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To the Graduate Council:

I am submitting herewith a thesis written by Oid Luther Robertson, Jr., entitled "Pelvic Area Measurements of Heifers as a Predictor of Calving Difficulty." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Husbandry.

George M. Merriam
Major Professor

We have read this thesis and
recommend its acceptance:

Robert R. Shrode
John D. Smalling

Accepted for the Council:

Hilton A. Smith
Vice President for
Graduate Studies and Research

PELVIC AREA MEASUREMENTS OF HEIFERS AS A
PREDICTOR OF CALVING DIFFICULTY

A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
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CHAPTER I

INTRODUCTION

In order to improve the economic situation of beef cattle enterprises in the Southeast and the nation as a whole, it is necessary to look at the areas of production which present problems related to the actual number of calves, pounds of calf, or pounds of meat marketed.

In doing this, one should look at the overall picture of beef cattle production to see where the greatest improvement is needed. It is an understatement to say that no areas exist where progress could not be made. Improvement in genetics and breeding is being made with the tools of production testing and type improvement programs. Studies in nutrition, breeding, and engineering have improved feed efficiency, carcass quality, and feedlot practices. However, if one compares the number of animals marketed with the number of breeding animals on farms, obviously, an increase in what is commonly called "calf crop" would be of significant aid in increasing the amount of product marketed and therefore the amount of profit to be made.

An increase in calf crop can best be made by determining at what point or points calf mortality is greatest and correcting those specific problems. Three reasons are generally given for low calf crops. These reasons are failure of cows to become pregnant, death of fetuses, and death of calves at or shortly after birth. Of these three the failure of cows to become pregnant and the loss of calves at or near birth have

been earlier considered as being most important. However, today most authorities seem to agree that the three factors are about equal in importance.

Research reported herein was designed to study methods of predicting and controlling calf losses at birth through measurements of the pelvic area of heifers. Specific objectives were to determine or evaluate the following:

1. Repeatability and accuracy of the measurements.
2. Correlations between the measurements of a young heifer and those of the same heifer immediately prior to parturition.
3. Relationship of internal pelvic area to certain external pelvic measurements.
4. Effect upon birth difficulty of maternal pelvic area and fetal weight and size.



CHAPTER II

LITERATURE REVIEW

Few references are found in the literature concerning the growth patterns of the bovine female pelvis, the relationship of the internal size of the pelvis to any external measurements, or the relation of the size of the pelvis to calving difficulty.

I. ECONOMIC IMPORTANCE OF SIZE OF CALF CROP

To establish the importance of increasing the calf crop, it is first necessary to consider how calf crop influences income in a beef cattle enterprise.

Wiltbank et al. (1966) states that calf crop is directly related to profit. Using the example of a 400 pound calf at \$26 per hundred-weight or a gross income of \$104 per calf and \$60 per year as the cost of keeping a cow, he indicated that profit varied from \$44 per calf with a 100 percent calf crop to a loss of \$16 per calf with a 50 percent calf crop. By increasing the calf crop from 75 to 80 percent, the profit per calf would be increased from \$24 to \$29. In a 100 cow herd this would mean an increase in profit of \$500. When all the beef cows in the United States were considered, this became an increase of 136 million dollars per year.

II. REPORTS OF CALF CROP SIZE AT THE PRESENT TIME

Hurst and Godly (1965) reported in a reproductive efficiency study that, of 678 calves born, 9 percent were born dead or died shortly after birth.

Temple (1963) in a summary of cow performance including 5,165 cows from USDA Southern Regional (S-10) herds indicated an average calving percentage of cows exposed of 80.9 percent. No breed differences were indicated.

Temple (1965) in a later study involving 19,388 cows in 14 southern and eastern states indicated a calving percentage of 77.3 percent. This percentage was of cows in the herd at breeding time minus those removed for other than reproductive causes. Of 13,885 calves born, 6.9 percent died before they were 36 hours old.

Wiltbank et al. (1966), using figures released by the American National Cattleman's Association for 1954, gave the average percent calf crop weaned as being 46 percent in the South, 67 percent in the West, 74 percent for the Pacific Northwest, and 80 percent for the Great Plains. These figures are for percentage of cows bred that weaned calves.

Bellows (1963) presented a 17-year summary of calving performance of cows at the Miles City, Montana, USDA Experiment Station. Percentage of cows giving birth to live calves ranged from 66 percent to 92 percent during the 17 years that the study was conducted. Also, from work at this station, he found that the yearly percentage of calves stillborn or dying shortly after birth was approximately 4 percent. The greatest

frequency of stillbirths was in first calf (three-year-old) heifers. All dead calves were autopsied, and the most frequent findings were bruises and hemorrhages indicative of a slow or difficult birth.

