A STUDY OF THE REPRODUCTIVE PERFORMANCE

OF A PUREBRED HEREFORD HERD

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PART I

A STUDY OF THE REPRODUCTIVE PERFORMANCE OF A PUREBRED HEREFORD HERD

INTRODUCTION

To be most profitable, a cow should calve at as early an age as practical and at yearly intervals for as long as she can profitably produce. Cows that fail to produce a calf every year cost as much to maintain as those that calve each year. Phillips (1939) estimated that 20 to 50 per cent of all matings in farm animals are infertile even under conditions of good management, nutrition, and sanitation. In a summary of data from sixteen sources, he found that the different sections of the Western beef cattle range area varied in calf crop percentage from 40 to 77 with an average of 63 per cent. The individual ranches ranged from 25 to 95 per cent. Ensminger et al. (1955), in a survey for the American National Cattlemen's Association, reported that in 1954 only 79 per cent of beef cows in the United States dropped live calves, and 30 per cent of the cows culled were taken out of the herd because they failed to wean calves. Johnson (1930), from a survey of the Great Plains area, found an average calf crop percentage of 74 for a three-year period. Individual ranches varied from 53 to 89 per cent.

Reproduction can be affected by many things since it is complicated in its physiology and takes place in several phases. Phillips (1939) listed physiology, nutrition, pathology, anatomical abnormalities, mechanical injury, heredity, or combinations of these as causes of reproductive failure. Evidence indicates that hormonal balance is necessary for normal reproduction. A vitamin A deficiency has been shown to cause reproductive troubles. Several diseases stop or at least hinder reproduction. That heredity is involved is evidenced by the fact that Kab (1937), Koch (1938), and Erb et al. (1940) found a relation between family and reproductive performance of cattle.

Reproductive performance in cattle has been measured in different ways. It has been expressed as per cent calf crop, per cent conception, services per conception, calving interval, interval from calving to first heat, interval from calving to first breeding, and interval from calving to conception. Speilman and Jones (1939) used the following score for reproductive efficiency in dairy cows:

$$\text{Per cent reproductive efficiency} = \frac{\text{100 per cent months}}{\text{reproductive months}}$$

The figure for 100 per cent months was determined by crediting each cow with twelve months for each pregnancy. Reproductive months was the number of months the cow stayed in the herd after breeding age. Buschner et al. (1950) proposed a measure of reproductive efficiency based on age at third calving. Anderson (1951) developed a measure that removed some of the environmental effects in Buschner's method.

To be most effective a measure of reproductive performance must be expressed early enough in the life of a cow to permit selection. None of these measures is available until after breeding age, and most are not available until the cow has had two calves. Also since the first record has not proved to be an accurate measure of reproductive performance, two or more records are necessary for selection purposes. Conley (1956) found that later records were better indicators of a cow's reproductive performance than the first record.

Repeatability is that portion of the variance in cows' records that is due to permanent differences between cows, or it is the correlation between repeated records by the same cow. Temporary environmental effects prevent these records from being the same from year to year. Repeatability sets an upper limit on heritability because it includes all the variance included in heritability plus any permanent environmental effects that cause the cows' records to be the same year after year.

Heritability is the fraction of the total variability of a trait that is due to genic effects. Lush (1948) defines heritability in both a broad and a narrow sense. He defines heritability in the broad sense as:

$$h^2 = \frac{\sigma^2_G + \sigma^2_D + \sigma^2_I}{\sigma^2_G + \sigma^2_D + \sigma^2_I + \sigma^2_E + \sigma^2_{EH}}$$

or in the narrow sense as:

$$h^2 = \frac{\sigma^2_G}{\sigma^2_G + \sigma^2_D + \sigma^2_I + \sigma^2_E + \sigma^2_{EH}}$$

Here, h^2 = heritability

σ^2_G = variance due to additive gene effects

σ^2_D = variance due to dominance effects

σ_I^2 : variance due to epistatic effects

σ_E^2 : variance due to environmental effects

σ_{EH}^2 = variance due to the interaction of heredity and environment

In general the repeatability and heritability estimates of reproductive performance have been very low. Lush (1945) pointed out that this could be due to the natural selection in the evolution of the species over many generations. This could have removed most of the genetic variability associated with reproductive performance. The low estimates could also be due to the large effect of environment on reproductive performance.

The repeatability and heritability of traits should be relatively high for selection to be effective. Low estimates indicate that there is little genetic variability in the trait concerned. Without additive genetic variability selection pressure is powerless to make any permanent change in the trait. Thus, if the estimates are as low as reported, selection for reproductive performance would be expected to be relatively ineffective.

There is little information concerning reproductive performance of beef cattle. The purpose of this study was to investigate further the influence of heredity and other factors on the reproductive performance of beef cattle.

REVIEW OF LITERATURE

Effect of Age of Dam

It has generally been found that farm animals increase in reproductive performance relatively early in life, reach a plateau, and then decline at older ages.

Lasley and Bogart (1943) studied the records of approximately 1,000 head of purebred Hereford cows owned by the San Carlos Apache Tribe at San Carlos, Arizona. They reported that fertility was lowest in heifers two to three years of age. Heifers required 2.4 services per calf and had only a 66.1 per cent calf crop. Fertility was highest in five- and six-year-old cows as shown by 1.36 services per calf and an 86.2 per cent calf crop. In cows over six years of age fertility gradually declined until nine- and ten-year-old cows required 2.09 services per calf and had a 69.2 per cent calf crop. Warren (1948) reported that heifers required 2.04 services per conception in an Oklahoma study involving 443 conceptions in Angus, Hereford, and Shorthorn cows. The most efficient age group was the eight- and nine-year-old cows with 1.31 and 1.09 services per conception, respectively.

Davis (1951) analyzed the records of a Nebraska Holstein herd for the years 1897 to 1950 and found that first-calf heifers and cows over seven years of age were less productive than cows of other ages as measured by number of services per conception, percentage of cows conceiving on two services, and percentage of conceptions for the first five services.

Tanabe and Salisbury (1946) reported in a study of the records on 12,621 services for Holstein cows that yearling heifers required more services per conception than older cows. The peak in reproductive efficiency was reached at about the third gestation. This peak was maintained for a few years, after which reproductive performance declined. Lewis (1950) reported data from 1,860 normal calvings in Michigan. Age had little relation to calving interval until after the ninth calf. The interval lengthened after this. The interval between the first and second calf tended to be longer than later intervals but not significantly so. In a study by Morgan and Davis (1938) involving 2,090 cows, virgin heifers required more services per conception than any other age group, but there was little difference among other ages. Seath *et al*. (1943) found heifers to be more difficult to settle than older cows. Cows over ten years of age also required more services per conception. Bowling *et al*. (1940) studied the records of 706 cows and observed that heifers required more services per conception than other age groups. Oloufa (1955) examined the records of 632 cows and 630 buffaloes in Egypt and reported that heifers required more services per conception than older animals.

Baker and Quesenberry (1944) at the U. S. Range Station, Miles City, Montana, analyzed the records of 412 cows. The highest per cent calf crop was produced by nine-year-old cows and the lowest by four-year-olds. The age differences were not significant and there was no indication of a trend with age. Most shy breeders were disposed of by six years of age, and over half of them had been culled by the time they were four. Hilder *et al*. (1944) noted that after the first gestation, age had little effect on breeding efficiency. Likewise, Carman (1955), in a study of

1,646 lactations in two Iowa Holstein herds, found that the age of cow had little relation to breeding efficiency. Burris and Blunn (1952), Jafar *et al*. (1950), Knapp *et al*. (1940), and Jordao and Assis (1943) found no significant effect of age on the length of gestation. Wheat and Riggs (1952) found that the age of dam had a significant effect on the length of gestation of beef cattle but observed no definite trend. Knott (1932) observed a gradual increase in gestation length in Holstein cows up to six years of age, but after that there was little change.

Lambert *et al*. (1939) reported data on the reproductive history of the U. S. Morgan Horse Farm, Middleborough, Vermont, in which they found that mares declined in fertility after fourteen years of age with a marked decline at nineteen. The most fertile age was from seven to fourteen years. Among 209 mares studied at the Miles City Station, Speelman *et al*. (1943) found that very young and very old mares were less fertile than mares of intermediate ages.

Terrill and Stoehr (1939) studied the breeding records of 7,919 ewes bred over a ten-year period at the Dubois, Idaho, Sheep Station. There was a steady increase in the percentage of ewes lambing, percentage of lambs born, percentage of ewes having mature lambs, and percentage of live lambs born up to five years of age. Selection between the second and third year had no effect on reproduction because few ewes were culled for low fertility until after the third year and the second lambing. There was a slight decline in fertility at six years of age. Selection probably prevented further decline because ewes that showed signs of decline in vigor with age were culled. Terrill (1944) reported a constant though slight increase in gestation length with an increase in age. Eight- and nine-year-old ewes averaged two days longer than two- and three-year-old ewes. Terrill and Hazel (1947) reported that for each year of increase in age the gestation period increased 0.27 day. Goot (1954) found that the age of the ewe accounted for 16 to 72 per cent of the variance in the different measures of fertility in ewes. The largest increase in fertility occurred between the two-tooth and four-tooth ages, with a further increase from the four to the six-tooth age and from the six-tooth to a full mouth. There was a decline in fertility at five and one-half years of age.

From the records of 487 litters of swine Braude (1954) observed no difference in the gestation length of sows and gilts. Gilts farrowed 10.3 pigs, while sows farrowed 12.6 pigs per litter. This was significant at the one per cent level. A significant regression of 0.30 ± 0.1 was found for number of pigs farrowed on litter sequence for the first four litters.

Effect of Age of Sire

In a study of the breeding records of the Oklahoma A. and M. College herds, Warren (1948) observed a general trend of more services per conception with an increase in the age of bull. Bowling et al. (1940) found that the decline in breeding efficiency resulting from age did not become significant until a dairy bull was six years old. Bulls over twelve years of age were much less efficient than six-year-old bulls. The regression coefficients for number of services per conception on age of bull for the first, second, third, fourth, and fifth conceptions were 0.20, 0.05, 0.05, 0.03, and 0.01, respectively. Data reported by Erb et al.(1940) showed wide variation among bulls. Yearling and two-year-old bulls were most efficient. There was a gradual decline with age.

Bishop *et al*. (1954) made a similar observation. Morgan and Davis (1938) observed that young bulls under two years of age were the most efficient, but bulls of other ages were little different. Hilder *et al*. (1944) reported that the number of services per conception in bulls showed a gradual increase to twelve years of age. One-year-old bulls required 2.24 services per conception, while twelve-year-old bulls required 2.82.

Tanabe and Salisbury (1946) found that the effect of age of bull on breeding efficiency yielded a bimodal curve which described two populations of bulls. The first showed that young bulls reached a maximum efficiency at two years and then declined. The second curve represented older bulls entering service without having been culled for fertility. After culling, these bulls gradually declined in fertility with advancing age.

The most efficient combination of bulls and cows according to age has been studied in several groups of data. Warren (1948) noted that the most efficient reproduction occurred when four- to seven-year-old bulls were bred to seven- to ten-year-old cows, and the least efficient performance was obtained from seven- and eight-year-old bulls mated to two- to four-year-old cows. Tanabe and Salisbury (1946) reported that the highest efficiency was obtained when bulls one to three years of age were mated to four- to six-year-old cows. No simple regression of efficiency on age for either bulls or cows was obtainable. Morgan and Davis (1938) reported that two-year-old bulls mated to two-year-old cows required fewer services per conception.

Wiggins *et al*. (1953) observed no correlation between the age of the ram and the percentage of ewes lambing. These same authors (1954) found no trend in fertility with increasing age. Four-year-old rams were highest in fertility followed by two-year olds, yearlings, three-year olds, and then lambs.

Seasonal Effect on Reproductive Performance

The reports of a seasonal effect on reproductive performance vary somewhat with locality. This is shown in Table I. In localities with high summer temperatures and reasonably mild winters the least efficient reproduction occurred in summer and early fall. For example, Nebraska, Indiana, Maryland, and Louisiana data followed this pattern. On the other hand, localities where winters are likely to be severe and summers relatively mild, reproductive efficiency tended to be highest in the summer. Erb and Waldo (1952) observed a similar pattern in Northwestern Washington. Schultze et al.(1948) at Nebraska reported a conception rate of 59 per cent in the spring and only 52 per cent in the summer. Mercier and Salisbury (1947) reported a significant correlation of 0.59 between fertility and the average monthly temperature of the month in which the cows were bred. They also found significant correlations of 0.73 and 0.69 between fertility and the temperature for the first and second months prior to breeding. Significant correlations between day length of the first, second, and third months prior to breeding were 0.60, 0.73, and 0.67, respectively. The correlations between daily hours of sunshine and fertility for the same periods were 0.57, 0.70, and 0.60, respectively, and all were significant. In no case was the correlation for the fourth month prior to breeding significant. The results suggested that longer daylight hours had a beneficial effect on conception rate.

TABLE I

SEASONAL VARIATION IN NUMBER OF SERVICES PER CONCEPTION

Authors	Morgan and Davis	Erb *et al.*	Hilder *et al.*	Clapp	Mercier	Phillips *et al.*
Date	1932	1940	1944	1946	1946	1943
Location	Neb.	Ind.	Md.	N.Y.	Canada	Md.
January	2.08	1.54	2.57	2.18	1.51	1.93
February	2.25	1.69	2.81	2.29	1.67	1.89
March	2.46	1.41	2.80	2.05	1.54	1.80
April	2.16	1.53	2.65	2.03	1.56	1.68
May	2.20	1.35	2.64	1.99	1.66	1.71
June	2.10	1.47	2.36	1.96	1.43	1.72
July	2.07	1.66	2.94	1.90	1.41	2.40
August	2.78	1.72	2.88	2.20	1.43	2.45
September	2.85	1.60	2.82	2.11	1.46	2.38
October	1.99	1.60	2.52	2.13	1.49	1.98
November	2.09	1.57	2.64	2.26	1.50	1.85
December	1.94	1.64	2.52	2.26	1.52	1.82
Average	2.16	1.56	2.67	2.11	1.53	1.94

Warnick (1955) reported a highly significant regression of -0.61 for calving date on the interval from calving to first heat. For each increase of ten days later in the year that a cow calved the interval was 6.1 days shorter. Carman (1955) observed a similar condition in Holstein cows. The cows in two herds that calved in March took sixty-five and eighty-three days to return to heat after calving. Those that calved in September required only forty-five and fifty-seven days.

Terrill (1944) found that ewes bred early in the breeding season tended to have a longer gestation than those bred late. Berliner (1942) observed in mares and jennets that those bred in early spring had longer gestations than those bred after May. Mares bred prior to May had gestation lengths of 340 to 360 days, whereas those bred in June and July had gestations of 320 to 350 days. The relation was similar for jennets except that they had longer gestations.

Braude (1954) reported no seasonal effects on the number of pigs farrowed when the two seasons--November to April and May to October--were considered. As the gilts were slaughtered, Wiggins _et al_. (1950) observed the reproductive organs of gilts farrowed in different seasons. The gilts born in the spring were slower to reach sexual maturity than those born in other seasons. Of gilts born prior to April 2, 57 per cent had not reached puberty when slaughtered, whereas of those born after April 2, 75 per cent had reached puberty although they averaged sixteen days younger.

Other Factors Influencing Reproductive Performance

Probably the most celebrated instance of reproductive inefficiency in beef cattle is that of the Duchess family of Shorthorns. This is evidence that "breeding" can have an effect on reproductive performance. Further evidence is provided by Chambers et al. (1954), who reported that twenty-four large-type Hereford cows produced forty-six calves and weaned forty-two in two years, while twenty-four small-type cows produced forty calves and weaned only twenty in the same period. Gerlaugh et al. (1951), in a cross-breeding study, reported a gestation length for purebred Angus cows of 276.5 days, for purebred Herefords 286.3 days, for Angus cows bred to Hereford bulls 282.0 days, and for Hereford cows bred to Angus bulls 283.3 days. Livesay and Bee (1945) found a significant difference between the gestation lengths of Hereford and Angus (2.7 days longer in Herefords) and a significant 5.4 days shorter gestation for three dairy breeds. Burns et al. (1954) reported that cows of Brahman breeding came into estrus 45.1 days from first exposure to the bull, while cows of the English breeds came into estrus in 12.4 days. At Cairo University in Egypt Oloufa (1955) reported an interval of forty-three days from parturition to first heat for cattle and sixty-seven days for buffaloes.

In sheep Chittenden and Walker (1936) reported a gestation of 150.5 days for Rambouillet ewes bred to Rambouillet rams and 148.6 days for those bred to Hampshire rams. Terrill and Hazel (1947) found that the sire of the lamb influenced the gestation length of ewes. Wiggins et al. (1954) noted that 92.5 per cent of Targhee ewes produced live lambs, while 91.6, 90.6, and 89.9 per cent of Corriedale, Rambouillet, and Columbia ewes produced live lambs.

Yearly differences in reproductive performance are sometimes large. Baker and Quesenberry (1944) reported data covering eighteen years at Miles City in which the per cent calf crop varied from 66.1 to 92.5. Warnick (1955) reported a significant year effect on days from parturition to first estrus in Angus and Hereford cows. Speelman and Dawson (1943) reported a significant effect of the year in which the mare was bred on the fertility level of the mare. Wiggins et al. (1954) found yearly averages in the percentage of ewes lambing to vary from 90.7 to 93.7.

The work of several authors indicates that the interval from calving to first breeding may affect the breeding efficiency of cattle. Trimberger (1954) bred three groups of cows at different intervals after calving. Group 1 was bred within sixty days post partum; Group 2 was bred from sixty to ninety days post partum; and Group 3 was bred over ninety days post partum. The results are shown in Table II.

TABLE II

THE EFFECT OF LENGTH OF INTERVAL FROM PARTURITION TO BREEDING ON FERTILITY

Group	Days	Number of Cows	Days to First Service	Days to Conception	Per Cent Conceived	Services Per Conception
1	Less than 60	50	47.7	87.5	48	2.09
	Less than 50	26	40.9	100.5	31	2.52
	51-60	24	55.2	74.5	67	1.65
2	60-90	50	74.3	93.8	70	1.55
3	Over 90	50	118.8	130.8	76	1.54

The cows bred earliest were the least efficient. Van Demark and Salisbury (1950) found a negative correlation of -0.02 between post partum interval to first service and number of services per conception. A significant correlation of -0.116 was found for those bred during the first eighty days post partum. Maximum fertility resulted when breeding was delayed 100 to 120 days. Conley (1956) found the interval from calving to exposure to the bull to be negatively associated (b = -0.35) with the interval from exposure to calving. From data on 7,071 cows Shannon et al. (1952) recommended that a minimum of fifty days from calving to insemination was necessary for the most satisfactory fertility. Hofstad (1941) studied 309 conceptions in dairy cows that had an average of 94.5 days of sexual rest after calving. Cows bred prior to sixty days post partum had more reproductive troubles than those bred later. The per cent conceptions for the group bred prior to sixty days was 56.7, and that for the group bred after sixty days was 62.3. Lasley and Bogart (1943) observed that an increase in the interval from calving to first heat increased the fertility. Only 48.6 per cent of cows bred ten to forty days after calving conceived with one service, while 75 per cent of the group bred 161 to 190 days after calving conceived on the first service. They recommended seventy to ninety days of rest after calving before rebreeding.

