670, in which the first record of a cow was not necessarily her first calf, was the only project in which the estimate of regression did not increase by removal of the first record. The regression of subsequent records on a cow's previous record produces estimates of repeatability comparable to those obtained from intra-class correlations. They both estimate the portion of the difference between two cows at one record which, on the average, may be expected in other records. Differences in years, breeding groups, and experimental treatments were not removed from the regression estimates. This may explain the lower estimates obtained by regression as compared to those from intra-class correlation analysis.

SUMMARY AND CONCLUSIONS

The data from the records of 251 cows with 981 calving intervals indicate that progress would be very slow when selecting for shorter calving intervals in range beef cattle bred during a restricted season. The repeatability estimate for calving interval was negative indicating that the real repeatability is probably close to zero.

The interval from the time a cow was exposed to a bull until she calved the following year was investigated as a measure of reproductive efficiency. This interval averaged 309 days with a standard deviation of 23 days. The environmental components of variance due to season, breeding group, and experimental treatment were removed from the data and their removal increased the repeatability estimates. The regression of the interval from exposure to calving on the interval from previous calving to exposure was calculated, but correction for this regression on an intra-cow basis did not increase the repeatability estimate. The pooled data on 1,492 successful exposures of 325 cows indicated that the repeatability of the interval from exposure to calving is greater than .10 and may be as high as .40.

If selection is based on records made in different years and under different feeding regimes, then a repeatability estimate of .14 may be applicable. In this case progress by selection would be increased 32 per cent by using the average of two records rather than by using a single record.

If selection is based on records made in the same year and under the same feeding regime, the most applicable repeatability would be .25. The progress made by selection could be increased by 26 per cent when using the average of two records rather than selecting from a single record.

If selection is based on records, not including the first calf, which were made in the same year and under similiar feeding regimes, then repeatability may be as high as .38. This indicates that records other than the first are the more reliable estimate of the cow's breeding value. With a repeatability this high the gain in rate of progress to be expected from selection would be only 20 per cent by waiting to get the average of two records.

Selection based upon days from exposure to calving will result in a group of calves which are more uniform in age. This would reduce the length of the calving season which would be desirable as it would reduce labor and increase the value of the calves.

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APPENDIX A

ANALYSES OF VARIANCE FOR CALVING INTERVAL

Analysis of Variance From Project 670

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Total	176	265,874		
Between Cows	60	76,137	1,269	1,636+2.90(-126)
Within Cows	116	189,737	1,636	1,636

The Confidence Interval for "R" at the 95% Prob. level is -.05 to -.22

Analysis of Variance From Project 650

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Total	410	223,476		
Between Cows	93	14,012	151	661+4.37(-117)
Within Cows	317	209,464	661	661

The Confidence Interval for "R" at the 95% Prob. level is -.13 to -.31

APPENDIX A (Continued)

Analysis of Variance From Project 526-S

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Total	237	144,708		
Between Cows	41	29,105	710	590+4.94(24)
Within Cows	196	115,603	590	590

The Confidence Interval for "R" at the 95% Prob. level is -.05 to .13

Analysis of Variance From Project 526-W

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Total	156	124,329		
Between Cows	53	23,325	440	981+2.90(186)
Within Cows	103	101,004	981	981

The Confidence Interval for "R" at the 95% Prob. level is .02 to .30

Analysis of the Variance Components in Project 670

Source	d f	Sum of Squares	Mean Square	F Test	Expected Mean Square
Total	176	265,874			
Between Cows	60	76,137	1,270	.77	1,653+2.9(-132)
Years	3	12,729	4,243	2.57	
Lines	3	4,165	1,388	.84	
L X Y	7	12,448	1,778	1.08	
Within Cows	97	160,395	1,653		1,653

The Confidence Interval for "R" at the 95% Prob. level is -.05 to -.22

APPENDIX A (Continued)

Analysis of the Variance Components in Project 650

Source	d f	Sum of Squares	Mean Square	F Test	Expected Mean Square
Total	410	223,476			
Between Cows	93	14,012	151	.22	679+2.90(-121)
Lots	7	1,471	210	.31	
Years	4	7,720	1,930	2.84	
L X Y	24	8,667	361	.53	
Within Cows	282	191,606	679		679