Merriman (1967) reported on a study that had been conducted at seven University of Tennessee Experiment Stations for five years. This study included both fall and spring calvings. Of the 3,712 spring parturitions, 93 percent of the calves were born alive, and 91 percent survived to weaning. In the fall calving seasons, a total of 765 calves were born and 96.3 percent of these calves were alive after the first 36 hours. Of those which were alive at 36 hours, 92 percent survived to weaning. During the five years, 325 spring-season calves died and 75 percent of these deaths occurred at birth. Deaths among fall calves for all years combined totaled 59, with 42 percent of these occurring at birth. Cattle of both Hereford and Angus breeds were used, and survival rates were nearly identical for the two breeds. Data for heifers and cows of all ages were considered together. These figures represent a loss of 384 calves from 4,477 births. These calves, had they lived to reach an average weaning weight of 450 pounds, could have been expected to gross a minimum of \$99 per head or a total of \$38,016 as "sold of grass."

Merriman and Hobbs (1962) conducted experiments in which the effects of fluorosis on beef cattle were studied. In the five years of the program difficult calving was a major problem; however, it had no relationship to the fluorine levels in soil, pasture, or water. Three

hundred and thirteen calves were born of a possible 331 gestations, and 283 (85 percent) of these calves survived to weaning age.

III. PREVIOUS WORK INVOLVING PELVIC MEASUREMENTS

Wiltbank et al. (1966) determined the pelvic areas of first-calf Hereford heifers by multiplying the measurements between the sacrum and the symphysis pubis by the measurements made between the two ilia. The measurements were taken per rectum. Almost one-half of the heifers with pelvic areas of less than 230 square centimeters had calving difficulty, whereas the incidence of calving difficulty in heifers with pelvic areas of more than 230 square centimeters was only 18 percent. Also, it was found that the average birth weight of the calves born dead was smaller than that for the calves born alive. But averages sometimes do not tell the whole story, so the birth weights were divided into ten-pound increments. Lack of the "ability to live" and calving difficulty were emphasized as causes of calf deaths. Losses were high in calves with small birth weights (below 50 pounds), and in those with heavy birth weights (80 pounds or more). Very little calving difficulty was encountered in cows giving birth to calves weighing between 50 and 59 pounds. The incidence of calving difficulty increased as the birth weight of the calf increased; in cows giving birth to calves weighing over 80 pounds the incidence of calving difficulty was high. However, a large number of heifers gave birth to calves weighing over 80 pounds and calved without difficulty.

The next year the possibility of using size of the pelvic opening as a predictive tool was studied by Wiltbank with 51 heifers. Results were quite good in predicting calving difficulty in first-calf, three-year-old Hereford heifers on the basis of pelvic measurements made in December before the spring calving season. However, the numbers were small and the incidence of calving difficulty and death loss was low.

Bellows et al. (1965) at Miles City, Montana, studied associations among pelvic opening area, hip width, rump length, and body weight in 178 three-year-old, first-calf Hereford heifers. He found correlations of pelvic area with hip width, rump length, and body weight of 0.52, 0.50, and 0.53, respectively. No measurements of calving difficulty were made.

Berry (1963) at the Wortham Foundation Research Laboratory at Cypress, Texas, turned his attention to the problem of pelvic size because of the occurrence of dystocia in first-calf heifers. Two measurements were made, and from these the area was obtained by the use of the formula $A = \left(\frac{H + P}{4} \right)^2 \mu$, where A designates area; H, the length of the measurement made between the floor of the pelvis and the sacrum; and P, the measurement made between the two ilia. Dividing by four yields a measurement similar to the radius of a circle. Then this number is squared and multiplied by pi. This formula in essence is equal to the usual formula $A = \mu r^2$ for finding the area of a circle. The study was not concluded because of the inaccessibility of a large number of the experimental animals for later observation.

CHAPTER III

EXPERIMENTAL PROCEDURE

I. ANIMALS

The 107 heifers used in this study were in the Alcoa Farms research unit of The University of Tennessee. Both purebred Angus and purebred Hereford heifers were used. As is shown in Table I, three different age groups of heifers were involved. However, only two of these groups had calved before termination of the experiment.