Heritabilities and Repeatabilities of Reproductive Performance

The estimates of heritability and repeatability of the measures of reproductive performance have been generally small and variable. Brown et al. (1954) obtained paternal half-sib estimates of heritability for calving interval in Angus of 0.008 and 0.012 for cows with three and five records, respectively. The heritability estimate from intra-sire daughter-on-dam regression for sixty-four daughter-dam pairs was -0.18. The repeatability estimates were essentially zero for cows with three and five records.

Warnick (1955) found a repeatability of 0.06 for the interval from calving to conception with Angus and Hereford cows. Carman (1955) reported a heritability estimate for the interval from calving to first heat of 0.15, for days from first breeding to conception of 0.08, and for number of services per conception of 0.06 in a Holstein herd. In another Holstein herd the heritabilities from intra-sire regressions of offspring on dam for the same traits were 0.27, 0.02, and 0.06. Repeatability estimates of these traits for the first herd were -0.06, 0.08 and 0.08, respectively, and for the second herd they were -0.03, -0.09, and -0.15, indicating a repeatability of essentially zero. Legates (1954) obtained heritability estimates of 0.026 and slightly negative for number of services per conception and calving interval by an intra-sire regression of daughter on dam for 398 daughter-dam comparisons. Repeatability of calving interval and number of services per conception were estimated to be 0.133 and zero, respectively. Olds and Seath (1950) found the correlation between the number of services required by cows the first year and the second year to be 0.084. Although this value was highly significant, it was too small to be of predictive value. Dunbar and Henderson (1953) estimated the repeatability of non-return rate to first service to be between 0.027 and 0.051. These estimates were computed from the components of variance for half-sisters and for cows in the same herd by different sires, respectively. The heritability of non-return rate was 0.004. Heritability of calving interval was zero. Olds and Seath (1953) estimated the repeatability of the interval from calving to first heat as 0.29. The heritability estimate based on the intra-sire regression of daughter on dam for the first record was 0.27. When all records were used the heritability estimate was 0.32 ($P < 0.05$).

The half-sib method produced a heritability estimate of 0.31. From data on 834 Holstein and Jersey cows Pou et al. (1953) estimated repeatability of number of services per conception, regularity of estrus and days from first breeding to conception at 0.12, 0.18, and 0.11, respectively. Their estimates from regression were 0.07 for number of services per conception, 0.05 for regularity of estrus and 0.07 for days from first service to conception.

In studying the performance of beef cows, Conley (1956) pooled the data from four herds and obtained an estimate for repeatability of calving interval of -0.09. Removing known environmental components of variance did not change the estimate. The repeatability of the interval from exposure to the bull to calving before removing certain environmental variance was 0.14. Removing these effects raised the repeatability to 0.25. He found that the first record of a cow was not as useful as later records in predicting the future performance of a cow. Removing all first records increased the repeatability of interval from exposure to calving from 0.25 to 0.38. Regression of subsequent records on first records yielded a repeatability of 0.06, while the regression on second records yielded one of 0.28.

A comparison of early records with later records and daughter and dam records indicates why heritability and repeatability estimates have been low. Olds and Seath (1950), though they found a highly significant correlation of 0.084 between first and second records for number of services per conception, state that the first record was of little value in predicting future performance. The 4,665 cows that required only one service per conception the first year required 1.44 services the second year. Those that required four services per conception for the first year required only 1.65 for the second. Evidently there was a regression toward the breed average. Pou et al. (1953) compared lifetime dam and daughter records for number of services per conception. The results are shown in Table III. There was little similarity between daughter's and dam's records. They also showed that there had been very little effective selection for breeding efficiency in the Beltsville dairy herd. Jersey dams required an average of 2.62 services per conception and had a mean of 50.1 days from first service to conception, while the daughters of these cows had records of 2.62 and 49.9 for the same traits. Holstein dams required 2.44 services per conception and had an interval from first service to conception of 48.4 days. Their daughters' records were 2.48 and 51.5 for the same traits. Dunbar and Henderson (1953) found that the mean calving intervals for daughters of different sires ranged from 11.0 to 17.3 months. Trimberger and Davis (1945) were unable to predict from the number of services per conception required by virgin heifers either their future performance or the performance of their daughters. Heifers that required one, two, three, four, and five services for the first conception needed 1.66, 1.63, 1.88, 1.79, and 1.60 services for the second conception, respectively. Dams that had a lifetime average number of services per conception of 1.08, 1.61, 2.18, and 3.23 produced daughters that required 1.72, 1.55, 1.91, and 1.33 services per conception, respectively.

Legates (1954) found that dams with a calving interval of 413 days and 1.88 services per conception had daughters whose records were 409 and 1.75, respectively.

In a study of a herd of purebred Herefords, Lasley and Bogart (1943) selected eighty cows that had good breeding records and forty cows that had been poor breeders. The records for the next two years are given in Table IV. Of the good breeders zero per cent were dry in both 1940 and 1941, 29 per cent were dry one of the two years, and 71 per cent produced a calf both years. The same figures for the poor breeders were 25 per cent, 30 per cent, and 45 per cent, respectively.

TABLE III

DAUGHTER-DAM LIFETIME COMPARISONS OF MEAN NUMBER OF SERVICES PER CONCEPTION

Lifetime Mean Number of Services Required by Dams	Lifetime Mean Number of Services Required by Daughters	Number of Daughters
1.00 - 1.50	2.41	152
1.51 - 2.00	2.56	156
2.01 - 2.50	2.57	188
2.51 - 3.50	2.61	203
3.51 - 4.50	2.95	87
Over 4.50	3.11	48

TABLE IV

BREEDING RECORDS OF COWS PREVIOUSLY CLASSIFIED AS HAVING GOOD OR POOR RECORDS

	1940		1941	
1939 Breeding Records	% Calf Crop	S/C	% Calf Crop	S/C
Cows with good record	73.8	1.58	88.8	1.27
Cows with poor record	67.0	2.77	57.9	3.32

Spielman and Jones (1939) used the previously mentioned formula to determine the breeding efficiency of dairy cows. They obtained a correlation of 0.546 ± 0.118 between reproductive efficiency of foundation cows and the mean efficiency of their daughters. The seventeen cow groups ranged in efficiency from 54.5 to 87.2. Jones et al. (1941) also found a high correlation between the records of dams and daughters.

The literature on family variance is conflicting. Erb et al. (1940) analyzed the records of the prominent cow families in the Purdue dairy herd and reported that some families had a higher breeding efficiency than others. Kab (1937) examined the records of Yellow Franconian cattle. Among forty-six families that were studied for several generations thirty-five had high fertility and eleven had low fertility. Koch (1938), in a study of Spotted Cattle of Baden, observed thirteen families with poor breeding records in which thirty-four of fifty-two cows culled were culled for breeding performance, whereas, in fifteen families with good breeding records, only one of seventy-two was culled because of breeding performance.

On the other hand, Tabler et al. (1951) reported data from nineteen Ayrshire cow families that indicated no important family differences in reproductive performance. Variability among families accounted for only a small part of the total variation and was actually negative for some measures. This indicated that there was little familial tendency in breeding efficiency. They considered the genetic variance between families to be too small for family selection to be effective. Chance and Mather (1949) studied the records of eighty-nine families and found significance among families in only one herd.

Terrill and Hazel (1947) found the paternal and maternal half-sib estimates of heritability for gestation length in ewes to be 0.11 and 0.18.

Measures of Reproductive Performance

Calving Interval

Calving interval determines to a large extent how profitable a cow herd will be. Gaines and Palfrey (1931) reported a calving interval of 401 days for 186 cows of four dairy breeds. Conley (1956) found a calving interval of 364 days for 325 Angus and Hereford cows from three different stations. This was after skip breeders were removed. Legates (1954) reported data on 1,129 cows of four dairy breeds with a calving interval of 406 days. Brown _et al_. (1954) found that Angus cows with three records had a calving interval of 14.4 months. Those with five records had intervals of 13.6 months.

Calving to First Heat

The interval from calving to first breeding is important because of its relation to calving interval. Lasley and Bogart (1943) observed 711 Hereford cows and found an interval of 80.2 days with a range of 10 to 200 days and a coefficient of variation of 43.1 per cent. Warnick (1955), from a three-year study of Hereford and Angus cows, found that the Angus returned to heat in 59.2 days while the Herefords returned in 62.7 days. Carman (1955) reported intervals of 55.4 ± 1.1 and 71.0 ± 1.8 days for two Holstein herds. Chapman and Casida (1934) found the interval for a dairy herd to be sixty-nine days, with a standard deviation of thirty-nine days. Clapp (1937) studied the effect of frequency of milking on return to heat. Cows milked twice daily returned to heat in 46.4 days, while those milked four times a day returned in 69.4 days. Cows used as nurse cows required 71.8 days to return to heat. Casida and Venske (1936) and Olds and Seath (1953) reported intervals of 32.1 days and 40.7 days, respectively. Oloufa (1955) found a difference between cattle and buffaloes in Egypt. The cattle returned to heat in forty-three days, while the buffaloes required sixty-seven days.

Number of Services Per Conception

Where bulls are being used on as many cows as possible, settling cows with as few services per conception as possible becomes even more important. Reported averages have varied considerably. Carman (1955) found an average of 1.8 services per conception for one Holstein herd in Iowa and 1.7 for another. For Holstein cows Tanabe and Salisbury (1946) reported 2.07 services per conception from 12,621 services. Hilder et al. (1944) found a very inefficient 2.67 for the Beltsville dairy herd. Legates (1954) observed 1.80 services per conception for 1,129 cows of four dairy breeds. Van Demark and Salisbury (1950) reported 1.97 services per conception for a twenty-eight year period involving 1,674 pregnancies and 593 cows. Davis (1951) found a Nebraska Holstein herd to require 2.51 services per conception. Covering a period from 1896 to 1934, Morgan and Davis (1938) reported 2.21 services per conception for Holsteins, Jerseys, Ayrshires, and Milking Shorthorns in Nebraska.

Conception Rate

The percentage of conceptions and the number of services per conception are closely related since the percentage of cows conceiving will determine the number of services required for each conception. Erb et al. (1950) and Erb and Waldo (1952) reported a 63.0 and a 57.9 per cent conception rate in two studies of dairy cows in the state of Washington. These studies involved 23,938 and 93,113 services, respectively. Seath et al. (1943), in a Louisiana study with Jerseys and Holsteins, observed a conception percentage of 63.3. Schultze et al. (1948) reported data on 25,146 services, of which 57.1 percent were successful.

Some conception rates with sheep are as follows: Wiggins et al. (1953), 90.43; Blunn (1943), 88.5; and Terrill and Stoehr (1939), 86.0. These reports involved 31,473, 1,839, and 7,919 ewes, respectively. Wiggins et al. (1954) obtained a lambing percentage of 92.5, 91.6, 90.6, and 89.9 for Targhee, Corriedale, Rambouillet, and Columbia ewes, respectively. Berliner et al. (1938) reported 84.2 per cent conception in mares and 80 per cent in jennets. Speelman and Dawson (1943) found a conception rate of 59.6 per cent for mares.

Gestation Length

Many data are available that give the average gestation length for livestock. Some of these data on cattle are presented in Table V. Several things apparently have an effect on gestation length. Knott (1932) observed that twins were carried 4.4 days less than singles in Holstein cows. The data in Table V show that breed and type have some effect on gestation length. Livesay and Bee (1945) reported a significant difference between gestation lengths in Angus and Herefords and between beef and dairy cattle. Season also apparently influences gestation length. Knapp et al. (1940) observed shorter, though not significant, gestations in cows bred in summer. Sex has consistently been observed to be associated with a difference in gestation length, with heifer calves having a shorter gestation length than bull calves. Jafar et al. (1950) found a significant regression of gestation length on calving sequence.

Other measures of reproductive performance have been used. Carman (1955) used days from first breeding to conception. For two herds the averages were twenty-eight and forty-two days. Conley (1956) found that the period from exposure to the bull to calving was 309 days, with a standard deviation of twenty-three days for Angus and Hereford cows.

TABLE V

GESTATION LENGTH

Author	Number of Gestations	Gestation Length	Breed
Burris and Blunn (1952)	184	281.7	Angus
	188	286.1	Hereford
	130	284.2	Shorthorn
Wheat and Riggs (1952)	229	285.2	Hereford
	195	279.5	Angus
	63	281.3	Shorthorn
	44	286.3	1/2 Hereford 1/2 Brahma
	20	285.7	3/4 Hereford 1/4 Brahma
Gerlaugh _et al_. (1951)	101	276.5	Angus
	100	286.3	Hereford
	94	282.0	Angus cows bred to Hereford bulls
	102	283.3	Hereford cows bred to Angus bulls
Dawson _et al_. (1947)	307	281.2	Shorthorn
Knapp _et al_. (1940)	164	280.8	Shorthorn
	133	281.7	Milking Shorthorn
Warren (1948)	137	284.4	Angus
	160	286.1	Hereford
	105	282.0	Shorthorn
Livesay and Bee (1945)	173	282.5	Angus
	174	285.2	Hereford
	265	277.9	Jersey
	580	277.8	Ayrshire
	415	278.3	Holstein
Fitch and McGilliard (1924)	100	284.3	Jersey
	103	283.0	Guernsey
	113	284.6	Ayrshire
	78	282.2	Holstein

MATERIALS AND METHODS

The data reported in this study were taken from the breeding records of the Turner Hereford Ranch for the period from 1935 through 1952. There were 848 cows with 3,606 gestations involved in the study. A total of 123 bulls sired calves in the herd during this period. The herd bulls were kept in individual pastures surrounded by cow pastures to assure adequate exercise for the bulls. Young bulls being tested were kept in the show barn. The cow herd was kept in excellent condition, typical of a good purebred herd.

The herd was relatively free of disease during the sixteen-year period. No vibriosis or trichomoniasis has ever been diagnosed on the ranch. There were some cases of granular vaginitis. During the early history of the herd, the test-and-slaughter method was used for brucellosis control. A total of thirty reactor cows were slaughtered. Since that time few cases have been diagnosed in the herd. A full-time veterinarian has been on the ranch since 1946.

The cows were hand mated, with the exception of a few pasture matings, from 1935 to 1946. After 1946 the breeding was entirely artificial. The cows were checked for heat twice daily. Any cows in heat were brought to the bulls to be bred or to a central corral to be inseminated and returned to pasture. The breeding data were recorded on cards for each cow.

To remove seasonal and yearly variation, the data were adjusted to the average for the summer season of 1939. This season and year were selected because fewer adjustments of the data would be required.

The date of breeding was used as the base for determining age of cow, season, and year. The data were punched on IBM cards for ease of tabulation. The statistical methods used were those described by Snedecor (1946). The repeatability estimates were determined by an intra-class correlation from the components of variance. The heritability estimates were determined by the half-sib method and by the daughter-dam regression method.

RESULTS AND DISCUSSION

Yearly and Seasonal Effects

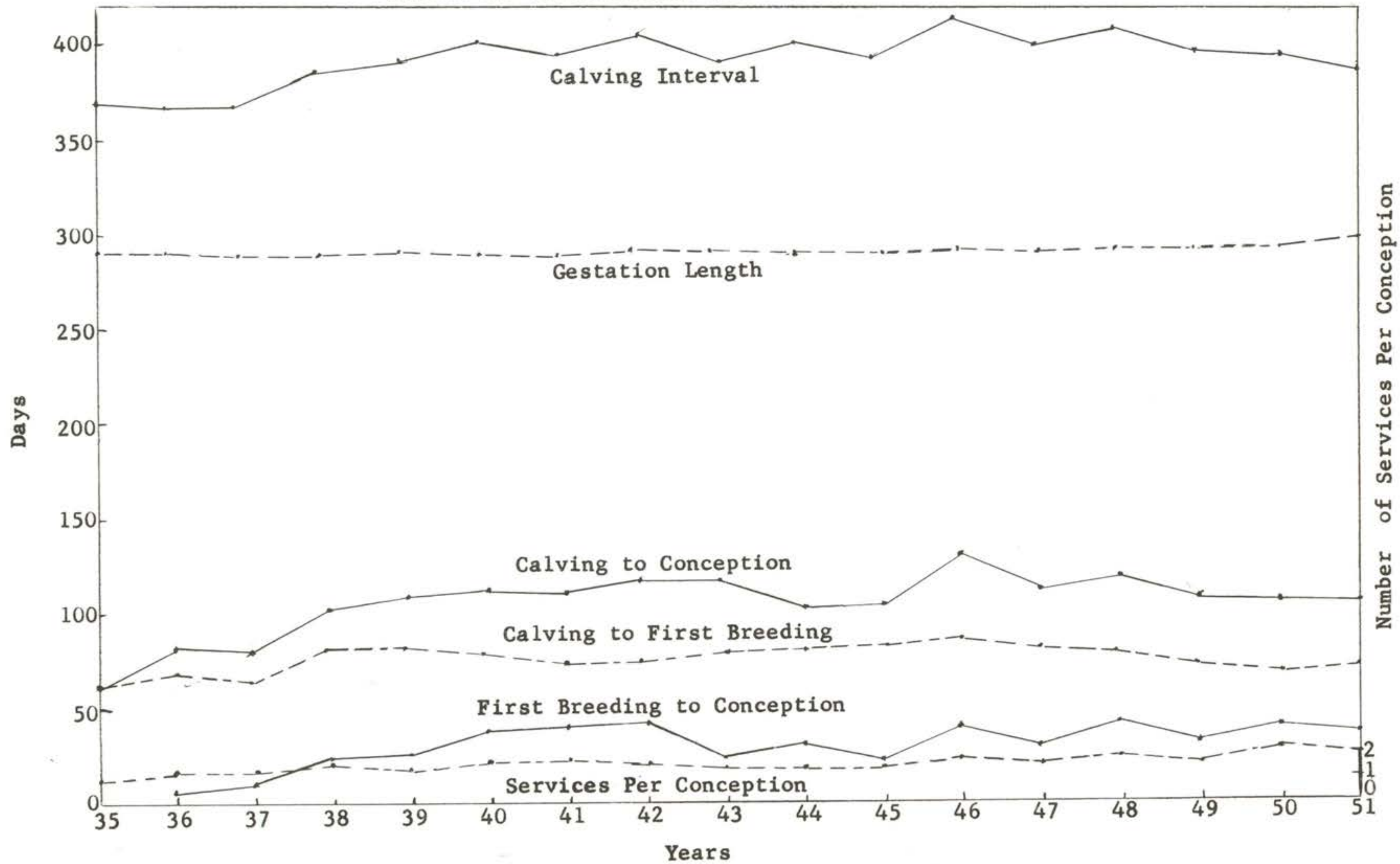
The yearly averages of reproductive performance are shown in Table VI and presented graphically in Figure 1. The averages were adjusted for yearly and seasonal effect. As is evident from this table and figure, reproductive performance gradually declined during the period covered by this study. The year 1935 involved only a few cows and may not be a true estimate of the reproductive performance. When the year 1936 is used as a starting date, the reproductive performance showed a gradual decline. The cows bred in 1951 required an average of 0.6 more services per conception than the cows bred in 1936. The average number of services per conception (1.7) for the sixteen-year period was 0.3 higher than that for 1936. The interval from calving to first breeding changed very little. The cows in 1936 were bred 3.6 days earlier after calving than those in 1951 and 6.6 days earlier than the sixteen-year average (75.5). The corresponding increases in the interval from first breeding to conception were 29.8 days and 24.9 days. The same increases in the interval from calving to conception were 22.9 and 26.2 days, while the calving interval increased twenty-one days from 1936 to 1951 and was 28.3 days above the sixteen-year average (394.2). The sixteen-year average for the interval from first breeding to conception was 31.0 days, and for the interval from calving to conception the sixteen-year average was 108.2 days. No explanation is offered for these increases unless selection pressure was applied to other traits and relaxed