The Confidence Interval for "R" at the 95% Prob. level is -.13 to -.31

Analysis of the Variance Components in Project 526-S

Source	d f	Sum of Squares	Mean Square	F Test	Expected Mean Square
Total	237	144,708			
Between Cows	41	29,105	710	1.52	468+4.94(49)
Lots	3	45	15	.00	
Years	8	23,802	2,975	6.36	
L X Y	21	14,960	712	1.52	
Within Cows	164	76,796	468		468

The Confidence Interval for "R" at the 95% Prob. level is .00 to .18

APPENDIX A (Continued)

Analysis of the Variance Components in Project 526-W

Source	d f	Sum of Squares	Mean Square	F Test	Expected Mean Square
Total	156	124,329			
Between Cows	53	23,325	440	.42	1,042 2.90(-208)
Lots	5	1,491	298	.29	
Years	2	4,920	2,460	2.36	
L X Y	10	4,985	498	.48	
Within Cows	86	89,608	1,042		1,042

The Confidence Interval for "R" at the 95% Prob. level is -.02 to -.31

APPENDIX B

COVARIANCE ANALYSES FOR DAYS FROM EXPOSURE TO CALVING WITH DAYS FROM CALVING TO EXPOSURE

Analysis of the Covariance in Project 670

Source	d f	Sum x^2	Sum xy	Sum y^2	Mean Square
Total	219	143,932	-34,402	130,348	
Between Cows	91	76,471	-46,442	83,240	310+2.40(252)
Subclass	13	24,509	5,012	11,443	
Within Cows	115	42,952	7,028	35,665	310
B Plus W	206	119,423	-39,414	118,905	

The Confidence Interval for "R"(y) at the 95% Prob. level is .32 to .58

Analysis of the Covariance in Project 650

Source	d f	Sum x^2	Sum xy	Sum y^2	Mean Square
Total	440	182,746	-68,758	189,118	
Between Cows	106	49,529	-74,133	80,634	310+4.12(109)
Subclass	35	24,468	-13,406	15,789	
Within Cows	299	108,749	18,781	92,695	310
B Plus W	405	158,278	-55,352	173,338	

The Confidence Interval for "R"(y) at the 95% Prob. level is .19 to .33

APPENDIX B (Continued)

Analysis of the Covariance in Project 526-S

Source	d f	Sum x^2	Sum xy	Sum y^2	Mean Square(y)
Total	304	107,255	-27,782	144,427	
Between Cows	57	32,475	-27,691	41,487	309+5.20(81)
Subclass	31	26,744	- 9,333	36,205	
Within Cows	216	48,036	9,242	66,735	309
B Plus W	273	80,511	-18,449	108,222	

The Confidence Interval for "R"(y) at the 95% Prob. level is .18 to .34

Analysis of the Covariance in Project 526-W

Source	d f	Sum x^2	Sum xy	Sum y^2	Mean Square(y)
Total	155	99,874	-51,163	136,990	
Between Cows	54	54,712	-50,394	94,635	282+2.77(531)
Subclass	17	5,722	- 6,788	18,671	
Within Cows	84	39,440	6,019	23,684	282
B Plus W	138	94,152	-44,375	118,319	

The Confidence Interval for "R"(y) at the 95% Prob. level is .49 to .81

APPENDIX C

ANALYSES OF VARIANCE FOR DAYS FROM EXPOSURE TO CALVING

Analysis of Variance From Project 670

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Total	350	191,017		
Between Cows	98	81,110	828	436+3.67(107)
Within Cows	252	109,907	436	436

The Confidence Interval for "R" at the 95% Prob. level is .13 to .26

Analysis of Variance From Project 650

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Total	557			
Between Cows	108	104,482	967	565+5.10(79)
Within Cows	449	253,736	565	565

The Confidence Interval for "R" at the 95% Prob. level is .07 to .17

APPENDIX C (Continued)

Analysis of Variance From Project 526-S

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Total	372	186,296		
Between Cows	57	37,298	654	473+6.43(28)
Within Cows	315	148,998	473	473

The Confidence Interval for "R" at the 95% Prob. level is .00 to .12

Analysis of Variance From Project 526-W

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
Total	210	176,589		
Between Cows	58	76,791	1,324	657+3.57(187)
Within Cows	152	99,798	657	657