All heifers of Lot 1 nursed their dams on pasture until weaned at six to eight months of age. They were continued on pasture until winter, at which time they were fed corn silage ad libitum. In the spring they were again placed on pasture with no supplementation. The second winter treatment was similar to the first, and this was continued through the calving season. The heifers in Lot 2 were handled in the same manner until their first winter when they were included in a simultaneous experiment that required that one-half of them be kept in a dry lot and fed corn silage ad libitum and a concentrate ration consisting of corn, cottonseed meal, and urea. The other one-half were kept on winter pastures, primarily wheat, and fed hay as needed. The following summer all were on pasture entirely. For the second winter they were fed to gain from .75 to 1.50 pounds per day on corn silage. The Lot 3 heifers were maintained on pasture while nursing as well as from weaning until winter

TABLE I
SUMMARY OF ANIMALS AND SCHEDULE OF MEASUREMENTS

	Lot 1	Lot 2 a	Lot 2 b	Lot 3
No. of heifers	36	18	28	25
Birth dates	Spring 1964	Fall 1964	Spring 1965	Fall 1965
Dates weaned	Oct. 10, 1964	April 8, 1965	Sept. 14, 1965	May 11, 1965
Dates of first measurement	January 1966	November 1965	January 1966	November 1966
Age at first measurement	20-23 months	11-13 months	11-13 months	11-13 months
Age at final measurement	23-26 months	28-31 months	26-29 months	15-18 months
No. of measurements	2	5	6	3
Dates bred	Spring 1965	Spring 1966	Spring 1966	Spring 1967
Calving dates	Spring 1966	Spring 1967	Spring 1967	--
Wts. at first measurement (av.)	815#	565#	545#	555#
Wts. at first measurement (range)	770#-895#	495#-595#	490#-590#	505#-600#
Wts. preceding calving (range)	770#-895#	915#-1095#	785#-905#	--

when they were fed corn silage ad libitum. They were a year and a half old when the experiment was terminated, at which time they were placed back on pasture.

II. INSTRUMENTS FOR MEASURING

Tube-like, sliding, calibrated instruments were used for taking the internal measurements. These instruments were patterned after those used by Dr. R. O. Berry at the Wortham Foundation. Two instruments were used: one was eight centimeters in length and could be extended to a length of 12 centimeters; the other was 12 centimeters long and could be extended to a length of 18 centimeters. The external measurements were made with a set of expanding metal calipers. Expansion of the calipers was measured on a meter stick.

III. MEASUREMENTS

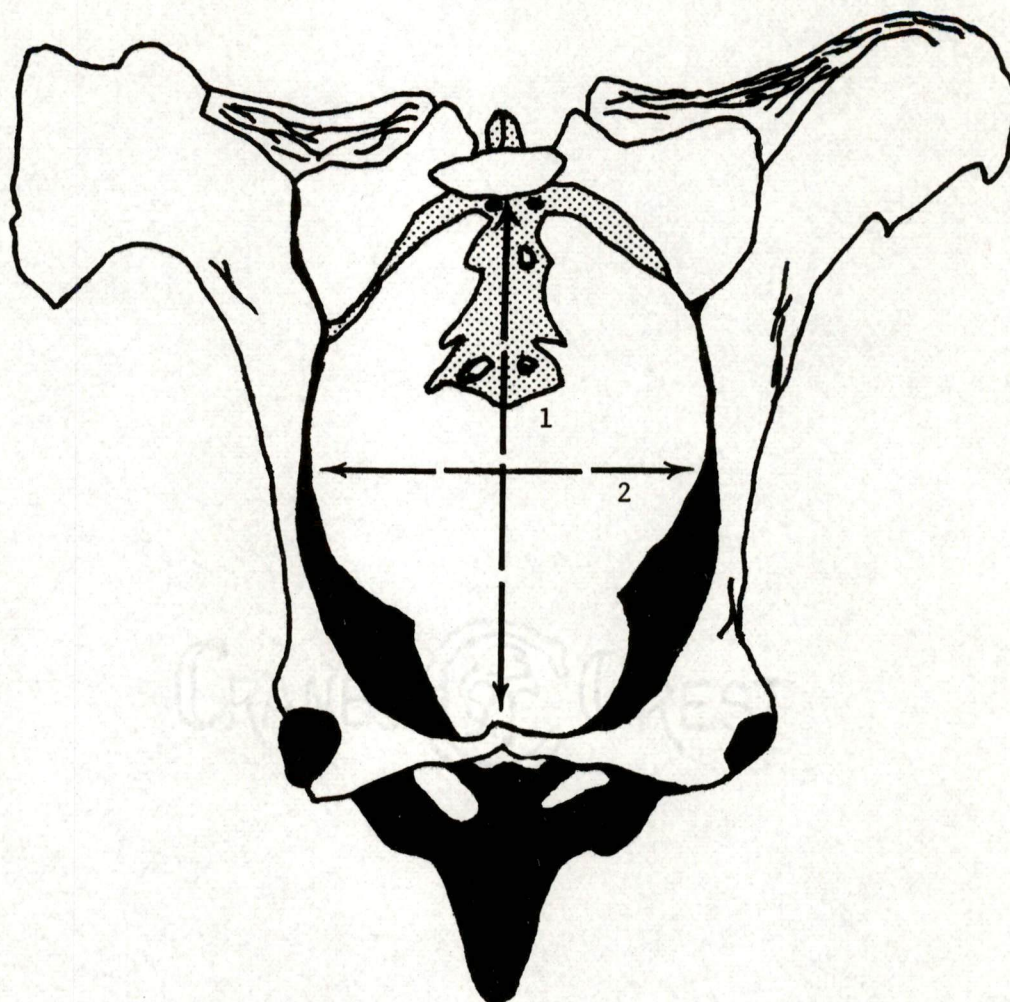
Measurements were made twice on the heifers in Lot 1, once just prior to calving and the other just after calving. Measurements on Lot 2 heifers were started when the heifers were yearlings and were made a total of five times on heifers born in the spring of 1965 (Lot 2b) and four times on heifers born in the fall of 1964 (Lot 2a). Though these lots of heifers varied approximately six months in age, they were simply listed as subgroups of Lot 2 as they did calve at the same time. These measurements were repeated at approximately equal intervals after the first was made until the heifers calved, and one other set of