TABLE VI

YEARLY AVERAGES OF REPRODUCTIVE PERFORMANCE

Year	Services		Intervals Calving to Conception		Gestation Lengths		Calving Intervals		Intervals Calving to First Breeding		Intervals First Breeding to Conception	
	No.	S/C	No.	Days	No.	Days	No.	Days	No.	Days	No.	Days
1935	10	1.0	12	62.8	55	289.4	12	368.6	9	62.2	9	0.0
1936	87	1.4	127	82.0	163	284.5	130	365.9	113	68.9	113	6.1
1937	135	1.5	140	79.5	193	285.8	140	364.6	124	64.9	125	8.8
1938	136	1.6	132	101.2	158	285.0	132	387.1	127	79.0	127	18.1
1939	137	1.5	127	106.1	163	286.4	127	392.1	125	79.6	125	24.1
1940	168	1.7	141	112.0	174	285.9	136	401.1	139	73.5	139	37.5
1941	205	1.8	156	109.5	222	283.6	156	395.8	154	69.8	154	39.2
1942	247	1.7	216	115.0	249	286.9	212	404.4	215	72.8	215	42.3
1943	235	1.5	215	115.0	241	286.4	207	386.4	210	77.0	210	20.7
1944	231	1.5	217	101.2	255	286.5	214	398.8	213	78.8	213	31.7
1945	211	1.4	204	104.1	269	284.7	205	392.8	196	80.9	196	18.5
1946	290	1.9	255	132.0	290	287.9	249	416.2	250	85.7	251	41.9
1947	234	1.7	188	112.4	233	283.1	186	397.1	187	80.5	187	31.7
1948	264	1.9	214	121.8	273	285.2	212	407.8	213	77.0	213	42.8
1949	228	1.8	189	106.9	247	284.3	189	392.7	188	74.0	188	33.1
1950	263	2.1	222	105.4	259	285.9	219	391.5	221	66.4	221	38.4
1951	168	2.0	168	104.9	161	288.4	161	386.9	168	72.5	168	35.9
Total	3249		2923		3605		2887		2852		2854	
Ave.		1.7		108.2		285.7		394.2		75.5		31.0

FIGURE 1. REPRODUCTIVE PERFORMANCE BY YEARS



on reproductive performance during this period. There is evidence from Figure 1 that these intervals tended to decrease during the last few years. This may indicate that selection pressure was again being focused on reproductive performance. Analysis of variance indicated that these yearly differences were significant only for the number of services per conception. Gestation length did not change during this period.

The seasonal averages for these measures of reproductive performance are given in Table VII and presented graphically in Figure 2. In general, the reproductive performance was higher in cows bred in summer and fall than in those bred in spring and winter. Approximately 0.15 less service per conception was required in summer and fall than in spring and winter. The interval from first breeding to conception averaged 13.2 days less in summer and fall than in the other two seasons. Possibly the cows' reproductive tracts involuted more quickly during these two seasons. The improved nutrition during the pasture season may explain this decrease in conception time, or cattle may have a tendency to be seasonal breeders. Cows bred in summer and fall also had shorter calving intervals and shorter intervals from calving to conception. These two intervals were shorter by approximately 7.0 and 6.6 days, respectively. The analysis of variance indicated seasonal differences in only the intervals from calving to first breeding and from first breeding to conception. However, season-within-year differences were significant for all traits except gestation length. The interval from calving to first breeding increased during the summer and fall as compared to the other two seasons. This increase was approximately 5.4 days. This may account for some of the decrease in the interval from first breeding to conception and the number of services per conception. Trimberger (1954),

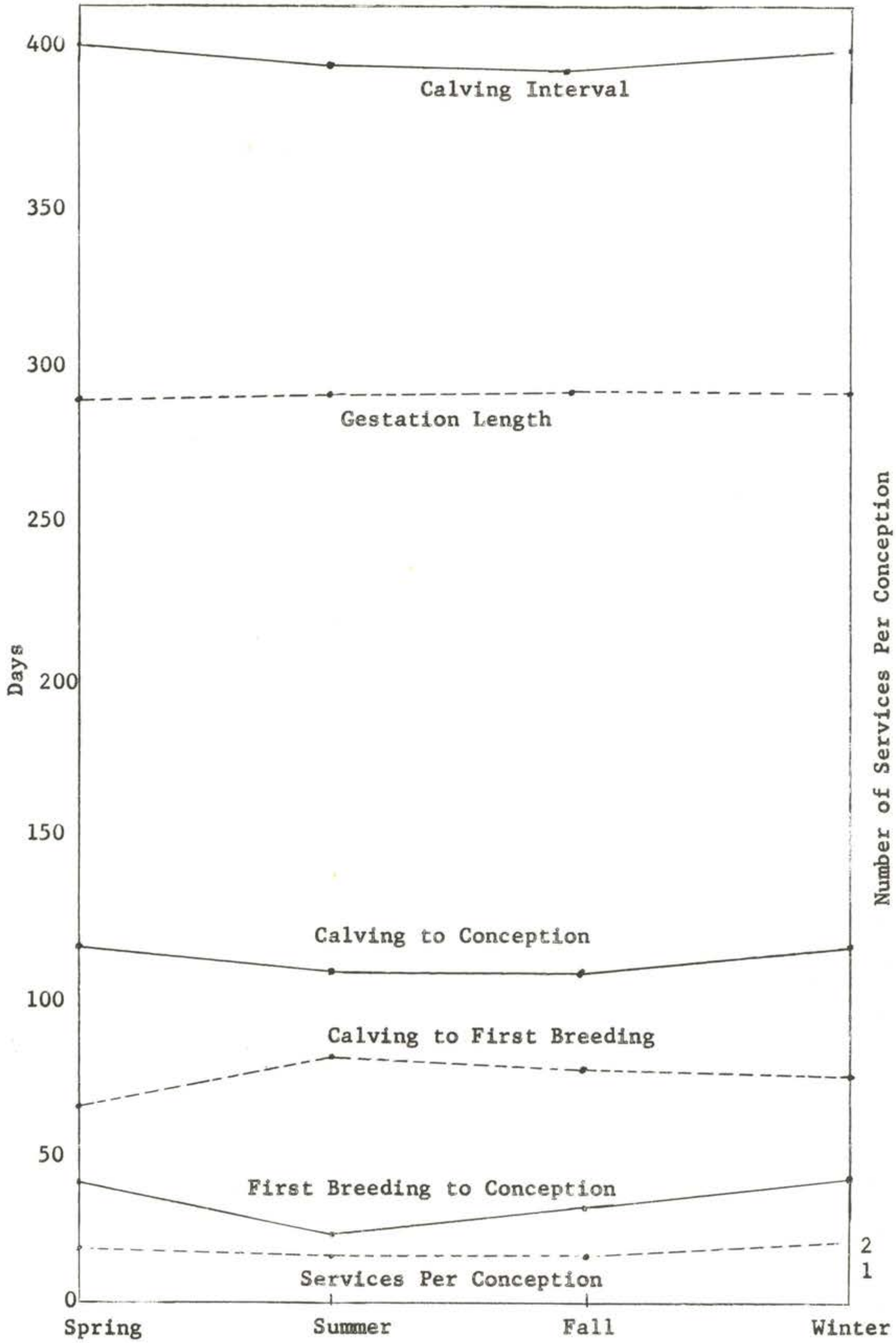
TABLE VII

SEASONAL AVERAGES OF REPRODUCTIVE PERFORMANCE

Season	Services	Intervals Calving to Conception (days)	Gestation Length (days)	Calving Intervals (days)	Intervals Calving to First Breeding (days)	Intervals First Breeding to Conception (days)
Spring						
Number	619	504	641	498	494	494
Average	1.8 S/C[1]	112.3	286.0	399.5	72.6	38.7
Summer						
Number	1177	1174	1392	1165	1137	1139
Average	1.6 S/C	105.4	285.8	391.9	79.4	23.5
Fall						
Number	646	580	719	569	566	566
Average	1.7 S/C	105.7	285.5	390.5	74.4	30.1
Winter						
Number	807	665	854	655	655	655
Average	1.8 S/C	112.0	285.5	397.4	72.0	39.1
Total						
Number	3249	2923	3606	2887	2852	2854
Average	1.7 S/C	108.2	285.7	394.2	75.5	31.0

[1] S/C = services per conception

FIGURE 2. REPRODUCTIVE PERFORMANCE BY SEASONS



Van Demark and Salisbury (1950), Conley (1956), Shannon *et al*. (1952), Hofstad (1941), and Lasley and Bogart (1943) found that an increase in this interval improved breeding efficiency. The season of breeding had no significant effect on gestation length.

The improved reproductive performance in summer and fall is contrary to some reports from localities where the summer temperatures are likely to be high, as is true in Oklahoma. Erb *et al*. (1940), Hilder *et al*. (1944), Phillips *et al*. (1943), and Seath *et al*. (1943) observed an increase in the number of services per conception during summer and fall. The average monthly temperature and the monthly rainfall for the period from 1934 to 1952 are given in Appendix A. Correlations between these values and the number of services per conception were near zero, indicating no relation to temperature and rainfall. Correlations between the previous season's temperature and rainfall also indicated no relationship. Mercier and Salisbury (1947) found high positive correlations between temperature and fertility. However, this was in New York, where summer temperatures are comparatively mild and winters are likely to be severe.

Effect of Age of Cow

The average reproductive performance of cows of different ages is given in Table VIII and in Figures 3 and 4. The correlations between the age of the cow and reproductive performance and regressions of reproductive performance on age of cow are shown in Table IX. All these correlations and regressions are positive and significant, indicating that, as cows become older, these intervals and the number of services per conception increase, or that reproductive performance declines.

FIGURE 3. NUMBER OF SERVICES PER CONCEPTION BY AGE OF COW

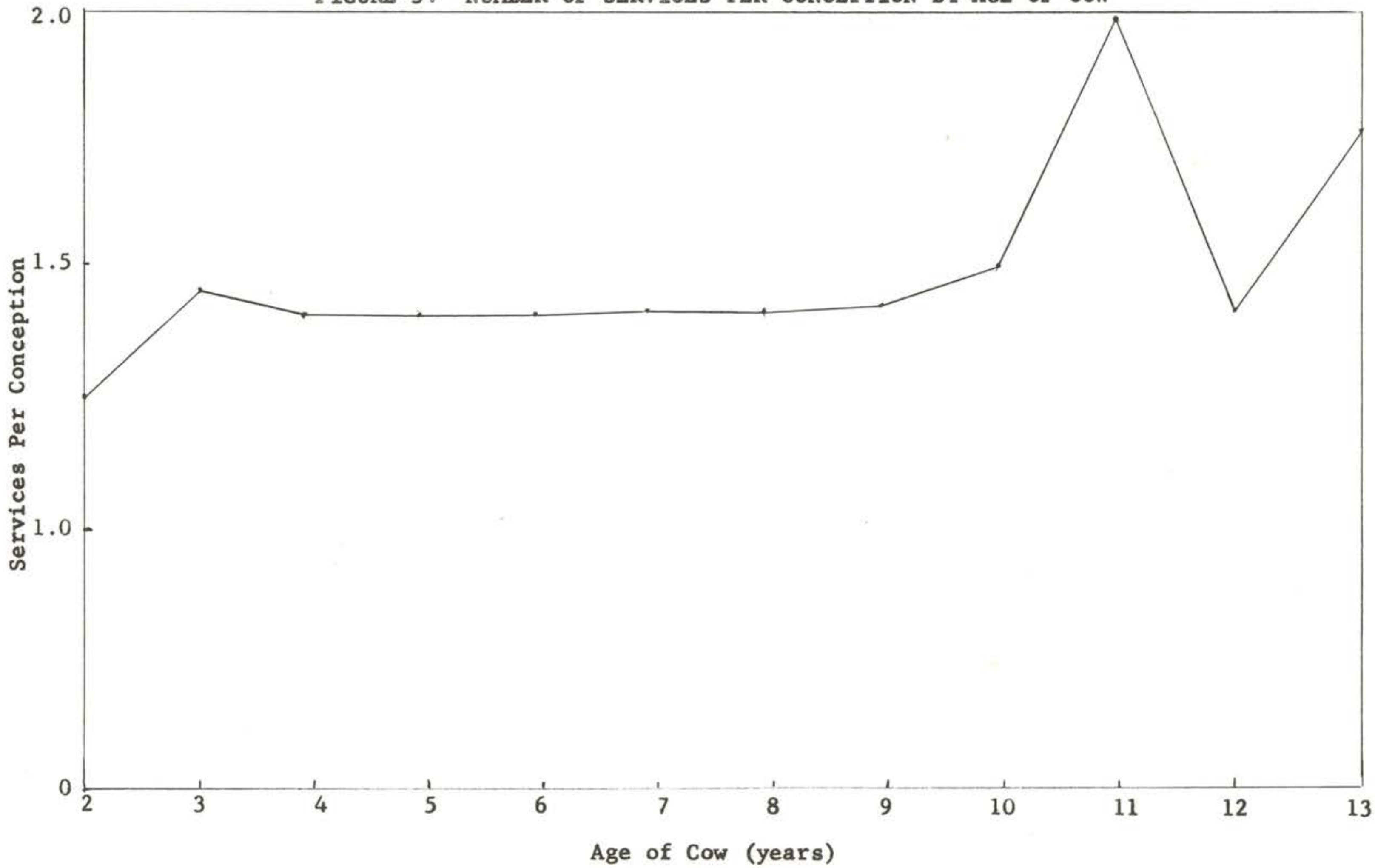


FIGURE 4. REPRODUCTIVE PERFORMANCE BY AGE OF COW

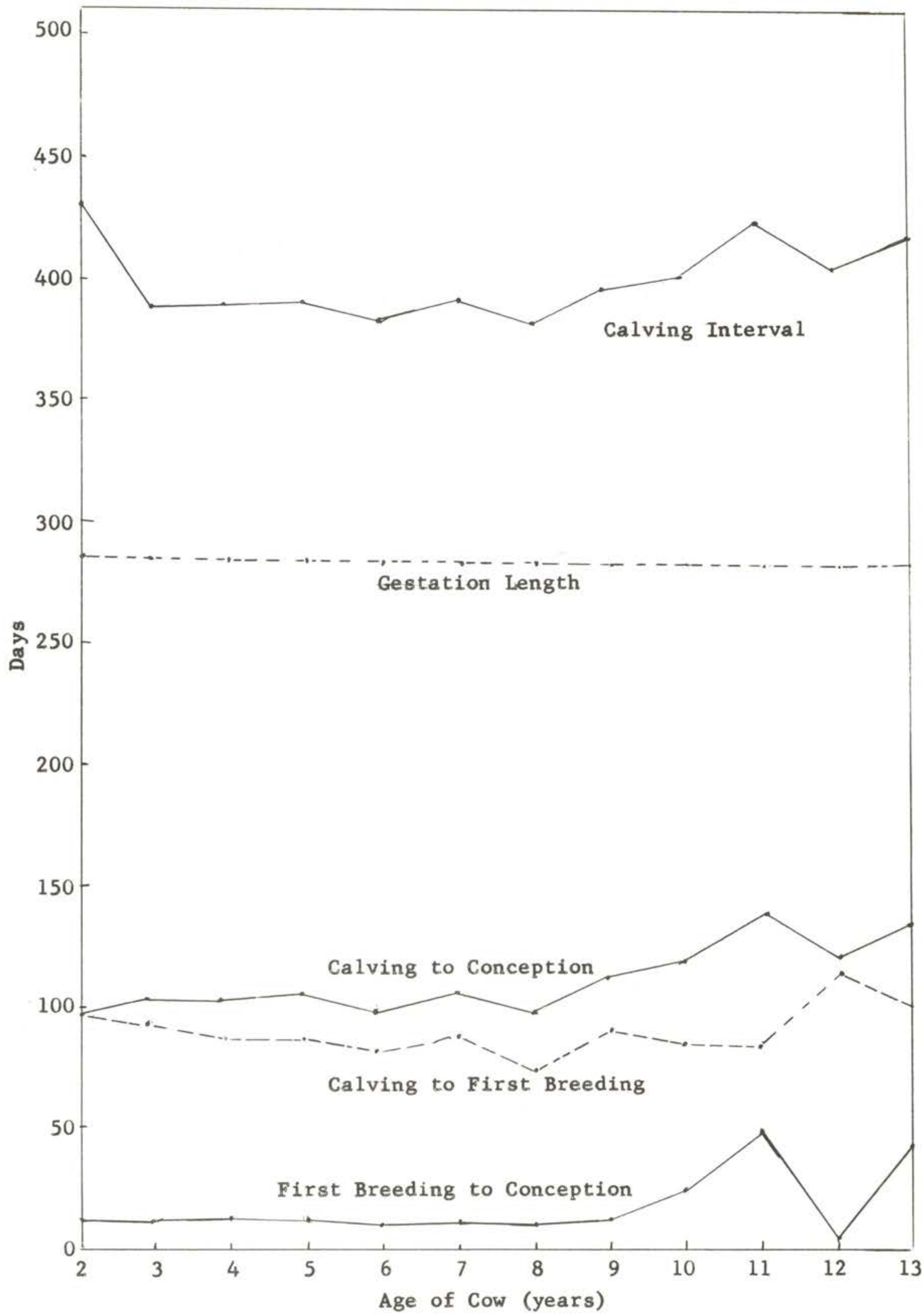


TABLE VIII

REPRODUCTIVE PERFORMANCE BY AGE OF COW

Age of Cow (years)	Number of Services Per Conception	Interval Calving to Conception (days)	Gestation Length (days)	Calving Interval (days)	Interval Calving to First Breeding (days)	Interval First Breeding to Conception (days)
2	1.27	97.2	285.3	431.7	95.1	13.7
3	1.45	102.7	286.4	388.4	88.0	13.1
4	1.35	101.6	286.3	388.6	83.9	14.9
5	1.34	104.3	286.5	390.9	84.8	13.7
6	1.33	96.2	286.6	382.2	81.3	11.3
7	1.34	103.0	286.7	389.6	88.6	13.4
8	1.35	94.5	287.0	380.6	78.7	12.8
9	1.37	108.8	286.2	394.3	92.6	14.3
10	1.47	114.5	287.1	399.1	86.5	24.0
11	1.98	133.4	287.1	420.5	85.9	45.2
12	1.35	116.0	286.8	402.3	110.7	2.9
13	1.72	128.3	288.6	415.1	91.7	40.0

This tendency is evident in Figures 3 and 4. However, when tested for deviations from linearity, all the regressions, except that for gestation length on age of cow, showed significant deviations from linearity, indicating that the relationship was curvilinear. The multiple-range test indicated that young cows and old cows were significantly different from cows of intermediate ages in length of calving interval. This is also evident from Figure 4. The multiple-range test indicated that old cows had significantly longer intervals from calving to first breeding and from first breeding to conception. These differences would cause the curvilinearity observed. No differences were indicated by the multiple-range test between ages in number of services per conception. However, the older cows again tended to require more services per conception. The large variations in reproductive traits at older ages might tend to mask differences. It is evident from Figures 3 and 4 that the older cows performed erratically. This probably was due to the culling being done. Large increases in the number of services per conception or the intervals studied were followed by sharp decreases because the poor producers were culled. This was also evident from the decline in numbers of cows at the older ages. Analysis of variance indicated significant differences among ages in all these traits.