The Confidence Interval for "R" at the 95% Prob. level is .11 to .33

Analysis of Variance Components From Project 670

Source	d f	Sum of Squares	Mean Square	F Test	Expected Mean Square
Total	350	191,842			
Between Cows	98	81,935	836	2.16	387+3.54(127)
Lines	3	919	306	.79	
Years	4	6,995	1,749	4.52	
L X Y	10	11,092	1,109	2.87	
Within Cows	235	90,903	387		387

The Confidence Interval for "R" at the 95% Prob. level is .17 to .33

APPENDIX C (Continued)

Analysis of Variance Components From Project 650

Source	d f	Sum of Squares	Mean Square	F Test	Expected Mean Square
Total	557	253,736			
Between Cows	108	104,482	967	3.21	301+5.10(131)
Lots	7	12,726	1,818	6.04	
Years	5	6,747	1,349	4.48	
L X Y	31	7,506	242	.80	
Within Cows	406	122,275	301		301

The Confidence Interval for "R" at the 95% Prob. level is .25 to .36

Analysis of Variance Components From Project 526-S

Source	d f	Sum of Squares	Mean Square	F Test	Expected Mean Square
Total	371	178,665			
Between Cows	57	36,923	648	1.71	378+6.41(42)
Lots	3	471	157	.42	
Years	8	28,167	3,521	9.31	
L X Y	24	7,552	315	.83	
Within Cows	279	105,552	378		378

The Confidence Interval for "R" at the 95% Prob. level is .04 to .16

APPENDIX C (Continued)

Analysis of Variance Components From Project 526-W

Source	d f	Sum of Squares	Mean Square	F Test	Expected Mean Square
Total	210	176,589			
Between Cows	58	76,791	1,324	2.31	573+3.57(210)
Lots	5	6,438	1,288	2.25	
Years	3	13,667	4,556	7.95	
L X Y	15	5,788	386	.67	
Within Cows	129	73,905	573		573

The Confidence Interval for "R" at the 95% Prob. level is .16 to .38

APPENDIX D

ANALYSES OF DAYS FROM EXPOSURE TO CALVING CORRECTED FOR ITS COVARIANCE WITH DAYS FROM CALVING TO EXPOSURE

Example Errors of Estimate From A Covariance Analysis

Source	d f	Sum of Squares	Mean Square
B Plus W	$CK_o - 2$	$Tyy - \frac{T^2xy}{Txx}$ or B	$\frac{B}{CK_o-2}$ or B'
Between Cows	$C - 1$	B - A or D	$\frac{D}{C-1}$ or D'
Within Cows	$C(K_o-1) - 1$	$Wyy - \frac{W^2xy}{Wxx}$ or A	$\frac{A}{C(K_o-1)-1}$ or A'

C = number of cows $\qquad$ K_o = weighted average number of calves

$\tau = \frac{Wxx}{Txx}$ or approximately .50 in the following analyses

A' is an unbiased estimate of the variance of measurements within cows.

$D' \left[\frac{C-1}{C-2+\tau}\right]$ is an unbiased estimate of the variance of measurements between cows.

Errors of Estimate From Project 670 Covariance Analysis

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
B Plus W	205	105,897		
Between Cows	91	71,382	784	303+2.4(200)
Within Cows	114	34,515	303	303

The Confidence Interval for "R" at the 95% Prob. level is .26 to .53

APPENDIX D (Continued)

Errors of Estimate From Project 650 Covariance Analysis

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
B Plus W	404	153,981		
Between Cows	106	64,529	609	300+4.12(75)
Within Cows	298	89,452	300	300

The Confidence Interval for "R" at the 95% Prob. level is .13 to .27

Errors of Estimate From Project 526-S Covariance Analysis

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
B Plus W	272	103,994		
Between Cows	57	39,037	685	302+5.2(74)
Within Cows	215	64,957	302	302

The Confidence Interval for "R" at the 95% Prob. level is .12 to .27

Errors of Estimate From Project 526-W Covariance Analysis

Source	d f	Sum of Squares	Mean Square	Expected Mean Square
B Plus W	137	97,405		
Between Cows	54	74,639	1,382	274+2.8(400)
Within Cows	83	22,766	274	274

The Confidence Interval for "R" at the 95% Prob. level is .44 to .75

VITA

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Master of Science

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