measurements was made following parturition. Lot 3 heifers were yearlings when they were first measured. Measurements of these heifers continued until the animals were one and a half years old at which time the experiment was terminated (Table 1, page 9).

Internal measurements were made per rectum with a horizontal and a vertical measurement being made at each of two locations (Figures 1 and 2). The anterior vertical measurement was made from the anterior border of the symphysis pubis to the sacrum. The anterior horizontal measurement was made between the two shafts of the ilia. The posterior vertical measurement was made from the posterior limit of the floor of the pelvis to the sacrum, and the posterior horizontal measurement was made between the inner walls of the tuber ischii. The area of the pelvic opening was found by the use of the formula $A = \left(\frac{H + P}{4} \right)^2 \mu$. Both anterior and posterior measurements were used to find an anterior area and a posterior area. In the formula, A designates area; H, the horizontal measurement; and P, the vertical measurement.

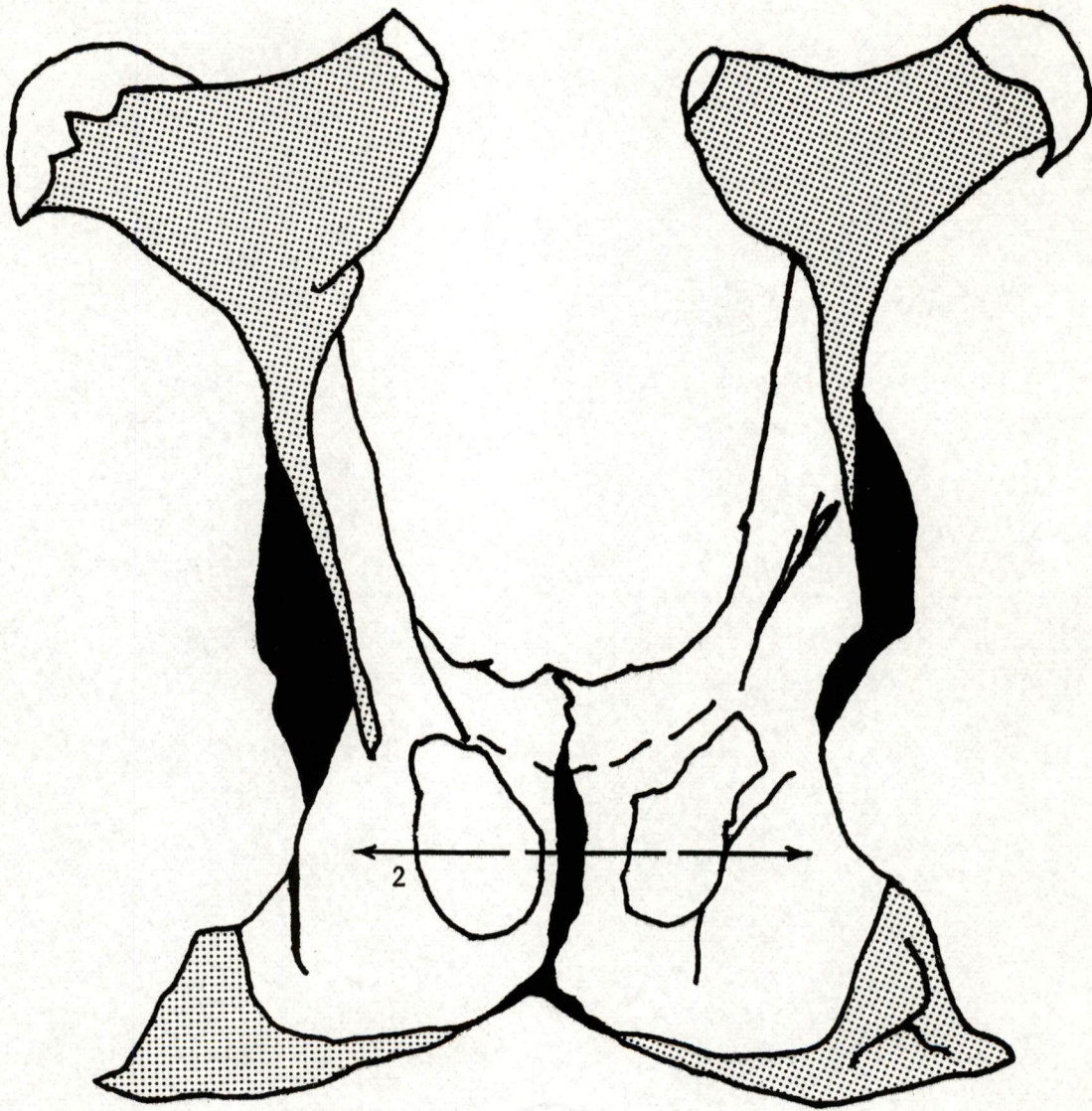
Three external measurements were made. Width of the hips was measured from the lateral surfaces of the two tuber coxae. Length of rump was measured from the anterior surface of the tuber coxae to the posterior surface of the tuber ischii. The width between the "pin bones" was measured by taking the width between the lateral surfaces of the two tuber ischii.