It has generally been observed that cows improve in reproductive efficiency early in life, reach a plateau for a few years and then gradually decline (Lasley and Bogart, 1943; Davis, 1941; and Tanabe and Salisbury, 1946). In this study reproductive performance declined with the age of the cow, with cows over ten years of age declining more rapidly. This was similar to the findings reported by Lewis (1950).

TABLE IX

CORRELATIONS AND REGRESSIONS OF REPRODUCTIVE PERFORMANCE ON AGE OF COW IN HALF YEARS

Measure	r	95% Confidence Limits	b	95% Confidence Limits
Number of Services Per	0.64**	0.32	0.02**	-0.10
Conception		0.83		0.14
Gestation Length	0.64**	0.35		0.06
		0.82	0.12**	0.18
Calving Interval	0.47*	0.08	1.59*	0.22
		0.74		2.96
Interval Calving to	0.46*	0.11	0.66*	0.10
First Breeding		0.71		1.22
Interval First Breeding	0.43*	0.07	0.99*	0.06
to Conception		0.70		1.92
Interval Calving to	0.65**	0.37	2.05**	0.97
Conception		0.82		3.13

* $(P < .05)$
** $(P < .01)$

Average Age of Cows at Disposal

The reproductive life of a cow is economically important to the beef producer. A long reproductive life for cows enables the breeder to make fewer replacements and thus have more younger breeding animals to market, and it also permits greater selection pressure. The average age of the 530 cows that were removed from the Turner herd for various reasons was 7.8 years as shown in Table X. This means that these cows had a productive life of approximately five years.

TABLE X

AVERAGE AGE OF COWS AT THE TIME OF DISPOSAL AND AVERAGE NUMBER OF CALVES PRODUCED PER COW

Reason for Disposal	Number of Cows	Average Age (years)	Average Number of Calves
Died	54	6.8	
Brucellosis	30	4.9	
Marketed	345	9.2	
Breeding Female	92	4.6	
Miscellaneous	9	4.2	
Total	530	7.8	
All Cows	775		4.6

Of particular interest is the group "marketed". This includes those cows, mostly old cows, that failed to produce a calf after a reasonable number of services and those cows that were considered not to be producing desirable calves. This group averaged 9.2 years of age when removed from the herd and thus had a productive life of about 7.5 years. Included in Table X are 775 cows on which records were available. This group included cows that had been removed from the herd and those that were still in the herd at the time these data were taken. It includes all ages of cows. These 775 cows had produced an average of 4.6 calves. Cows that had reached a possible age of nine years (the average age of the marketed group) had produced an average of 5.6 calves.

The analysis of variance showed no sire or sex effect on gestation length. The average gestation length by sire and sex of calf is shown in Table XI. The gestation length for bull calves averaged 287.2 days as compared to 286.0 days for heifers. It has generally been observed that bull calves are carried longer than heifers. Gerlaugh et al. (1951) observed that the gestation length of calves was influenced by the genotype of the calf.

TABLE XI

GESTATION LENGTH BY SIRE AND SEX OF CALF

Sire Code	Number of Calves	Gestation Length (days)
63[1]	52	284.2
69	133	287.8
84	75	285.2
85	191	286.4
93	32	285.1
111	316	287.8
118	482	286.0
133	184	286.9
139	87	288.5
140	34	288.1
142	36	285.8
143	60	287.4
159	97	290.2
163	58	285.1
164	156	289.8
169	50	285.5
170	55	284.5
171	380	284.5
185	377	286.6
213	38	289.5
240	62	283.9
248	31	291.3
Heifer Calves	1931	286.0
Bull Calves	1611	287.2

[1] Only those bulls that sired 30 or more calves are included.

There were twenty-seven cows during the sixteen-year period that failed to produce a calf from an average of 8.8 services. These were classified as barren cows and sold. This group included 3.2 per cent of the cows.

Repeatability and Heritability of Reproductive Performance

The repeatability and heritability estimates of reproductive performance are shown in Table XII.

TABLE XII

REPEATABILITIES AND HERITABILITIES OF REPRODUCTIVE PERFORMANCE

	Repeatability	Heritability		
		p	r	b
Number of Services Per Conception	0.07	0.05	-0.18	-0.24 (356)[1]
Gestation Length	0.15	-0.05	0.04	0.24 (364)
Calving Interval	0.06	0.07	0.14	0.14 (309)
Interval Calving to First Breeding	0.03	0.02	0.22	0.30 (308)
Interval First Breeding to Conception	0.06	0.04	0.01	0.01 (308)
Interval Calving to Conception	0.07	0.04	0.12	0.14 (313)

p Estimated from paternal half-sib correlation.
r Estimated from correlation of daughter-dam records.
b Estimated from regression of daughter on dam records.
[1] Numbers in parentheses indicate the number of daughter-dam pairs.

The repeatability estimates were determined by the intra-class correlation from the components of variance in Appendix D. The paternal half-sib heritability estimates were determined by the intra-class correlation from the components of variance in Appendix E. The average performance of dams and daughters is shown in Table XIII. The performance of daughters of various bulls is given in Table XIV. All estimates were generally low. Repeatability estimates as low as these indicate that culling cows on the basis of early records for reproductive performance would be of little value. Future performance cannot be predicted accurately from early records when the repeatability estimates are as low as these. The low heritability estimates indicate that there is very little genetic variability in the traits measured. The fact that some of the estimates were negative and others positive indicates that the true estimates are near zero. The performance of daughters cannot be predicted from the records of the dams when heritability estimates are as low as some of these. Progress by selection for these traits would be exceedingly slow. In a selection program effort could well be expended on other more highly heritable traits. These estimates in general agree with those found in the literature (Carman, 1955; Legates, 1954; Olds and Seath, 1950; Olds and Seath, 1953; Dunbar and Henderson, 1953; and Pou et al., 1953).

With a heritability estimate of 0.14, it might be possible to select for a shorter calving interval. Also an estimate of 0.22 and 0.30 for the interval from calving to first breeding indicates that a shorter interval could be obtained by selection. However, data in the literature indicate that excessively short intervals from calving to first breeding are not desirable (Trimberger, 1954; Van Demark and Salisbury, 1950; Shannon et al., 1952; Hofstad, 1941; and Lasley and Bogart, 1943).

In this study the regression of the number of services per conception on the length of interval from calving to first breeding was -0.10 ($P < .01$), indicating that cows bred at shorter intervals after calving required more services per conception than those bred after longer

TABLE XIII

AVERAGE REPRODUCTIVE PERFORMANCE OF DAMS AND DAUGHTERS

	Number of Services Per Conception	Interval Calving to Conception (days)	Gestation Length (days)	Calving Interval (days)	Interval Calving to First Breeding (days)	Interval First Breeding to Conception (days)
Dams	1.48	109.2	286.6	397.1	83.1	21.2
Daughters	1.45	100.0	286.5	386.8	82.5	14.9
Number of Pairs	356	313	364	309	308	308

TABLE XIV

AVERAGE PERFORMANCE OF THE DAUGHTERS OF BULLS WITH TEN OR MORE DAUGHTERS

Sire Code	Number of Services Per Conception	Intervals Calving to Conception (days)	Gestation Lengths (days)	Calving Intervals (days)	Intervals Calving to First Breeding (days)	Intervals First Breeding to Conception (days)
001	1.63 (17)[1]	128.3 (15)	289.9 (17)	418.2 (15)	85.3 (15)	41.8 (15)
002	1.64 (13)	113.3 (13)	288.9 (13)	397.5 (13)	88.4 (13)	23.6 (13)
008	1.41 (11)	112.2 (10)	295.6 (11)	400.9 (10)		
036	1.71 (10)	120.6 (12)	285.9 (12)	412.6 (12)	71.5 (12)	28.2 (12)
063	1.45 (21)	98.6 (21)	285.3 (21)	384.2 (21)	77.3 (21)	20.1 (21)
069	1.40 (13)	111.7 (13)	285.7 (13)	396.8 (13)	82.2 (13)	25.8 (13)
085	1.44 (29)	107.6 (27)	286.9 (29)	395.6 (27)	86.7 (27)	19.4 (27)
111	1.45 (52)	101.8 (44)	287.3 (52)	388.2 (43)	79.4 (32)	16.5 (44)
118	1.42 (57)	89.1 (52)	287.0 (58)	377.3 (51)	80.6 (52)	10.1 (51)
133	1.35 (26)	92.0 (19)	286.5 (26)	390.6 (20)	76.5 (19)	12.2 (20)
163	1.22 (17)	91.8 (16)	279.7 (17)	380.4 (16)	84.9 (16)	39.1 (16)
164	1.27 (23)	100.5 (25)	285.8 (30)	386.9 (25)	84.3 (26)	13.3 (26)
171	1.29 (67)	96.5 (47)	288.2 (67)	376.9 (46)	85.9 (47)	6.1 (47)

[1] Numbers in parentheses indicate the number of daughters.

intervals. This is shown in Table XV. Cows bred from twenty-seven to fifty days after calving required 1.94 services per conception; those bred fifty-one to sixty days required 1.76; those bred sixty-one to ninety days required 1.38; and those bred over ninety days required 1.33. It appears desirable to wait until at least sixty days post partum before rebreeding.

TABLE XV

AVERAGE NUMBER OF SERVICES PER CONCEPTION FOR VARIOUS LENGTH INTERVALS FROM CALVING TO FIRST BREEDING

Interval from Calving to First Breeding (days)	Number of Services Per Conception	Number of Cows
27 - 50	1.94	32
51 - 60	1.76	52
61 - 90	1.38	426
Over 90	1.33	225

The heritability estimates determined by the regression of daughters' records on dams' records were generally larger than those determined from the correlation of these records. Lush (1948) stated that this is to be expected when the parents are selected.

Apparently the environmental component in the paternal half-sib estimates was small, since multiplying the covariance by four produced small estimates. The estimates from the correlation between daughter and dam records and the regression of daughter records on dam records were generally larger than those determined by paternal half-sib correlations. Lush (1948) stated that environmental variations may be correlated between individual parent and offspring and that some of the epistatic deviations will be correlated between parent and offspring. This may account for the larger estimates by this method. Sampling errors might also cause the variation in heritability estimates by the different methods.

The regression of number of services per conception on age of cow at disposal was 0.24 ($P < .01$), indicating that the cows that were taken from the herd at older ages required more services per conception. This might mean that no selection for efficient breeding performance was practiced during the period of this study. The average number of services per conception for cows taken from the herd is given in Table XVI.

TABLE XVI

AVERAGE NUMBER OF SERVICES PER CONCEPTION FOR COWS
TAKEN FROM THE HERD AT VARIOUS AGES

Age at Disposal (years)	Number of Services Per Conception	Number of Cows
3	1.15	25
4	1.27	49
5	1.43	94
6	1.38	40
7	1.42	23
8	1.65	52
9	1.46	30
10	1.53	40
11	1.53	35
12	1.50	40
13	1.53	22
15 and over	1.87	11

SUMMARY AND CONCLUSIONS

The reproductive performance of the Turner Hereford Ranch herd, Sulphur, Oklahoma, was studied for the period from 1934 through 1952. The reproductive performance of this herd gradually declined during this period. The average reproductive performance for this period was: number of services per conception, 1.7; interval from calving to conception, 108.2 days; gestation length, 285.7 days; calving interval, 394.2 days; interval from calving to first breeding, 75.5 days; and interval from first breeding to conception, 31.0 days. In general, the reproductive performance was higher in summer and fall than in spring and winter.

Old cows were less productive than young cows. Cows more than ten years of age declined rapidly in performance. All correlations and regressions of performance on age of cow were positive and significant. The rapid decline at the older ages caused the regression to be curvilinear. Culling at the older ages tended to cause an erratic performance at these ages.

During the period of this study 530 cows were taken from the herd at an average age of 7.8 years. Cows that were sent to market at the end of their productive life had an average age of 9.2 years. Thus they had a productive life of 7.5 years. Records were available for 775 cows. These cows produced an average of 4.6 calves while in the herd. Some of these cows were still in the herd at the end of this study. There were no sex or sire effects on gestation length.

Heritability estimates were determined by the paternal half-sib intra-class correlation, the correlation between daughter and dam records, and regression of daughters' records on dams' records. The repeatability estimates were determined by intra-class correlations from components of variance. These estimates were generally low. Repeatability estimates ranged from 0.03 for the interval from calving to first breeding to 0.15 for gestation length. The heritability estimates varied from -0.24 for the number of services per conception to 0.30 for the interval from calving to first breeding. The heritability estimates by the paternal half-sib and regression of daughters' records on dams' records were: number of services per conception, 0.05 and -0.24; gestation length, -0.05 and 0.24; calving interval, 0.07 and 0.14; interval from calving to first breeding, 0.02 and 0.30; interval from first breeding to conception, 0.04 and 0.01; and interval from calving to conception, 0.04 and 0.14.

Cows bred more than sixty days post partum required fewer services per conception than those bred prior to sixty days post partum. Cows disposed of at older ages required more services per conception than those taken from the herd at younger ages.

PART II

CERTAIN SEMEN CHARACTERISTICS AND THEIR RELATION TO REPRODUCTIVE PERFORMANCE IN HEREFORD CATTLE

INTRODUCTION

Artificial insemination has been widely used in the dairy industry. It has come to be used extensively with beef cattle, particularly in purebred herds and in some grade herds where the system of management permits. An increase in the use of artificial insemination has made it necessary to develop methods of predicting the potential fertility of semen samples. A number of tests have been developed, but not all of them are adaptable to field use. None of them are entirely accurate in predicting fertility of semen. As evidence of this Buckner *et al*. (1954) tried a large number of tests and combinations of tests to find tests that were accurate in predicting fertility. Only two of these were considered accurate enough measures of semen fertility to be of value in practical use. These two tests were (1) motility after incubation at 38°C in yolk-citrate plus antibacterial agents and (2) the combination of methylene blue reduction time, drop in progressive motility after 120 minutes in 3 per cent aniline blue solution at 4°C and initial motility in yolk-citrate solution.

REVIEW OF LITERATURE

Most of the investigations of semen quality in relation to fertility have been made with dairy cattle.

Semen Motility

Spermatozoan motility has probably been used more than any other method as an indicator of semen quality. Swanson and Herman (1947) stated that the rating of motility is somewhat lacking in precision, but in spite of its errors, motility may be of great value as an aid in determining potential fertility. Motility has been expressed as a percentage of motile spermatozoa (Donham *et al*.,1931), rated from zero to five (Swanson and Herman, 1947), or rated zero to ten (Erb *et al*., 1950), with zero being lowest in both systems. Lasley (1951) used a modification of a method described by Brady and Gildow (1939), in which the non-motile spermatozoa in fresh semen were counted in an hemocytometer and the number of these expressed as a percentage of the total count. Any method of estimating motility has errors, as pointed out by Salisbury (1955). These errors are reflected in the varying results obtained when motility is compared to the actual fertility of the semen. Erb and Waldo (1952) obtained varying correlations between motility and fertility when these were computed from month to month for the same animals. Bishop *et al*. (1954) found no significant relation between semen motility and fertility. Donham *et al*. (1931) classified as normal bulls those that produced semen with an estimated ninety per cent or more motile sperm. Bulls producing semen with a motility less than this were considered abnormal. In field tests 130 of 181 cows bred to normal bulls conceived and required a total of 273 services, or 2.10 services per conception. Of 207 cows bred to abnormal bulls only 118 conceived, and these required 2.94 services per conception. In an experiment station herd 53 per cent of the matings to normal bulls resulted in pregnancies, while only 24 per cent of the cows conceived to abnormal bulls. Lasley and Bogart (1943) found no relation ($r = 0.003$) between motility ratings and fertility with 2,118 purebred Hereford cows inseminated from 296 ejaculates. The average motility was 4.7 ± 0.03 with six being the highest rating. In a group of similar cows, Lasley (1951) obtained a highly significant correlation ($r = 0.314$) between conception rate and per cent motile spermatozoa. Fertility increased 4.6 per cent for each 10 per cent increase in motile sperm. This was based on 740 cows inseminated with semen diluted one to four.

From 590 samples of semen (each used on twenty or more cows) from Guernsey, Jersey, and Holstein bulls, Erb _et al_. (1950) obtained a highly significant correlation of 0.14 between initial motility and fertilizing capacity of the semen. Mercier and Salisbury (1946), Branton _et al_. (1951), and Cupps _et al_. (1953) obtained low correlations between motility and fertilizing ability of semen. These were 0.11, 0.04, and 0.02, respectively. Branton _et al_. (1951) observed correlations in dairy cattle of 0.26 and 0.49 between fertility and the number of motile spermatozoa per ml. and the number of motile spermatozoa per insemination, respectively.

Ehlers and Erb (1950) rated semen on motility after two days storage. The semen was rated ten (highest motility), eight, six, four and two or less and had non-return rates of 63.4, 56.2, 50.3, 49.9, and 39.9 per cent, respectively. They found that the ability of semen to maintain motility during storage up to six days was a better criterion of fertilizing capacity than initial motility. Buckner et al. (1954) studied a large number of tests and combinations of tests in an attempt to find a single test or a combination of tests that would be highly accurate in predicting the fertility of semen. The only tests that were correlated 0.90 or higher with fertility were (1) motility after incubation at 38°C in yolk-citrate plus antibacterial agents and (2) the combination of methylene blue reduction time, drop in progressive motility after 120 minutes in 3 per cent aniline blue solution at 4°C and initial motility in yolk-citrate solution. Swanson and Herman (1950) reported a highly significant correlation of 0.84 between the ability of semen to maintain a motility of two or higher (rating on the basis of zero to five) and per cent conception.

Swanson and Herman (1944) plotted motility ratings (zero to five) against the conception rate of 565 inseminations of dairy cows and obtained an indication of a non-linear correlation. Conception from semen with a motility of one was very poor. Semen that was rated two produced 43 per cent conceptions, and semen with a rating of three showed a corresponding improvement. However, there was no important increase in conception with semen rated four and five, even though semen with a motility of five produced the highest rate of conception. The conception rate increased rapidly with an increase in motility up to a rating of three. The index of correlation of 0.97 revealed that there was a significant curvilinear correlation between motility rating and conception percentage.

Terrill (1937) reported that higher motilities were generally associated with higher levels of breeding capacity in rams. Wiggins _et al_. (1953) observed no significant correlation between spermatozoan motility score and the percentage of ewes lambing ($r = 0.06$). The correlation for the percentage of motile spermatozoa and the percentage of the ewes lambing was 0.06. Motility was scored from one to six, with one being the highest motility.

Semen Volume

It is generally recognized that there is a minimum volume necessary for the best conception. Of course, volume varies with species, but within species the volume per ejaculate may be related to the fertilizing ability of the semen.

Lasley and Bogart (1943), working with purebred Hereford cattle, evaluated 476 ejaculates and obtained a mean volume of 4.84 ± 0.07 cc., with a range of 0.5 to 10.5 cc. They obtained the highest fertility from ejaculates that contained the highest volume ($r = 0.91$). On the contrary, Bishop _et al_. (1954) observed a decline in fertility as the volume per ejaculate increased. However, they used only eighty ejaculates. Mercier and Salisbury (1946) also obtained a negative though small correlation between the volume of 330 ejaculates and fertility ($r = -0.03$).

Terrill (1937) evaluated ram semen immediately following the breeding season. Semen from five rams, that was used to breed a group of ewes of which 97.8 per cent lambed, had a higher volume per ejaculate, greater concentration, higher numbers of spermatozoa per ejaculate, higher motility, higher percentage of motile spermatozoa, better maintenance of motility during storage, and a higher percentage of normal spermatozoa than did the semen from four rams bred to ewes of which only 87.7 per cent lambed. Wiggins et al. (1953) obtained a significant correlation of 0.06 between the percentage of ewes lambing and the volume of semen per ejaculate and a significant correlation of 0.10 between semen volume and the percentage of live lambs.

Dilution Rate

When bulls have been proved to possess a greater than average ability to transmit good genes to their offspring, it is desirable to breed them to as many cows as possible. Dilution of semen is one way to accomplish this. Thus, knowledge of the effect of dilution on the fertility of semen is essential.

Underbjerg et al. (1942) diluted dairy-bull semen 1:4 and 1:1 with an egg-yolk buffer and autoclaved milk. Chi-square methods indicated that diluting the semen caused no lowering of the conception percentage as compared to undiluted semen. Salisbury et al. (1943) based the dilution rate on concentration of spermatozoa. Semen for 3,940 services from seventeen Holstein and eleven Guernsey bulls was diluted at various levels from 1:2 to 1:16. They observed no obvious trends in conception percentage with changes in dilution rate. Willett (1950) diluted semen from Guernsey and Holstein bulls at rates from 1:100 to 1:300 and observed that the decrease in the number of spermatozoa was more important in causing the decrease in non-return rate than the direct depression of motility. His data were based on 11,372 services in four experiments. In each there was a downward trend in fertility with increased dilution, but none of the differences were significant. As the sperm number decreased from twelve million per ml. to six million, there was an approximate decrease of 0.5 per cent in non-return rate. This corresponded roughly to an increase in dilution from 1:100 to 1:200. Significant regression coefficients in two experiments of 0.78 and 0.77 were obtained for non-return percentages on the number of spermatozoa. When semen contained less than six million spermatozoa per ml., there was a drop of 2.6 non-return percentage for each million decrease in spermatozoan numbers. There was a marked decrease in livability of spermatozoa with an increase in dilution rate. Salisbury and Bratton (1948) worked with dilution rates of 1:100, 1:200, 1:400, and 1:800. By analysis of covariance, they found that the five-month non-return rate was significantly lower for the 1:400 and 1:800 than the 1:100 dilution rate. They noted a slight though not significant decline in fertility with the decrease in spermatozoan concentration that was associated with the dilution rate. The decrease in fertility was approximately 0.8 per cent for each one million decrease in spermatozoa.

Age of Semen at Insemination

One advantage of artificial insemination is that semen can be stored and used later, thus increasing the use of outstanding bulls. However, fertility of semen will decline with length of storage. It is of value to know the magnitude of this decline in fertility.

Underbjerg et al. (1942) reported that stored semen, irrespective of treatment, showed a highly significant lowering of conception percentage as compared to fresh semen. Semen stored for 36, 39, 54, and 61 hours produced a conception percentage of 36.7, 30.8, 38.5, and 25.9 as compared to 63.5, 46.5, 42.9, and 54.5 for fresh semen from the same treatments, respectively. Salisbury et al. (1943) reported data involving 3,940 services from seventeen Holstein and eleven Guernsey bulls and found no important deviations in fertility up to the fifth day of storage.

Schultze et al. (1948), from Nebraska data involving 25,146 inseminations and over 2,500 semen samples, reported an average decline in fertility of 4.61 per cent conception for each day of storage up to four. Chi-square analysis indicated this decline in fertility was highly significant. Bulls differed in rate of decline. Erb et al. (1950) reported data from Guernsey, Jersey, and Holstein cattle that included 23,938 services. The non-return rate declined four per cent for Guernsey and Jersey semen between the second and third day of storage. The corresponding drop for the Holsteins was six per cent. The drop was as much as thirteen per cent for individual bulls used for 300 or more services. The over-all drop was five per cent between the second and third days, with no difference existing between the first and second days. The non-return rate for the first, second, and third days of storage was 64, 64, and 59 per cent, respectively.

Swanson (1951) reported data on Jersey, Guernsey, and Holstein bulls used for artificial insemination in East Tennessee. The non-return rate for semen used on the first, second, and third days after collection was 63.3, 62.0, and 55.7 per cent, respectively. The first and second days were not statistically different, but the third day was significantly lower than the first two days. Willett (1953) observed a 3.6 per cent decline in non-return rate from the first to the second day after collection for semen diluted 1:100 and 8.2 per cent for the 1:300 diluation. Campbell (1953) reported a four per cent decline in conception rate for each additional day of age of semen for 50,213 inseminations of cattle.

Walton (1938) observed a decline in fertility of horse semen with an increase in storage time.

Other Indicators of Semen Fertility

Lasley and Bogart (1943), working with purebred Hereford cattle, obtained an index of correlation between sperm concentration and fertility. The relationship was apparently curvilinear. Ejaculates in which concentration ranged between 800,000 and 1,000,000 per ml. produced the lowest fertility, while ejaculates of lower and higher concentration produced higher fertility. Mercier and Salisbury (1946) reported a highly significant correlation ($r = 0.16$) between fertility and concentration of semen. Swanson and Herman (1947) obtained a non-significant correlation between fertility and concentration of semen ($r = 0.16$). Swanson and Herman (1947) obtained a non-significant correlation of 0.63 between concentration of semen and conception in Holsteins, Jerseys, and Guernseys. Cupps *et al*. (1953) found a correlation of 0.08 between semen concentration and thirty to sixty-day non-return rate.

Terrill (1937) observed that higher breeding capacity of rams was associated with semen concentration. Wiggins *et al*. (1953) reported non-significant correlations between semen concentration in the ram and the percentage of ewes lambing ($r = 0.02$) and between semen concentration and the percentage of live lambs ($r = 0.02$). The regression coefficients of percentage of ewes lambing and percentage of live lambs on semen concentration were both 0.002.

Lasley and Bogart (1943) used the percentage of live spermatozoa after a cold shock as an indication of fertility. The percentage of live spermatozoa in undiluted semen after shock was not correlated to fertility (r = 0.06), whereas the percentage of live spermatozoa in semen diluted in egg-yolk buffer was significantly correlated with fertility (r = 0.83). Branton *et al*. (1951) obtained a non-significant correlation (r = 0.06) between fertility and motility after cold shock.

Methlene blue reduction time has been used extensively to indicate semen fertility. Branton *et al*. (1951) found methylene blue reduction time to be significantly related to fertility when 300 million or more spermatozoa were present (r = 0.25). Mercier and Salisbury (1946) obtained a highly significant correlation of -0.13 between these two variables.

The percentage of normal spermatozoa was observed to be related to fertility in sheep by Terrill (1937). Wiggins *et al*. (1953) reported significant correlations of 0.43 and 0.32 between the percentage of normal spermatozoa, the percentage of ewes lambing and the percentage of live lambs, respectively. Lasley and Bogart (1943) found no relation between the percentage of abnormal spermatozoa and the fertility of 178 semen samples. From 525 inseminations Swanson and Herman (1947) found no significant correlation between conception rate and the percentage of abnormal spermatozoa (range 0 to 30 per cent). However, Mercier and Salisbury (1946) did obtain a significant negative correlation (r = -0.13) between the percentage of abnormal spermatozoa and fertility for 280 ejaculates.

Many other measures of semen quality have been used to indicate potential fertility. Wiggins *et al*. (1953) used libido (time between ejaculates) and found a significant correlation between it and the percentage of ewes lambing. These same workers studied pH of semen and found that it was not related to fertility. Cupps et al. (1953) used a fructolysis index for bull semen. Branton et al. (1951) used resistance to a NaCl solution and found no relation. Viscosity (Wiggins et al., 1953), abnormal heads and tails, resazurin reduction (Erb and Ehlers, 1950), and other tests have been used with varying success in predicting fertility.

Seasonal Changes in Semen Quality and Fertility

Season may be one of the important factors influencing the variation in semen quality and fertility. It probably is complicated in its influence, since it not only affects the animal directly but also indirectly through type of feed, amount of feed, and general comfort.

McKenzie and Berliner (1937) effectively demonstrated that the season affects semen quality in rams. They observed a marked decrease (70 per cent in Shropshire rams and 20 per cent in Hampshire rams) in semen quality during the months of July, August, and September. Spermatozoa concentration and total number of spermatozoa were reduced. The number and percentage of abnormal spermatozoa were greatly increased, but semen volume and the number of copulations were not materially affected. Later they produced a similar reduction in semen quality in late winter by keeping the rams in hot rooms. There was a decided increase in the semen quality in early October.

Phillips et al. (1943) studied the seasonal changes in the semen produced by three Shorthorn and three Milking Shorthorn bulls. The volume of semen produced was highest in the winter and lowest in summer. The total number of spermatozoa was highest in the spring and lowest in the fall. Abnormal heads, necks, and mid-pieces were highest in summer and lowest in winter. Motility, volume, total abnormal spermatozoa and survival were not significantly different in the different seasons. The highest percentage of fertile matings occurred in April (59.6 per cent) and the lowest in August (40.8 per cent) for 1,135 matings. It appeared that the decrease in semen quality in summer was reflected in decreased breeding efficiency.

Erb et al. (1942) observed significant seasonal differences in the initial motility, volume, concentration, total spermatozoa, abnormal spermatozoa and survival of semen in 879 ejaculates from Holstein, Jersey, Guernsey, and Ayrshire bulls at Purdue University. The quality of semen was significantly superior in spring as compared to summer.

Erb and Waldo (1952) analyzed the results of 93,113 inseminations from Guernsey, Jersey, and Holstein bulls used for artificial insemination in Northwestern Washington. They found a highly significant monthly variation in non-return rate, with a low in January and a gradual increase to a high in September, October, and November. There was a large monthly variation in spermatozoan concentration, initial motility, and motility after thirty minutes at 45°C. Mercier and Salisbury (1947) noted a similar condition in Eastern Canada, where the fertility of Ayrshire, Holstein, Shorthorn, and Milking Shorthorn bulls was highest in summer and lowest in winter. Schultze et al. (1948) at Nebraska noted among 25,146 services a decreased conception rate in the summer (52.5 per cent) as compared to the spring (59.4 per cent). Seath et al. (1943) reported decreased fertility among Jersey and Holstein cattle in Louisiana in the summer. Berliner (1942) noted seasonal variation in the reproductive performance of mares and jennets in Mississippi. Braude et al. (1954) found no seasonal influence on the fertility of swine.

MATERIALS AND METHODS

The semen used in this part of the study was collected from thirty-one Hereford bulls for the routine breeding operation of the Turner Hereford Ranch, Sulphur, Oklahoma, during the period from 1946 through 1952. The majority of bulls were kept in individual pastures surrounded by cow pastures to assure adequate exercise for the bulls. The young bulls that were being tested were kept in the show barn and received exercise at intervals. The cow herd was kept in excellent condition typical of a good purebred herd. There were 614 cows bred one or more times during the period covered by this study.

The herd was relatively free of disease during this time. A full-time veterinarian was on duty at all times. No vibriosis or trichomoniasis has ever been diagnosed on the ranch. There were some cases of granular vaginitis. During the early history of the herd the test and slaughter method was used for brucellosis control. Since that time very few cases have been diagnosed in the herd.

The semen was collected twice weekly by the use of an artificial vagina. Only one ejaculate was taken in most instances. The volume, measured in ml., and initial semen motility ratings were made routinely. The motility ratings were zero to five, with five being the highest motility. The semen was diluted according to estimated needs. The greatest dilution used was 1:7. Until 1950 the semen was diluted in a half egg-yolk and half one-eighth molar phosphate buffer (Na_2 HPO_4 and KH_2 PO_4). The pH of the buffer was 7.2. After 1950 the diluter was half egg-yolk and half 3-per-cent sodium citrate, to which 1,000 units of penicillin and 1 mg. of streptomycin or dehydrostreptomycin per ml. of diluter was added.

The diluted semen was stored at 36 to 38°F. The cows were checked twice daily for heat. Any cows in heat were usually bred between four and six o'clock in the afternoon, except for a few which were bred on the mornings that semen was collected. One ml. of semen was used per insemination.

The data were punched on IBM cards for ease of tabulation. The statistical methods used were those described by Snedecor (1946). The repeatability estimates of the number of services per conception were determined by the intra-class correlation from the components of variance.

RESULTS AND DISCUSSION

Motility

The average initial motility ratings of semen used for 3,204 inseminations is given by season and year in Table XVII. The average initial motility for the seven years was 4.85. These averages may not be entirely correct, since a single ejaculate may have been used for more than one insemination and all ejacultes may not be equally represented. However, the error introduced by this procedure should be small. Comparisons of motility ratings with other literature mean little, since different systems of motility rating have been used. However, Erb and Waldo (1952), rating motility from zero to ten, found an average of 8.4 for one year. Monthly averages varied from 8.1 to 9.0. Lasley and Bogart (1943), with purebred Herefords and using a rating system of zero to six reported an average motility of 4.7 ± 0.03, which is nearly the same as reported here.

The analysis of variance in Table XVIII shows that there were no important yearly differences in initial motility. However, the seasonal, season-within-year, and season-within-age-of-bull differences were significant at the one per cent level. The motility tended to be lower in the summer and fall than in the winter and spring. This is shown graphically in Figure 7B. Plotting the motility by season within year showed no definite pattern to seasonal variation in motility. If motility is highly associated with fertility, the conception rate would thus be

TABLE XVII

THE AVERAGE VOLUME PER EJACULATE AND INITIAL MOTILITY OF SEMEN BY YEAR AND BY SEASON

	Volume					Motility Rating				
Year	Spring	Summer	Fall	Winter	Ave.	Spring	Summer	Fall	Winter	Ave.
1946	5.81	5.83	5.73	5.03	5.75	4.81	4.69	4.75	4.67	4.72
1947	4.76	5.41	5.37	4.66	5.09	4.98	4.88	4.82	4.61	4.82
1948	4.19	4.17	3.79	4.18	4.15	4.70	4.90	4.82	4.85	4.84
1949	4.85	4.65	5.16	4.20	4.57	4.90	4.85	4.98	4.93	4.90
1950	5.04	4.18	4.29	4.34	4.45	5.00	4.93	5.00	4.99	4.97
1951	5.16	4.64	4.49	4.99	4.89	4.96	4.72	4.27	4.94	4.83
1952	5.46	6.30		5.62	5.58	4.96	5.00		5.00	4.99
Ave.	4.95	4.91	5.05	4.53	4.82	4.90	4.83	4.78	4.88	4.85

TABLE XVIII

ANALYSIS OF VARIANCE OF INITIAL MOTILITY RATINGS

Source	d.f.	Mean Squares	F
Total	3203		
Year	6	3.67	1.36
Age of Bull	19	5.15	0.87
Season	3	2.00	40.00**
Season-Within-Year	20	2.70	54.00**
Season-Within-Age-Of-Bull	46	5.93	118.60**
Error	3109	0.05	

S.D. = 0.22
** ($P < .01$)

FIGURE 5. 5A - SEMEN VOLUME AND MOTILITY BY YEAR. 5B - THE RELATIONSHIP BETWEEN MOTILITY AND NUMBER OF SERVICES PER CONCEPTION. 5C - THE REGRESSION OF INITIAL MOTILITY OF SEMEN ON VOLUME PER EJACULATE.