Five measurements and the birth weight of each calf were recorded for calves born to Lot 2 (a,b) heifers and birth weight only for calves



1. Anterior vertical measurement.
2. Anterior horizontal measurement.

FIGURE 1
ANTERIOR VIEW OF THE BOVINE PELVIS



1. Posterior vertical measurement. This measurement was made from the posterior edge of the pelvic floor to the sacrum.
2. Posterior horizontal measurement.

FIGURE 2
POSTERIOR VIEW OF THE BOVINE PELVIS

from Lot 1 heifers. These measurements were taken within 12 hours of birth. Measurements taken were width of the head, width of the shoulders, circumference of the shoulders, hip width, and circumference of the hips. The calf was stretched on the ground while being measured to approximate as closely as possible its position during birth. These measurements of the calf were made with the same calipers and meter stick that were used in taking the external cow measurements plus a length of prestretched cord.

Data on difficulty of parturition were recorded by the herdsman on a prepared form (Appendix). These forms were collected and each parturition was assigned a number designating the degree of difficulty of calving. These designations range from 0 through 5 and indicate calving difficulty as follows: 0--normal parturition, 1--calf had to be straightened, 2--calf was pulled by one person, 3--calf was pulled by two or more persons or with the aid of a block and tackle or "calf jack," 4--embryotomy was required, 5--caesarian section was required. Malpresentations, of themselves, were recorded but were not considered as a cause of calving difficulty except for the amount of help needed after the malpresentation was corrected.

IV. STATISTICAL METHODS

A total of seven measurements (four internal and three external) were taken each time measurements were made. The internal measurements were then used to calculate pelvic area. The two anterior measurements

were used to calculate the anterior pelvic area, and the two posterior measurements were used to calculate the posterior pelvic area. This gave a total of nine measurements for each cow plus a body weight measurement taken just prior to calving.

Accuracy of the measurements was determined by taking a series of measurements on a group of heifers and immediately taking another series of measurements on the same heifers. Thirty-seven animals, each with two sets of measurements, were used in calculating repeatability. From these two series of measurements, product-moment correlations were calculated to measure variation between measurements made on the same animals with a short time interval and made by the same person.

Changes in the same measurements because of age were only available for the Lot 2(a,b) animals. The Lot 1 heifers were measured only one time prior to calving, and the Lot 3 heifers did not calve before the experiment was terminated. Again, product-moment correlations were used as a measure of change in pelvic size. To show any changes that did occur, all different measurements were correlated with the set of measurements made just prior to calving. Therefore, the first correlations made were between the measurements taken when the heifers were yearlings and the measurements taken just prior to calving. Then the second set of measurements were correlated with the set of measurements taken just prior to calving and so on until all correlations of this type had been computed.

Relations of certain combinations of external measurements (hip width, pin width, rump length, and body weight) with internal area were made by using least-squares analyses to fit models and then determining which combinations of external measurements were most valuable in predicting internal area. Also, product-moment correlations were used to determine the relationship of each external measurement to internal area (anterior and posterior).