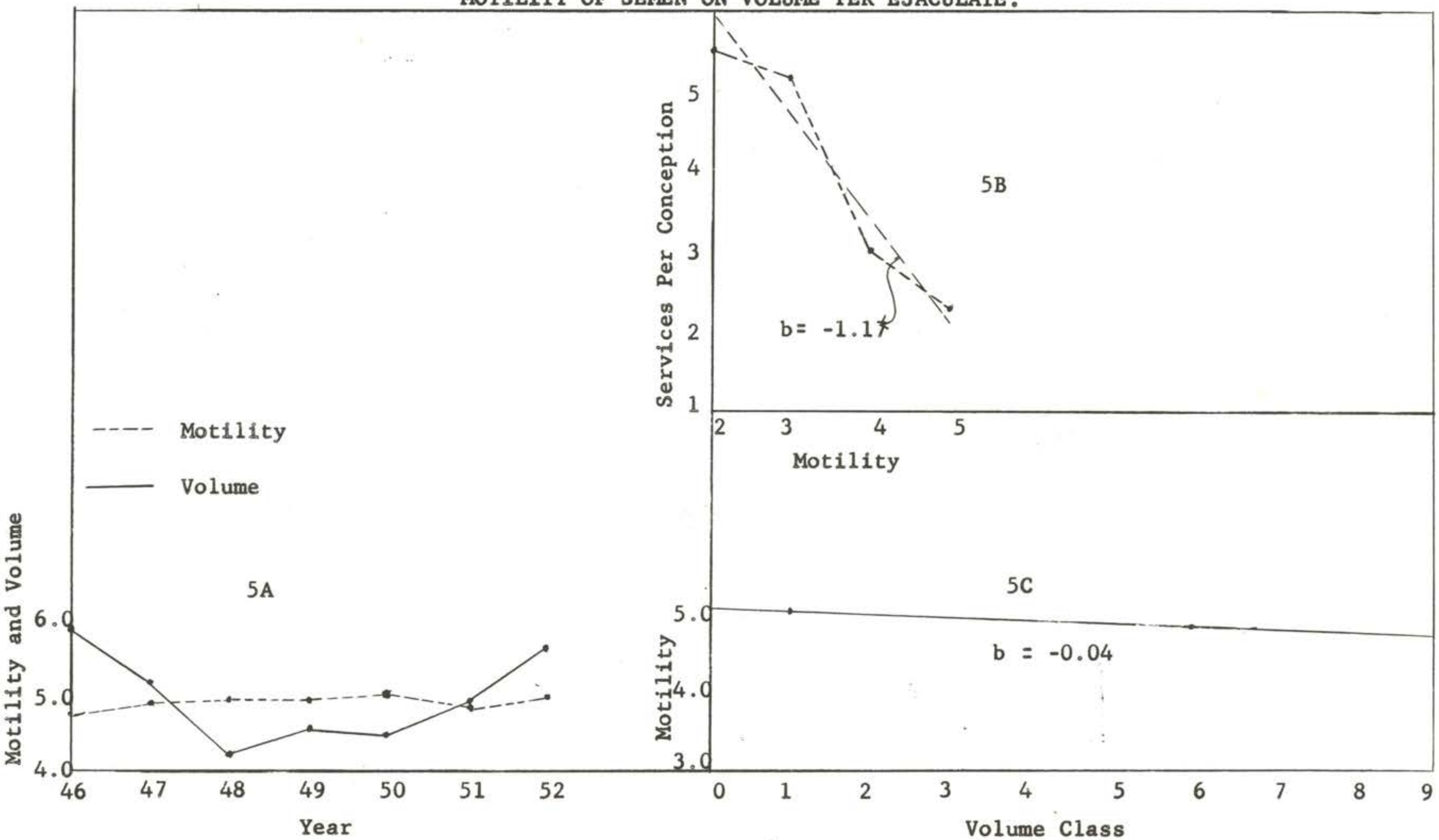


FIGURE 6. SEMEN VOLUME AND MOTILITY AS RELATED TO AGE OF BULL

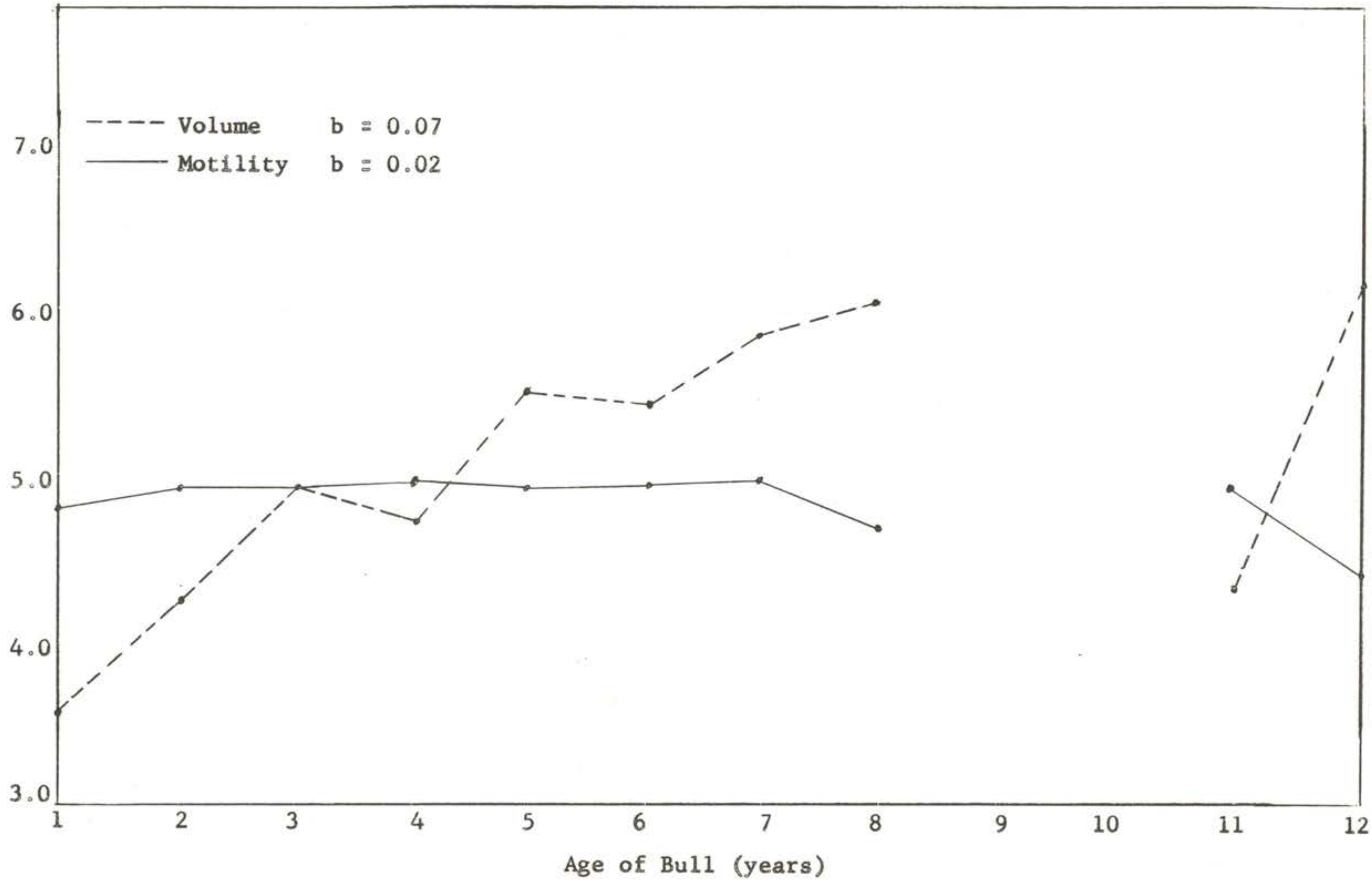
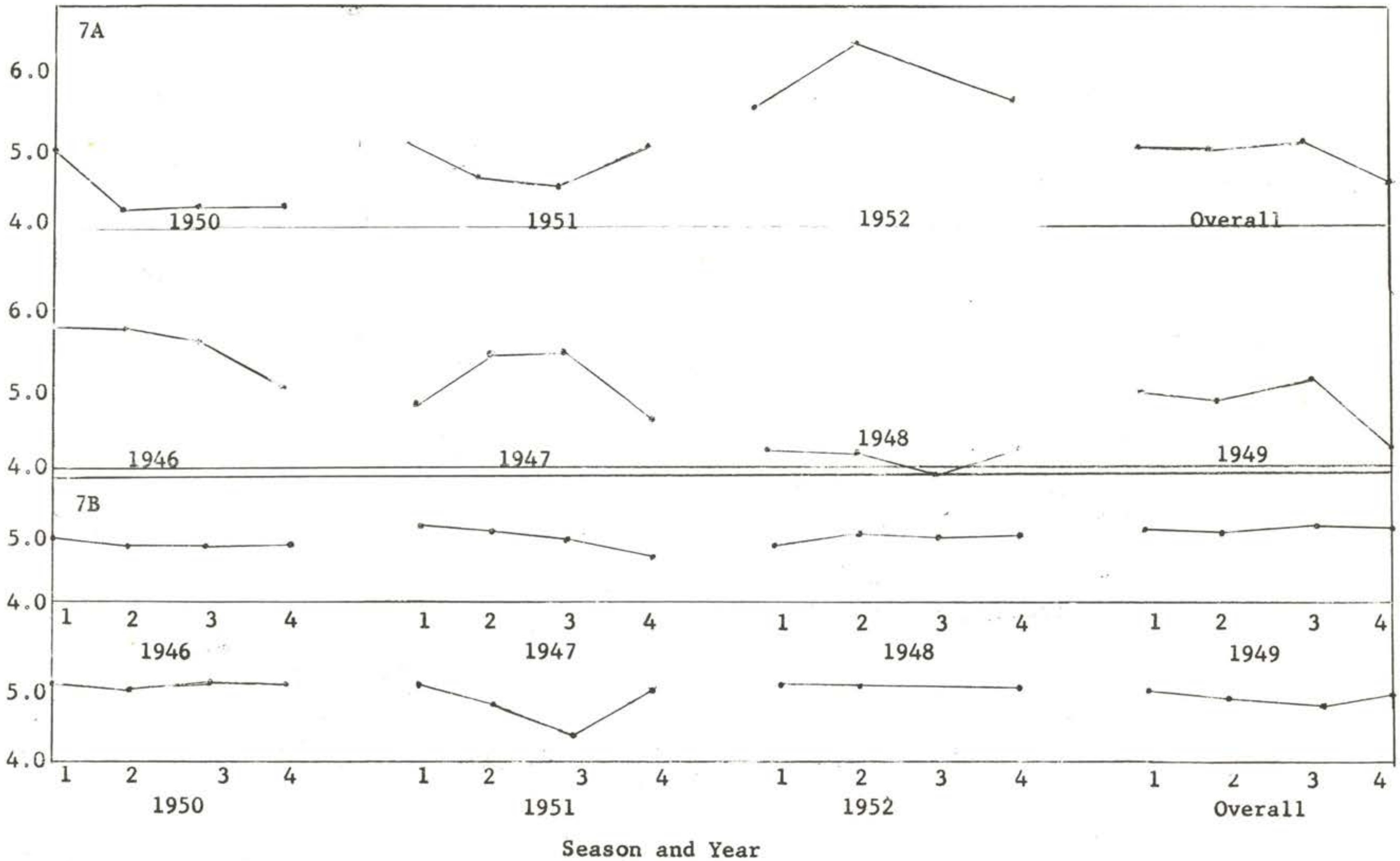


FIGURE 7. SEMEN VOLUME AND MOTILITY BY SEASON AND YEAR. 7A - Volume. 7B - Motility.
1 = Spring 2 = Summer 3 = Fall 4 = Winter



lower in summer and fall. The yearly variation in motility is plotted in Figure 5A. Phillips et al. (1943) found no significant seasonal differences in semen motility, but Erb et al. (1942) at Purdue University found a significant difference in motility.

The motility of semen produced by bulls of different ages is shown in Table XIX and presented graphically in Figure 6. The analysis of variance in Table XVIII indicated no difference in motility due to the age of the bull. However, as shown in Table XX, there was a highly significant negative correlation of -0.62 between the age of the bull and semen motility. The correlation was determined from the average motility and the age of the bull. Also a significant negative regression of -0.018 was found for motility on age of bull. Deviation due to regression was significant at the one per cent level. These figures indicate that as bulls get older they tend to produce semen of lower motility. Since the analysis of variance was determined from individual semen samples and the correlations and regressions from averages, the true values for correlations and regressions may not be as high as indicated.

The relation of initial motility to fertility was determined by its effect on the number of services per conception. The average number of services per conception for each motility rating is shown in Table XXII. There were so few services from semen with motility below two that they were grouped in the class with a motility rating of two. The chi-square value indicated that a deviation as large as this, or larger, would occur by chance less than one per cent of the time. It is evident that as the semen motility increased the number of services per conception declined. This high relationship is evident from the significant negative correlation of -0.96 and regression of -1.17 (Table XXI). The deviations due

TABLE XIX

AVERAGE VOLUME PER EJACULATE AND AVERAGE INITIAL MOTILITY OF SEMEN BY AGE OF BULL

Age of Bull (years)	1	2	3	4	5	6	7	11	12 and Over	Ave.
Average Volume	3.52	3.97	4.43	4.64	5.25	5.19	6.02	4.18	7.13	4.82
Average Motility	4.82	4.83	4.91	4.97	4.93	4.84	5.00	4.88	4.33	4.85

TABLE XX

CORRELATIONS AND REGRESSIONS OF INITIAL MOTILITY ON VOLUME OF SEMEN AND AGE OF BULL

	d.f.	r	95% Confidence Limits	b	95% Confidence Limits
Volume	6	-0.26	0.62 -0.85	-0.042	0.05 -0.13
Age of Bull	17	-0.62**	-0.23 -0.83	-0.018*	-0.01 -0.03

** ($P < .01$)
* ($P < .05$)

TABLE XXI

CORRELATION AND REGRESSION COEFFICIENTS FOR SEMEN CHARACTERISTICS AND SERVICES PER CONCEPTION

	d.f.	r	95% Confidence Limits	b	95% Confidence Limits
Motility	2	-0.96*	-0.12 -0.99	-1.17*	-0.41 -1.93
Volume	6	0.42	1.32 -0.42	0.03	0.09 -0.03
Dilution	5	0.67	1.74 -0.22	0.14	0.29 -0.03
Age of Semen at Insemination	3	0.94*	0.99 0.30	0.47*	0.76 0.19
Age of Bull	6	0.54	1.48 -0.28	0.06	0.14 -0.04
Age of Cow	7	0.71*	0.93 0.05	0.12*	0.22 0.02

* ($P < .05$)

TABLE XXII

NUMBER OF SERVICES PER CONCEPTION AS AFFECTED BY INITIAL MOTILITY

Motility (rating)	2 and below	3	4	5	Total
Total Services	22	103	357	2981	3463
Number of Services Per Conception	5.50	5.15	3.00	2.32	2.42

Chi-square = 39.22 3 d.f.
($P < .01$)

to regression were also significantly greater than the deviations from regression, which means that the regression was significantly different from zero. The regression of number of services per conception on motility rating is plotted in Figure 5B.

This seems to be somewhat in conflict with the fact that both motility and the number of services per conception tended to be lower in summer and fall. The correlation between motility and number of services per conception could still be high, since neither motility nor number of services per conception showed a definite relation to season when examined for each year. Also, as the correlation is based on initial motility and not on motility at the time of insemination, the fact that semen with low motility lost its fertility sooner than high-motility semen would tend to cause the high correlation. That this did happen is shown in Table XXIII. Semen with a motility of five dropped from 1.84 services per conception on the day of collection to 3.58 on the third day after collection. Semen with a motility of four dropped from 1.94 to 10.75 services per conception in the same length of time. Motility at the time of insemination would probably have been a better measure of fertility than initial motility.

However, a correlation as high as this indicates that initial motility in these data accurately measured semen fertility. This correlation is higher than most of the similar figures found in the literature. Lasley (1951) obtained a highly significant correlation of 0.31 between the percentage of motile spermatozoa and the conception rate in Hereford cattle. Lasley and Bogart (1943) found no relation between motility and fertility ($r = 0.003$). The fertility of semen in the present study was reduced approximately 23 per cent from a motility of five to four and approximately 65 per cent from five to three. Thus, with the cattle involved in this study, the use of semen with a motility less than four reduced the chances of conception to less than one in five.

TABLE XXIII

NUMBER OF SERVICES PER CONCEPTION AS AFFECTED BY INITIAL MOTILITY AND SEMEN AGE

Age of Semen (days)	Motility Rating		
	3 and below	4	5
0	3.53 (53)[1]	1.94 (128)	1.84 (871)
1	10.00 (40)	3.05 (118)	2.30 (894)
2	15.00 (15)	6.18 (68)	2.61 (774)
3 and over	4.25 (17)	10.75 (43)	3.58 (441)

1. Figures in parentheses indicate number of services
Chi-square = 9.849 (P = .14) 6 d.f.

The relation between motility and the number of services per conception can also be seen in Table XXIII, where the number of services per conception are grouped by motility and by age of semen at insemination. The lowest number of services per conception was obtained from semen that had a motility rating of five and was used the day of collection. There was a two-way gradient increase in number of services per conception, an increase with a decreased motility and with an increase in age of semen. The chi-square value approached significance at P = 0.14. The small numbers in some classes may have prevented this value from being significant. The data in Table XXIII indicate that the fertility of semen with a motility of less than four and stored longer than one day was markedly reduced. Two-day-old semen with an initial motility of four produced only one conception in six services.

Further evidence of the relation between the number of services per conception and motility is shown in Table XXIV. Here the number of services per conception is grouped according to motility and dilution rate. Again the number of services per conception increased with decreased motility.

TABLE XXIV

NUMBER OF SERVICES PER CONCEPTION AS AFFECTED BY INITIAL MOTILITY AND SEMEN DILUTION

Dilution Rate	Motility Rating		
	3 and below	4	5
0	5.10 (102)[1]	2.86 (309)	2.19 (1895)
1	6.00 (18)	2.71 (19)	2.83 (894)
2 and over	5.00 (5)	7.25 (29)	2.55 (981)

Chi-square $\cong$ 2.172 (P $\cong$ 0.7) 4 d.f.
1. Numbers in parentheses indicate the number of services.

The only relation between tests of semen quality possible in this study was between motility and volume. The correlation and regression were determined from the average volume and motility for the years involved. Neither the correlation of -0.26 nor the regression of -0.04 for motility on volume was significant. The regression line is plotted in Figure 5C. This relation can also be noted from Figure 5A. Correlations reported in the literature were 0.06 (Lasley and Bogart, 1943), 0.38 (Davis and Williams, 1939), and -0.03 (Rashwan, 1953). These correlations vary from highly significant positive to non-significant negative correlations.

Volume

The average volume of semen per ejaculate is given in Table XVII by year and season. The average for the seven years was 4.82. This agrees with the average volume of 4.84 ± 0.07 ml. reported by Lasley and Bogart (1943) for Hereford bulls. The analysis of variance in Table XXV indicates that year, season, season-within-year, and season-within-age-of-bull contributed significantly to the variance of semen volume. Phillips _et_ _al_. (1943) with bulls, and McKenzie and Berliner (1937), with rams, found no seasonal variation in volume per ejaculate. Erb _et_ _al_. (1942) reported seasonal changes in semen volume for dairy bulls. The over-all averages indicate that semen volume tended to be lower in winter than in the other seasons. In three of the seven years, semen volume was lowest in winter, and in two other years it was as low in winter as in any other season. In no year was volume highest in winter. These relations are plotted in Figure 7A. The yearly fluctuation in volume is shown in Figure 5A.

The analysis of variance in Table XXV indicates no relation between the age of the bull and semen volume. The correlation, regression, and deviations due to regression of age of bull on semen volume were not significant. However, all these values approached significance, and as shown in Figure 6, there was a tendency for the volume to increase with the age of the bull.

The volume per ejaculate was not significantly related to fertility as measured by the number of services per conception. The average services per conception for each volume is given in Table XXVI. The chi-square value indicated that departures from expectation as large as

TABLE XXV

ANALYSIS OF VARIANCE OF SEMEN VOLUME PER EJACULATE

Source	d.f.	Mean Squares	F
Total	3192		
Year	6	15,948	2.71*
Age of Bull	19	16,479	1.80
Season	3	4,082	170.8**
Season-Within-Year	20	5,881	246.1**
Season-Within-Age-Of-Bull	46	9,151	382.9**
Error	3098	23.9	

Standard Deviation = 17.99
Standard Error = 20.32
* ($P < .05$)
** ($P < .01$)

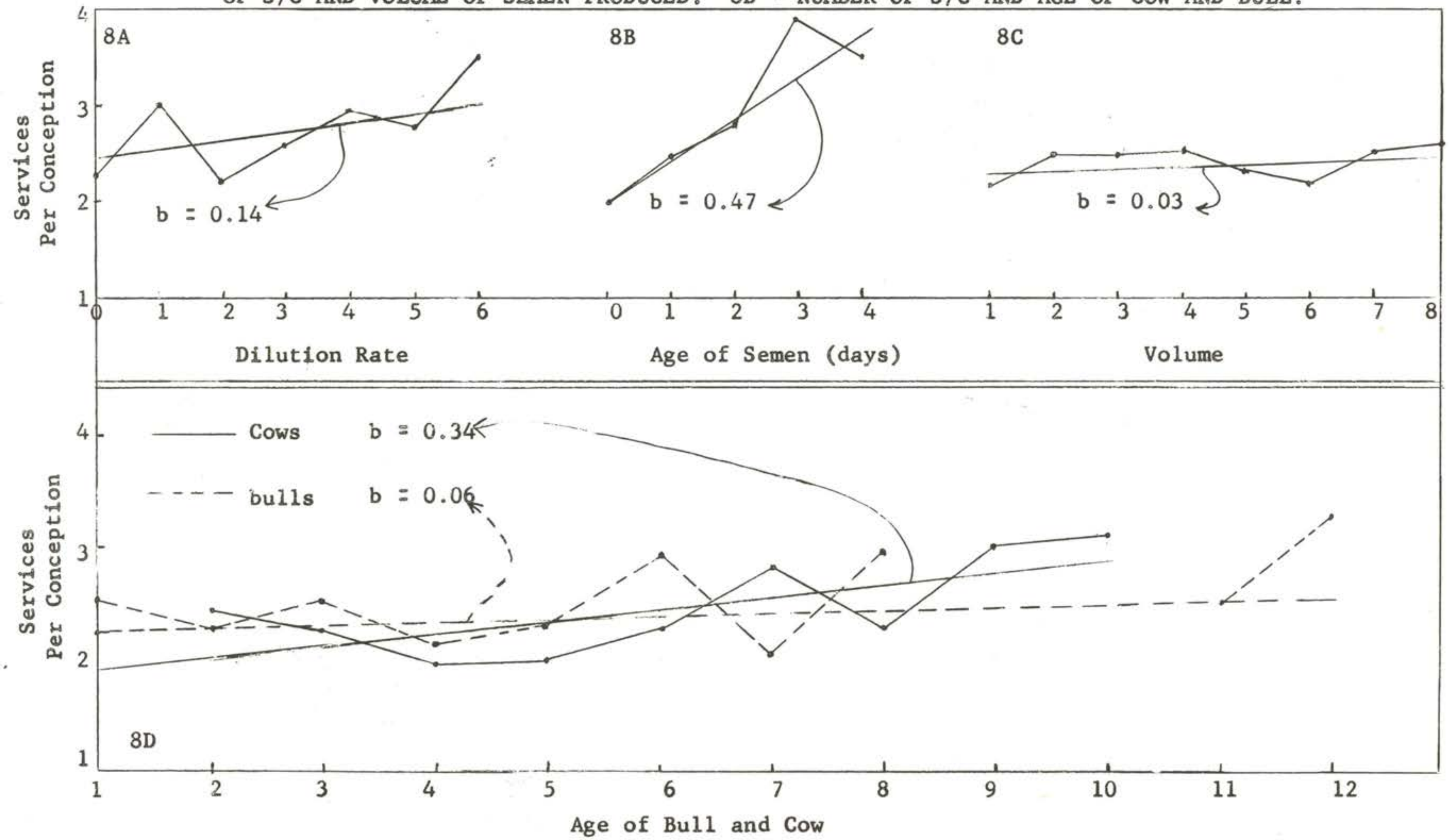
TABLE XXVI

NUMBER OF SERVICES PER CONCEPTION AS AFFECTED BY VOLUME PER EJACULATE

Volume (ml.)	0-1.9	2-2.9	3-3.9	4-4.9	5-5.9	6-6.9	7-7.9	8 & Over	Total
Total Number Of Services	50	276	717	941	669	462	141	207	3463
Number of Services Per Conception	2.7	2.51	2.48	2.53	2.32	2.16	2.56	2.62	2.42

Chi-square = 8.18 ($P = 0.42$) 8 d.f.

FIGURE 8. RELATION OF SEMEN QUALITY AND AGE OF BULL AND COW TO NUMBER OF S/C. 8A - NUMBER OF SERVICES PER CONCEPTION AND DILUTION RATE. 8B - NUMBER OF S/C AND AGE OF SEMEN. 8C - NUMBER OF S/C AND VOLUME OF SEMEN PRODUCED. 8D - NUMBER OF S/C AND AGE OF COW AND BULL.



these, or larger, would occur by chance 40 per cent of the time. The correlation and regression in Table XXI were not significant. That there was no trend in the number of services per conception with changes in volume is further demonstrated in Table XXVII. The number of services per conception remained relatively constant for the different volumes within each age class of semen. The numbers of services per conception are plotted against volume in Figure 8C. The regression line in this figure also shows the low relation between volume and fertility.

TABLE XXVII

NUMBER OF SERVICES PER CONCEPTION AS AFFECTED BY AGE OF SEMEN AND VOLUME PER EJACULATE

Volume Per Ejaculate (ml.)	Age of Semen (days)			
	0	1	2	3 & Over
0-1.9	1.77 (23)	2.75 (11)	1.80 (9)	3.50 (7)
2-2.9	1.94 (93)	2.90 (90)	3.05 (64)	2.90 (29)
3-3.9	1.92 (202)	2.30 (214)	3.03 (176)	3.79 (125)
4-4.9	1.91 (273)	2.42 (306)	3.26 (238)	4.47 (134)
5-5.9	1.67 (207)	2.60 (195)	2.75 (176)	3.75 (90)
6-6.9	1.83 (139)	2.28 (132)	2.13 (132)	3.47 (59)
7-7.9	2.05 (45)	2.47 (37)	2.57 (36)	5.75 (23)
8 & Over	2.59 (70)	2.39 (67)	2.78 (36)	3.09 (34)

Chi-square = 1.847 ($P > .99$) 21 d.f.

It is generally recognized that a minimum volume of semen is necessary for best results. Unless volume is closely related to other semen characteristics, high relations between volume and fertility are difficult to interpret. Lasley and Bogart (1943) obtained a very high correlation of 0.91 between semen volume and conception rate, whereas Bishop et al. (1954) and Mercier and Salisbury (1946) obtained low negative correlations. Wiggins et al. (1953) found a significant though small correlation of 0.06 between volume and percentage of ewes lambing. In the present data, volume was of little value in predicting the fertility of semen.

Dilution

The average number of services per conception for each dilution rate is given in Table XXVIII. The chi-square value for these figures indicated a significant association between number of services per conception and dilution. However, there was no discernible trend from the averages. Also, the correlation and regression of number of services per conception on dilution rate, as given in Table XXI, were not significant. In addition, when the variance due to regression was calculated, it indicated that the linear regression was not different from zero. The relation of dilution to the number of services per conception is presented graphically in Figure 8A. That dilution rate did not affect the number of services per conception is shown also in Tables XXIV and XXIX. The number of services per conception showed no change with an increase in dilution rate within motility and age-of-semen classes.

It was not surprising that dilution rate was not related to number of services per conception since the highest dilution rate was 1:7. Underbjerg et al. (1942) observed no effect on the conception rate when semen was diluted 1:1 and 1:4. Salisbury et al. (1943) could see no

TABLE XXVIII

NUMBER OF SERVICES PER CONCEPTION AS AFFECTED BY SEMEN DILUTION

Dilution Rate	0	1	2	3	4	5	6 & Over	Total
Total Number of Services	2306	142	318	417	136	66	78	3463
Number of Services Per Conception	2.32	3.02	2.25	2.67	2.95	2.75	3.54	2.42

Chi-square = 19.44 7 d.f. ($P < .05$)

TABLE XXIX

NUMBER OF SERVICES PER CONCEPTION AS AFFECTED BY AGE OF SEMEN AND SEMEN DILUTION

Dilution Rate	Age of Semen (days)			
	0	1	2	3 & Over
0	1.90 (731)[1]	2.38 (689)	2.49 (546)	3.36 (340)
1	1.85 (37)	3.21 (45)	4.20 (42)	6.00 (18)
2	2.02 (81)	2.12 (104)	2.15 (84)	3.77 (49)
3	1.66 (133)	2.70 (119)	4.81 (106)	6.44 (58)
4	1.95 (39)	3.20 (48)	3.78 (34)	7.50 (15)
5	2.25 (9)	2.33 (21)	2.67 (24)	6.00 (12)
6 & Over	2.00 (22)	2.89 (26)	21.00 (21)	9.00 (9)

1. Figures in parentheses indicate number of services.
Chi-square = 13.96 15 d.f. ($P = .53$)

trend with semen diluted as much as 1:16. Willett (1950) found that there was only a 0.5 per cent drop in non-returns from a dilution rate of approximately 1:100 to 1:200.

Age of Semen at Insemination

The increase in the number of services per conception with increasing age of semen from the day of collection (zero) to four days or over is given in Table XXX. There was a gradual increase in the number of services per conception up to three days and a slight drop from three to four days. However, the sampling error with the small number of services in the four-day group could account for this slight decline. The chi-square value showed that deviations as large as those in Table XXX, or larger, would occur by chance less than one per cent of the time. This decline in fertility with increasing age of semen is also evident in Tables XXVII, XXVIII, and XXIX. These data show that the number of services per conception generally increased as the age of semen increased, regardless of the class into which the data were grouped.

TABLE XXX

NUMBER OF SERVICES PER CONCEPTION AS AFFECTED BY AGE OF SEMEN AT THE TIME OF INSEMINATION

Age of Semen (days)	0	1	2	3	4 & Over	Total
Total Number of Services	1052	1052	857	469	32	3462
Number of Services Per Conception	1.89	2.45	2.77	3.84	3.56	2.42

Chi-square = 108.55 5 d.f. ($P < .01$)

The significant correlation and regression of the number of services per conception on the age of semen shown in Table XXI also indicate that there is a relation between the two variables. This relation is plotted in Figure 8B.

Most other workers have observed a decline in fertility with increased age of the semen. This decline has generally been approximately a four per cent drop in conception rate with each day of age. The greatest decline occurred after the second day (Schultze et al., 1948; Erb et al., 1950; and Swanson, 1951). In this study there was a drop of 12.1 per cent between the day of collection and the following day. Between the first and second day there was a 4.7 per cent drop and a 10 per cent drop from the second to the third day. In this study, fertility of the semen was reduced by about one-half by the third day. Therefore, the age at which the semen should be used would depend on the breeding value of the bull and how urgent the need for settling the cow.

Number of Services Per Conception

The number of services per conception by season and by season-within-year are shown in Table XXXI. The number of services per conception in this table for the seasons and years shown were higher than those in Part I. This resulted from including in the data of Part II the services for each cow after the last calf, except for the last service. The number of services per conception tended to be lower in summer and fall than in spring and winter. No significant seasonal difference in the number of services per conception was indicated by chi-square analysis (Table XXXII, $P \doteq 0.11$). Further evidence of this is shown by the low negative correlation between the number of services per conception and average seasonal temperature. The correlation between the number of services per conception and temperature the previous season was positive, indicating that these correlations are not significantly different from zero. However, the season-within-year differences were significant ($P < 0.01$), showing that the seasonal response was different from year to year. This is also shown in Table XXXI, where no season was highest or lowest in the number of services per conception more than twice in the six years. Thus there was no obvious seasonal trend in the number of services per conception, although when all services were grouped, summer and fall were lowest in the number of services per conception. The seasonal and yearly rainfall and the monthly average daily temperature for Sulphur, Oklahoma, are given in Appendix A. There was no correlation between the seasonal rainfall and the number of services per conception and between yearly rainfall and the number of services per conception. There was a low non-significant negative correlation between the number of services per conception and average seasonal temperature. There may be a tendency for cattle to be seasonal breeders, which could cause a decline in the number of services per conception in summer and fall. Apparently some factor(s) caused improved reproductive efficiency in summer and fall despite a decline in semen quality. The fertility of the cows might be raised enough by improved nutrition during the pasture season to more than offset the lowered semen quality of the bulls.

The number of services per conception for bulls and cows of different ages is given in Tables XXXIII and XXXIV. This is presented graphically in Figure 8D. The age of bull and age of cow differences in the number of services per conception were both significant, as shown

TABLE XXXI

NUMBER OF SERVICES PER CONCEPTION BY SEASON-WITHIN-YEAR

	Spring	Summer	Fall	Winter	Average
1946	2.29 (78)[1]	2.22 (286)	2.41 (166)	2.77 (36)	2.31 (566)
1947	2.34 (89)	1.99 (227)	2.15 (28)	2.44 (127)	2.17 (471)
1948	2.54 (117)	2.15 (232)	1.88 (51)	2.49 (212)	2.30 (612)
1949	2.40 (77)	2.76 (181)	2.63 (87)	2.46 (176)	2.56 (521)
1950	2.48 (139)	2.32 (242)	2.19 (74)	1.98 (268)	2.22 (723)
1951	2.34 (110)	2.47 (151)	3.90 (39)	3.40 (187)	2.86 (487)
Average	2.51	2.27	2.43	2.58	2.42

1. The numbers in parentheses indicate the number of services.

TABLE XXXII

CHI-SQUARE VALUES FOR BULL, COW, SEASON, SEASON WITHIN YEAR AND YEAR EFFECT ON SUCCESS OF SERVICES

	d.f.	Chi-square	
Bulls	24	86.922	($P < .01$)
Cows	609	866.157	($P < .01$)
Season	4	7.653	($P = .11$)
Season-Within-Year	24	46.660	($P < .01$)
Year	6	16.215	($P < .02$)

These chi-square values were determined from different groupings of the data and compiled into a single table.

TABLE XXXIII

THE EFFECT OF AGE OF BULL ON NUMBER OF SERVICES PER CONCEPTION

Age of Bull (Years)	1	2	3	4	5	6	11	12 & Over	Total
Total Number of Services	106	691	378	659	718	187	139	281	3159
Number of Services Per Conception	2.59	2.37	2.64	2.17	2.35	2.88	2.53	3.31	2.45

Chi-square = 25.958 ($P < .01$) 8 d.f.

TABLE XXXIV

THE EFFECT OF AGE OF COW ON NUMBER OF SERVICES PER CONCEPTION

Age of Cow (Years)	2	3	4	5	6	7	8	9	10 & Over	Total
Total Number of Services	512	485	396	338	336	376	279	247	494	3463
Number of Services Per Conception	2.45	2.32	1.92	1.99	2.29	2.74	2.36	3.09	3.23	2.42

Chi-square = 66.020 ($P < .01$) 9 d.f.

by chi-square (Table XXXII) and by analysis of variance. There was no definite pattern between the number of services per conception and the age of the bull. This is evident in Figure 8D and from the non-significant correlation and regression (Table XXI). However, the correlation between the age of the cow and the number of services per conception and the regression of the number of services per conception on age of cow were both significant. There was an indication from the values in Table XXXIV and Figure 8D that the relation might be curvilinear, but the deviations from linearity were not significant. However, the number of services per conception decreased from two to five years of age and then increased above five years of age. Two-year-old cows required 2.45 services per conception and four- and five-year-old cows required 1.92 and 1.99 services per conception, respectively. Cows over nine years of age required 3.23. Generally heifers and old cows have required more services per conception than cows of intermediate age (Warren, 1948; Davis, 1951; Tanabe and Salisbury, 1946; and Lasley and Bogart, 1943).

The number of services per conception for cows of different ages mated to bulls of different ages is given in Table XXXV. The most efficient matings involved five-year-old bulls mated to four-year-old cows. They required only 1.58 services per conception. On the average, the most efficient age groups were the four- and five-year-old bulls mated to four- and five-year-old cows, with 1.74 services per conception. The least efficient groups were bulls over five years of age mated to cows over six years of age, with 2.91 services per conception. This is similar to the findings of Tanabe and Salisbury (1946), in which bulls one to three years of age mated to four- to six-year-old cows were the most efficient. Warren (1948) reported that the most efficient reproduction occurred when four- to seven-year-old bulls were bred to seven- to ten-year-old cows and the least efficient reproduction was obtained from seven- to eight-year-old bulls mated to two- to four-year-old cows.

TABLE XXXV

THE EFFECT OF AGE OF BULL AND AGE OF COW ON THE NUMBER OF SERVICES PER CONCEPTION

Age of Cow	Age of Bull								
	1	2	3	4	5	6	11	12 & Over	Average
2	2.50 (10)[1]	2.17 (104)	2.83 (51)	2.66 (109)	2.19 (92)	2.40 (12)	3.67 (22)	2.18 (24)	2.45 (512)
3	3.00 (12)	2.43 (90)	2.50 (60)	1.63 (75)	2.42 (126)	2.27 (25)	3.13 (25)	3.17 (38)	2.32 (485)
4	1.83 (11)	1.97 (59)	2.15 (43)	1.73 (76)	1.58 (76)	3.09 (34)	1.70 (17)	3.00 (45)	1.92 (396)
5	4.00 (12)	1.72 (79)	1.75 (42)	2.08 (52)	1.73 (57)	2.60 (24)	2.83 (17)	3.43 (24)	1.99 (338)
6	2.20 (11)	2.11 (76)	2.18 (37)	2.29 (80)	1.89 (53)	5.67 (17)	2.17 (13)	5.17 (31)	2.29 (336)
7	8.00 (16)	2.81 (76)	8.75 (35)	2.20 (77)	3.00 (78)	3.00 (12)	2.09 (23)	2.50 (30)	2.74 (376)
8	1.00 (3)	2.63 (63)	2.00 (24)	2.14 (47)	2.28 (66)	2.57 (18)	2.20 (11)	3.36 (37)	2.36 (279)
9	1.57 (11)	3.50 (35)	3.13 (25)	2.24 (38)	3.53 (60)	2.40 (24)	2.00 (4)	7.50 (30)	3.09 (247)
10 & Over	2.86 (20)	3.30 (109)	3.81 (61)	2.76 (105)	3.55 (110)	4.75 (19)	3.50 (7)	3.14 (22)	3.23 (494)
Average Total	2.59 (106)	2.37 (691)	2.64 (378)	1.88 (659)	2.35 (718)	2.88 (187)	2.53 (139)	3.31 (281)	

1. The numbers in parentheses indicate the number of services.

The chi-square values in Table XXXII indicate that the bulls and cows were highly variable in reproductive ability. This was also indicated by the analysis of variance. The cows were of all ages and were represented by one to twenty-five services. Bulls with one hundred or more services varied from 1.88 to 3.26 services per conception. Within-cow variance was almost as large as between-cow variance (Appendix F), indicating cows were not consistent in success of service. The data in Appendix F indicate bulls were more consistent. Between-bull variance was 6.5 times as large as within-bull variance.