One model including all four external measurements and models consisting of all possible combinations of the individual measurements were fitted. The overall model was:

$$\hat{Y}_{ijklm} = \mu + h_i + p_j + r_k + b_l + e_{ijklm}$$

where

$\hat{Y}_{ijklm}$ is the observed value of a given trait for the
ijklm-th individual;

μ is the effect common to all observations and is the
mean of the population when equal numbers exist in
the subclasses (absorbed);

h_i is the effect of the i-th hip width;

p_j is the effect of the j-th pin width;

r_k is the effect of the k-th rump length;

b_l is the effect of the l-th body weight; and

e_{ijklm} is the random error associated with the ijklm-th
individual.

These models were fitted for all three lots of heifers that were used in the study.

A "left-handed" approach was necessary to determine the effect of maternal pelvic area and fetal weight and size upon calving difficulty. Calving difficulty was classified according to the classification given on page 14, thus it became a discrete variable. Since a discrete variable cannot be used as the dependent variable, internal area was made the dependent variable. Using the least-squares analysis with internal area as the dependent variable, determinations could be made as to whether there were or were not significant differences in the pelvic areas of those heifers that had difficulty in calving and those that did not. Also, other factors were present which might have been expected to exhibit some effect on calving difficulty; therefore, these factors were fitted in models with calving difficulty. These other factors were sire of the calf, birth weight of the calf, and size of the calf at birth at certain defined locations.

The models that were fitted to determine whether significant differences existed in the pelvic areas of those heifers that had difficulty and those that had no difficulty are shown below:

$$\hat{Y}_{ij} = \mu + d_i + e_{ij}$$

where

$\hat{Y}_{ij}$ is the observed value of a given trait for the ij -th individual;

- μ is the effect common to all observations and is the mean of the population when equal numbers exist in the subclasses (absorbed);
- d_i is the effect of the i -th calving difficulty; and
- e_{ij} is the random error associated with the ij -th individual.

Models fitted to include calving difficulty, sire, and calf measurements are illustrated below.

$$\hat{Y}_{ijkl} = \mu + d_i + s_j + h_k + e_{ijkl}$$

where

- Y_{ijkl} is the observed value of a given trait for the $ijkl$ -th individual;
- μ is the effect common to all observations and is the mean of the population when equal numbers exist in the subclasses (absorbed);
- d_i is the effect of the i -th calving difficulty;
- s_j is the effect of the j -th sire;
- h_k is the effect of the k -th external measurement; and
- e_{ijkl} is the random error associated with the $ijkl$ -th individual.

Five different calf measurements were fitted into models which included both discrete variables, calving difficulty and sire of calf, and in models with calving difficulty alone plus the five measurements and sire alone plus the five calf measurements.

CHAPTER IV

RESULTS AND DISCUSSION

I. REPEATABILITY OF MEASUREMENTS

Product-moment correlations between two sets, a set being all the measurements made on one animal at one time, of measurements (seven measurements per set) taken at short intervals on the same animals gave correlations of from .84 to .92 (Table II). The highest correlation (.925) was for hip width and the lowest (.841) was for the posterior vertical (internal) measurement.

All seven correlations are reasonably high. Therefore, it appears that measurements of the internal pelvic dimensions by a single operator are highly reliable.

II. RELATION OF MEASUREMENTS MADE AT DIFFERENT TIMES ON THE SAME ANIMALS

This work was undertaken to determine if calving difficulty in heifers could be predicted by determining pelvic area. Further, if pelvic dimensions of weaned heifer calves were found to correlate closely with pelvic dimensions of these same females at parturition, heifers liable to dystocia could be sold as feeder cattle rather than being placed in breeding herds. Therefore, correlations of each set of early dimensions with the set obtained immediately prior to calving were

TABLE II
PRODUCT-MOMENT CORRELATIONS FOR DETERMINATION
OF REPEATABILITY

Measurement	Measurement						
	1 ^a	2 ^b	3 ^c	4 ^d	Hip Width	Pin Width	Rump Length
1	.889						
2		.861					
3			.841				
4				.876			
Hip Width					.925		
Pin Width						.853	
Rump Length							.848

^aMeasurement 1--Anterior vertical measurement.

^bMeasurement 2--Anterior horizontal measurement.

^cMeasurement 3--Posterior vertical measurement.

^dMeasurement 4--Posterior horizontal measurement.

determined. In addition, pelvic dimensions of the heifers after calving were correlated with the measurements taken just prior to parturition. Summaries of the measurements for each period are shown in Tables III, IV, and V, while the correlations are shown in Tables VI and VII. Correlations are reported only for the two lots of heifers which calved during the experiment and had had more than one set of measurements made prior to calving.

As can be seen from Tables VI and VII there is, generally speaking, an increase in the correlations of the measurements as calving time approaches. However, this change is not at all consistent. Anterior area, area being the internal measurement with which we are most concerned, does exhibit a consistently increasing correlation with the measurement made just prior to calving. On the other hand posterior area at one point shows a potential decrease in correlation which may be in part accounted for by changes in the posterior vertical measurement. The two posterior measurements are used in the formula given on page 11 for the determination of posterior area. This change in the posterior vertical measurement may be caused by two factors. First, the measurements may be affected by a decrease in flexibility of the sacrum with an increase in age of the animal. Second, the heifers may have gained in weight during the experiment not only by overall growth but by increased fat deposition. Thus, changing accumulations of fat in the pelvic region may have affected these vertical measurements.

Lot 2b exhibits a change in that the correlations for both anterior and posterior area decrease after the first measurement and

TABLE III
MEANS AND STANDARD ERRORS OF PELVIC MEASUREMENTS,
LOT 1^a

	First Measurement (22 months of age)		Second Measurement (26 months of age)	
	Mean	Standard Error	Mean	Standard Error
	(cm.)	(cm.)	(cm.)	(cm.)
<u>Internal Measurements</u>				
Anterior vertical	15.211	± .1268	16.036	± .1467
Anterior horizontal	13.512	± .1619	13.920	± .1304
Anterior area	161.734	±2.6990	176.569	±2.7235
Posterior vertical	14.905	± .1831	14.647	± .1675
Posterior horizontal	12.876	± .1170	13.144	± .1280
Posterior area	151.920	±2.8156	151.436	±2.5690
<u>External Measurements</u>				
Hip width	44.95	± .3512	45.32	± .3099
Pin width	26.47	± .3138	25.42	± .3466
Rump length	43.70	± .3176	44.10	± .3466

^aCalved at 24 months.

TABLE IV
MEANS AND STANDARD ERRORS OF PELVIC MEASUREMENTS, LOT 2a

	First Measurement (16 months of age)		Second Measurement (20 months of age)		Third Measurement (24 months of age)		Fourth Measurement (27 months of age)		Fifth Measurement (30 months of age)	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
<u>Internal Measurements</u>										
Anterior vertical	13.672	± .2012	14.772	± .1540	15.038	± .1079	15.727	± .1365	16.277	± .1569
Anterior horizontal	12.144	± .1658	13.083	± .1813	13.461	± .1479	14.166	± .1880	14.283	± .1473
Anterior area	131.241	± 3.1954	152.773	± 3.4128	159.630	± 2.0840	175.75	± 2.9190	183.633	± 2.7379
Posterior vertical	12.405	± .1933	13.988	± .1865	13.272	± .1849	14.533	± .1871	14.938	± .1528
Posterior horizontal	11.344	± .2005	12.100	± .2374	12.550	± .1373	13.455	± .1796	13.633	± .1718
Posterior area	111.230	± 3.1464	134.493	± 3.8949	131.197	± 2.6255	154.886	± 3.0357	160.084	± 2.9633
<u>External Measurements</u>										
Hip width	41.08	± .6720	45.68	± .5266	48.45	± .6611	49.39	± .6167	49.75	± .6300
Pin width	24.22	± .4871	23.43	± .4394	27.32	± .6466	28.11	± .4662	29.53	± .4548
Rump length	41.80	± .4956	44.90	± .6109	45.76	± .4118	46.73	± .3479	46.66	± .5073

^a Calved at 27-28 months of age.