The most efficient bull was two years old when these data started and was eight at the finish. He accounted for 635 services, with a yearly range in number of services per conception of 1.60 to 2.50. However, these extremes were for ages when he had few services. For 100 or more services his conception rate was near his lifetime record of 1.88 services per conception. The least efficient bull was used from one and one-half to three and one-half years of age. He had a lifetime average of 3.26 services per conception.

Another bull averaged 2.48 services per conception for 1,119 services. He was used from two to six years of age and varied from 1.94 to 6.54 services per conception. These extremes are based on 90 and 85 services, respectively. When used for more services a year, he approached his lifetime average.

Two old bulls were used heavily for two years. They had 3.00 and 3.01 services per conception. They were both eleven and twelve years of age when used.

The repeatability of success of service was determined by an intraclass correlation utilizing the components of variance in Appendix F.

The effects of year and season were not removed in this analysis. In Appendix F σ^2 is the variance due to temporary environmental effects which cause the same cow's records to differ, while σ_c^2 is the variance due to differences between cows. The latter includes genetic, permanent environmental effects, and any genetic and environmental interactions that were different from one cow to another. The components yielded a repeatability of 0.08. This is another indication of the high within variance compared to that between cows. With a repeatability as low as this, selection on the basis of early performance of a cow would be of little value. This repeatability agrees closely with values found by Carman (1955), Legates (1954), Pou et al. (1954), and Dunbar and Henderson (1953). The repeatability estimate of the number of services per conception in bulls was 0.06.

SUMMARY AND CONCLUSIONS

The reproductive performance of the Turner Hereford Ranch Herd, Sulphur, Oklahoma, under artificial breeding for the period from 1946 through 1952 was studied. The motility of the semen was rated from zero to five with five being the highest motility. The motility ratings averaged 4.85 for the seven years. There were no important yearly differences in initial motility. The seasonal variation in initial motility was significant. Initial motility was lower in summer and fall than in winter and spring. There was an indication that as bulls get older, they produce semen of lower motility. The correlation between initial motility and the number of services per conception was -0.96, and the regression of the number of services per conception on initial motility was -1.17. Initial motility was not related to volume of semen per ejaculate.

The average volume of semen for the seven years and for thirty-one bulls was 4.82 ml. The yearly and seasonal differences in volume were significant. Volume tended to be low in winter. There was a tendency for old bulls to produce a higher volume of semen than young bulls. The semen volume showed no relation to the number of services per conception.

The semen was undiluted or diluted from 1:1 to 1:7. There was no apparent relation between dilution rate and the number of services per conception. The age of the semen was closely related to the fertility of the semen. A significant correlation of 0.94 was found between the age of the semen in days and the number of services per conception. The significant regression of the number of services per conception on age of semen was 0.47.

Although the number of services per conception showed a tendency to decline in summer and fall, the difference was not significant. The rainfall by seasons was not related to the number of services per conception. The average seasonal temperature was not significantly related to the number of services per conception, though there was a tendency for the number of services per conception to be low in summer and fall. Both age of bull and age of cow varied significantly in the number of services per conception. There was no consistent trend with age of bull. The significant correlation between age of cow and the number of services per conception was 0.71, and the significant regression was 0.12. There was an indication that younger and older cows were less efficient than cows of intermediate age. Cows four and five years of age mated to bulls four and five years of age were the most efficient. The least efficient matings were those of old cows and old bulls.

Cows and bulls were highly variable in reproductive ability. The bulls with 100 or more services varied from 1.88 to 3.26 services per conception. The within-cow variance was about two-thirds as large as the between-cow variance. The cow repeatability of the number of services per conception was 0.08, determined by intra-class correlation without removing year and seasonal variance. The repeatability of bulls for number of services per conception was 0.06.

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APPENDIX A

MONTHLY TEMPERATURES AND RAINFALL AT SULPHUR, OKLAHOMA

MONTHLY RAINFALL AT SULPHUR, OKLAHOMA, FOR THE PERIOD FROM 1934 THROUGH 1952

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Total
1934	2.40	2.72	3.80	2.97	3.00	2.81	.00	.87	6.38	1.06	5.98	.48	32.47
1935	1.89	.85	5.38	4.31	12.54	7.48	2.34	4.14	5.45	3.84	3.09	3.05	54.36
1936	.43	.40	1.61	1.07	8.38	.60	2.52	T[1]	12.68	3.56	.30	1.62	33.17
1937	2.47	.18	4.06	3.68	2.22	2.79	4.63	4.38	.05	3.27	2.10	2.93	32.76
1938	2.60	9.55	4.61	2.55	6.05	4.83	2.57	1.43	2.44	.50	2.80	.68	40.61
1939	3.07	1.73	1.96	2.78	2.70	4.35	1.26	2.67	.59	2.91	2.28	1.20	27.50
1940	.45	2.87	T	6.82	9.33	6.58	6.83	2.47	.22	3.28	6.67	2.87	48.39
1941	2.88	3.18	.47	6.89	4.62	7.71	1.06	6.63	4.02	15.89	1.59	1.58	56.52
1942	.46	2.30	1.70	10.62	4.28	8.18	.77	4.76	3.68	5.41	2.24	2.53	46.93
1943	.15	.74	3.14	4.23	7.81	2.73	1.21	T	1.21	1.63	.12	3.87	26.84
1944	2.78	4.76	2.63	2.75	5.86	2.74	3.21	2.77	.85	4.44	3.82	2.65	38.97
1945	1.70	4.44	9.76	8.61	1.41	10.99	4.58	6.13	11.13	.78	.72	.08	60.33
1946	6.42	3.66	4.01	2.83	5.66	3.43	.84	6.71	2.72	.14	6.80	8.42	51.64
1947	.32	.34	1.21	9.04	8.04	4.28	1.57	1.13	3.33	1.61	2.87	2.70	36.44
1948	.98	4.19	2.51	.70	7.59	6.64	3.62	1.32	.12	.78	.48	1.27	30.20
1949	5.97	2.69	3.38	2.13	6.14	4.90	.58	2.75	6.28	4.54	.00	1.48	40.84
1950	3.02	1.86	.35	2.03	6.44	3.39	5.91	7.94	2.48	.71	.22	.10	34.45
1951	1.14	3.61	1.35	1.43	5.88	6.87	5.54	2.92	1.78	3.15	1.84	.31	35.82
1952	.31	1.23	3.33	4.72	4.86	.50	2.85	.90	.10	.03	4.47	1.45	24.75
Ave.	2.08	2.70	2.91	4.22	5.94	4.83	2.73	3.15	3.45	3.03	2.55	2.07	39.53

1. Indicates trace.

MONTHLY AVERAGE TEMPERATURE AT SULPHUR, OKLAHOMA, FOR THE PERIOD FROM 1934 THROUGH 1952

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1934	44.9	44.9	51.9	64.9	72.1	82.8	88.4	88.0	73.8	68.0	57.1	43.7
1935	45.8	47.8	60.3	61.2	67.2	75.6	82.6	84.2	70.8	64.6	47.8	41.5
1936	38.6	37.8	59.4	62.8	71.5	80.6	84.8	87.7	78.0	60.6	50.4	46.6
1937	36.4	44.4	49.2	63.6	72.0	79.8	83.6	84.6	75.9	63.7	49.4	41.2
1938	45.2	50.2	61.5	60.4	70.2	77.8	83.2	84.6	77.0	69.8	50.8	43.4
1939	46.5	42.2	58.0	61.4	72.6	80.3	86.0	84.2	82.3	68.7	50.9	47.8
1940	29.8	43.8	56.4	61.9	68.2	75.6	79.7	79.1	74.6	68.4	48.4	45.0
1941	45.0	43.2	49.4	63.4	72.4	75.5	82.4	81.4	76.6	67.8	52.4	47.0
1942	38.7	45.0	53.0	64.2	68.8	78.2	81.4	80.6	72.2	63.4	57.0	44.2
1943	41.5	49.2	48.5	66.6	70.2	80.3	84.5	88.8	75.8	63.7	52.0	40.2
1944	42.0	48.6	51.8	62.6	70.1	80.5	82.6	84.2	75.3	65.8	55.2	39.6
1945	41.8	44.6	58.2	61.6	69.1	76.5	79.5	80.0	74.9	63.2	55.0	39.2
1946	42.2	50.4	58.2	66.6	67.8	77.2	83.4	83.8	74.0	67.3	53.8	49.6
1947	42.5	41.2	47.4	62.0	68.1	78.4	79.8	84.7	79.0	71.3		
1948	35.4	42.2	49.8	67.6	69.7	78.6	81.6	81.7	75.9	61.8	49.4	42.7
1949	33.6	42.1	51.1	59.3	71.7	78.5	84.3	79.4	70.6	62.7	53.5	42.9
1950	41.6	47.1	51.3	61.2	70.4	77.0	77.7	77.9	71.9	68.8	50.9	41.3
1951	40.8	45.5	53.1	60.3	68.8	76.7	82.8	86.3	75.9	65.6	47.2	44.5
1952	49.6	50.0	51.1	59.1	69.4	82.3	83.2	88.0	77.6	62.0	51.1	41.9

APPENDIX B

ANALYSIS OF VARIANCE FOR SIRE AND SEX EFFECTS ON GESTATION LENGTH

Source	d.f.	Mean Squares	F
Total	3541		
Sire of Calf	120	113	.30
Sex of Calf	1	1015	2.67
Error	3420	380	

S. D. = 19.5 days

APPENDIX C

ANALYSIS OF YEARLY AND SEASONAL EFFECTS

ANALYSIS OF VARIANCE FOR YEARLY AND SEASONAL EFFECTS ON NUMBER OF SERVICES PER CONCEPTION

Source	d.f.	Mean Squares	F
Total	3248	1.47	
Year	16	9.50	1.85*
Season	3	3.00	2.19
Season-Within-Year	50	5.14	3.75**
Error	3179	1.37	

S. D. = 1.17
* $(P < .05)$
** $(P < .01)$

ANALYSIS OF VARIANCE FOR YEARLY AND SEASONAL EFFECTS ON THE INTERVAL FROM CALVING TO CONCEPTION

Source	d.f.	Mean Squares	F
Total	2922		
Year	16	28,402	1.39
Season	3	10,222	1.83
Season-Within-Year	50	20,436	3.66**
Error	2853	5,590	

S. D. = 74.7 days
** $(P < .01)$

ANALYSIS OF VARIANCE FOR YEARLY AND SEASONAL
EFFECTS ON GESTATION LENGTH

Source	d.f.	Mean Squares	F
Total	3605	385.49	
Year	17	461.06	.50
Season	3	48.33	.12
Season-Within-Year	51	922.04	2.44
Error	3534	377.63	

S. D. = 19.4 days

ANALYSIS OF VARIANCE FOR YEARLY AND SEASONAL
EFFECTS ON CALVING INTERVAL

Source	d.f.	Mean Squares	F
Total	2886	6,102.41	
Year	16	28,755.25	1.34
Season	3	11,573.00	2.03
Season-Within-Year	50	21,448.80	3.77**
Error	2817	5,695.53	

S. D. = 75.5 days
** ($P < .01$)

ANALYSIS OF VARIANCE FOR YEARLY AND SEASONAL EFFECTS ON THE INTERVAL FROM CALVING TO FIRST BREEDING

Source	d.f.	Mean Squares	F
Total	2851	1,558	
Year	16	5,672	1.07
Season	3	10,217	7.01**
Season-Within-Year	50	5,279	3.62**
Error	2782	1,459	

S. D. = 38.2 days
** ($P < .01$)

ANALYSIS OF VARIANCE FOR YEARLY AND SEASONAL EFFECTS ON THE INTERVAL FROM FIRST BREEDING TO CONCEPTION

Source	d.f.	Mean Squares	F
Total	2853		
Year	16	21,275	1.51
Season	3	45,649	10.78**
Season-Within-Year	50	14,339	3.39**
Error	2784	4,233	

S. D. = 65 days
** ($P < .01$)

APPENDIX D

ANALYSIS OF THE COW EFFECT ON REPRODUCTIVE PERFORMANCE

ANALYSIS OF VARIANCE FOR COW EFFECTS ON NUMBER OF SERVICES PER CONCEPTION

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	3248				
Between Cows	847	1.70	1.28**	$\sigma^2 + k\sigma_c^2$	.10
Within Cows	2401	1.33		σ^2	1.33

** ($P < .01$)
k = 3.8 = Average number of records per cow.

ANALYSIS OF VARIANCE OF COW EFFECTS ON GESTATION LENGTH

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	3605				
Between Cows	847	569	1.75**	$\sigma^2 + k\sigma_c^2$	57
Within Cows	2758	326		σ^2	326

** ($P < .01$)
k = 4.3 = Average number of records per cow.

ANALYSIS OF VARIANCE FOR COW EFFECTS ON CALVING INTERVAL

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	2886				
Between Cows	775	6960	1.25**	$\sigma^2 + k\,\sigma_C^2$	366
Within Cows	2131	5569		σ^2	5569

** ($P < .01$)
k $\doteq$ 3.8 $\doteq$ Average number of records per cow.

ANALYSIS OF VARIANCE FOR COW EFFECTS ON THE INTERVAL
FROM CALVING TO FIRST BREEDING

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	2851				
Between Cows	751	1658	1.13*	$\sigma^2 + k\,\sigma_C^2$	50
Within Cows	2100	1468		σ^2	1468

* ($P < .05$)
k $\doteq$ 3.8 $\doteq$ Average number of records per cow.

ANALYSIS OF VARIANCE FOR COW EFFECTS ON THE INTERVAL FROM FIRST BREEDING TO CONCEPTION

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	2853				
Between Cows	751	5149	1.25**	$\sigma^2 + k\sigma_C^2$	271
Within Cows	2102	4121		σ^2	4121

** ($P < .01$)
k = 3.8 = Average number of records per cow.

ANALYSIS OF VARIANCE FOR COW EFFECTS ON THE INTERVAL FROM CALVING TO CONCEPTION

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	2922				
Between Cows	760	6973	1.29**	$\sigma^2 + k\sigma_C^2$	286
Within Cows	2162	5400		σ^2	5400

** ($P < .01$)
k = 3.8 = Average number of records per cow.

APPENDIX E

ANALYSIS OF THE PERFORMANCE OF DAUGHTERS OF VARIOUS SIRES

ANALYSIS OF VARIANCE OF NUMBER OF SERVICES PER CONCEPTION IN THE DAUGHTERS OF VARIOUS SIRES

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	2798				
Between Sires	116	1.78	1.29*	$\sigma^2 + k\,\sigma_s^2$	.017
Within Sires	2682	1.38		σ^2	1.38

* ($P < .05$)
k = 23 = Average number of records per sire.

ANALYSIS OF VARIANCE OF THE INTERVAL FROM CALVING TO CONCEPTION IN THE DAUGHTERS OF VARIOUS SIRES

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	2518				
Between Sires	115	6841	1.24*	$\sigma^2 + k\,\sigma_s^2$	57
Within Sires	2403	5536		σ^2	5536

* ($P < .05$)
k = 21 = Average number of records per sire.

ANALYSIS OF VARIANCE OF GESTATION LENGTH IN THE DAUGHTERS OF VARIOUS SIRES

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	3112				
Between Sires	117	211	.64	$\sigma^2 + k\sigma_S^2$	-4.5
Within Sires	2995	328		σ^2	328

k = 26 = Average number of records per sire.

ANALYSIS OF VARIANCE OF CALVING INTERVAL IN THE DAUGHTERS OF VARIOUS SIRES

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	2886				
Between Sires	115	7108	1.45**	$\sigma^2 + k\sigma_S^2$	92
Within Sires	2771	4896		σ^2	4896

** ($P < .01$)

k = 24 = Average number of records per sire.

ANALYSIS OF VARIANCE OF THE INTERVAL FROM CALVING TO FIRST BREEDING OF THE DAUGHTERS OF VARIOUS SIRES

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	2459				
Between Sires	114	1756	1.13	$\sigma^2 + k\,\sigma_S^2$	9
Within Sires	2345	1560		σ^2	1560

k = 21 = Average number of records per sire.

ANALYSIS OF VARIANCE OF THE INTERVAL FROM FIRST BREEDING TO CONCEPTION IN THE DAUGHTERS OF VARIOUS SIRES

Source	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	2460				
Between Sires	114	4666	1.13	$\sigma^2 + k\,\sigma_S^2$	25
Within Sires	2346	4136		σ^2	4136

k = 21 = Average number of records per sire.

APPENDIX F

ANALYSIS OF SUCCESS OF SERVICE

ANALYSIS OF VARIANCE OF COW DIFFERENCES IN SUCCESS OF SERVICES

	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	3459				
Between Cows	613	.35	1.59**	$\sigma^2 + k\,\sigma_C^2$	.02
Within Cows	2846	.22		σ^2	.22

** ($P < .01$)
k = 5.6 = Average number of services per cow.

ANALYSIS OF VARIANCE OF BULL DIFFERENCES IN SUCCESS OF SERVICES

	d.f.	Mean Squares	F	Component Expectation	Component Estimates
Total	3203				
Between Bulls	30	1.50	6.52**	$\sigma^2 + k\,\sigma_b^2$	.014
Within Bulls	3173	.23		σ^2	.230

** ($P < .01$)
k = 87.8 = Average number of services per bull.

VITA

Charles Edward Lindley

Candidate for the Degree of

Doctor of Philosophy

Thesis: A STUDY OF THE REPRODUCTIVE PERFORMANCE OF A PUREBRED HEREFORD HERD

Major Field: Animal Breeding

Biographical:

Personal data: Born at Macon, Mississippi, December 21, 1921, the son of William E. and Hazel Lindley. Married Nancy Kathryn Penick December 21, 1945; the father of one son, Charles E. Lindley, Jr.

Education: Attended grade school at Salem community school near Macon, Mississippi; graduated from Macon High School in 1939; received the Bachelor of Science degree from Mississippi State College, with a major in Animal Husbandry, in May, 1946; received the Master of Science degree from the State College of Washington, with a major in Animal Husbandry, in May, 1948; completed requirements for the Doctor of Philosophy degree in May, 1957.

Professional experience: Spent 33 months in the United States Air Force as an Aviation Cadet and Fighter Pilot in the European Theater during World War II, and is now a member of the Air Force Reserve with the rank of Captain.

Instructor of Animal Husbandry at Mississippi State College summer of 1946; Graduate Assistant at the State College of Washington from 1946 to 1948 and Assistant Professor of Animal Husbandry from 1948 to 1951; Graduate Assistant Oklahoma Agricultural and Mechanical College from 1951 to 1952; Professor and Head of Animal Husbandry at Mississippi State College 1952 to present (on leave for graduate study at Oklahoma Agricultural and Mechanical College 1955 to 1956).

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