TABLE V
MEANS AND STANDARD ERRORS OF PELVIC MEASUREMENTS, LOT 2b

	First Measurement (12 months of age)		Second Measurement (15 months of age)		Third Measurement (18 months of age)		Fourth Measurement (21 months of age)		Fifth Measurement (24 months of age)		Sixth Measurement (26 months of age)	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
<u>Internal Measurements</u>												
Anterior vertical	12.614	± .1212	13.353	± .3617	13.614	± .1493	14.035	± .1428	14.796	± .1281	15.664	± .1413
Anterior horizontal	11.342	± .0915	11.857	± .1499	12.480	± .1367	12.771	± .1024	13.450	± .1227	13.857	± .1354
Anterior area	110.810	± 2.4818	125.868	± 4.3941	134.049	± 2.4062	141.332	± 1.9694	156.865	± 2.0846	193.922	± 23.8888
Posterior vertical	11.560	± .1051	12.271	± .1469	12.817	± .1685	13.128	± .1579	13.896	± .1371	14.464	± .1222
Posterior horizontal	10.611	± .1122	11.022	± .1438	11.514	± .1916	12.117	± .1557	12.796	± .1000	13.097	± .1252
Posterior area	127.585	± 29.2217	129.256	± 19.4324	116.925	± 2.7194	125.662	± 2.3536	139.133	± 1.8864	164.936	± .1314
<u>External Measurements</u>												
Hip width	42.53	± 1.6906	38.03	± 1.8460	42.71	± .3076	45.03	± .3664	45.26	± .3163	48.27	± 1.2890
Pin width	23.26	± .7641	24.09	± 1.1760	24.54	± .3079	26.58	± .2864	27.35	± .2426	30.63	± 1.8512
Rump length	42.83	± 1.7286	41.11	± 2.4433	41.73	± .2586	43.64	± .3401	43.75	± .3432	46.40	± 1.7008

^aCalved at 24 months of age.

TABLE VI
PRODUCT-MOMENT CORRELATIONS OF THE IMMEDIATE PREPARTURIENT
MEASUREMENTS WITH MEASUREMENTS MADE AT OTHER
TIMES,^{a, b} LOT 2a

Measurement	Time of Measurements			
	1 ^c	2 ^d	3 ^e	5 ^f
Anterior vertical	.233	.533	.670	.615
Anterior horizontal	.585	.399	.869	.453
Posterior vertical	.380	.061	.766	.666
Posterior horizontal	.154	.507	.365	.604
Hip width	.817	.657	.918	.865
Pin width	.296	.514	.938	.805
Rump length	.663	.459	.681	.672
Anterior area	.469	.517	.810	.472
Posterior area	.247	.116	.551	.514

^aThe heifers calved at approximately 27-28 months of age.

^bMeasurement four was the preparturient measurement.

^cThe first set of measurements was made when the heifers were 16 months of age.

^dThe second set of measurements was made when the heifers were 20 months of age.

^eThe third set of measurements was made when the heifers were 24 months of age.

^fThe fifth set of measurements was made when the heifers were 30 months of age, within a short interval after parturition.

TABLE VII
PRODUCT-MOMENT CORRELATIONS OF THE IMMEDIATE PREPARTURIENT
MEASUREMENTS WITH MEASUREMENTS MADE AT OTHER
TIMES,^{a,b} LOT 2b

Measurement	Time of Measurement				
	1 ^c	2 ^d	3 ^e	4 ^f	6 ^g
Anterior vertical	.743	-.000	.710	.739	.648
Anterior horizontal	.663	.271	.671	.549	.687
Posterior vertical	.000	.127	.321	.384	.376
Posterior horizontal	.559	.514	.681	.615	.629
Hip width	-.098	.398	.852	.845	.230
Pin width	.199	-.184	.489	.701	.002
Rump length	-.075	.287	.472	.752	.291
Anterior area	.731	.159	.729	.604	.089
Posterior area	-.099	-.070	.457	.476	.041

^aThe heifers in Lot 2b calved at approximately 24 months of age.

^bMeasurement five was the preparturient set of measurements.

^cThe first set of measurements was made when the heifers were yearlings.

^dThe second set of measurements was made when the heifers were 15 months of age.

^eThe third set of measurements was made when the heifers were 18 months of age.

^fThe fourth set of measurements was made when the heifers were 21 months of age.

^gThe sixth set of measurements was made when the heifers were 26 months of age, within a short interval after parturition.

then increase until calving time. The same reasons that were given for Lot 2a would be applicable here also. Other than these reasons, the author has not been able to determine why the aforementioned changes in Lots 2a and 2b occurred.

It will be noticed also that the pelvis undergoes changes approximately in accordance with the accepted theory of growth that most texts of anatomy describe, with some dimensions changing more than others.

It was found, in this experiment, that pelvic measurements of yearling heifers could not be used to predict the pelvic measurements of these same heifers just before parturition as two-year-olds.

III. RELATION OF EXTERNAL MEASUREMENTS TO INTERNAL AREA

Product-moment correlations were used to determine the relationship between external measurements, including body weight, and internal area (Table VIII).

In Tables IX and X the effects of the various combinations of external measurements on internal area are shown. These effects were determined by least-squares analysis. Hip width is the external measurement which is most consistently correlated with anterior area across all three lots. Also, cow weights, although the correlation is not significant in all cases, has a relatively high correlation with anterior area. These correlations are in accordance with or even a little higher than those found by Bellows et al. (1965). No high, consistent correlations

TABLE VIII
PRODUCT-MOMENT CORRELATIONS OF INTERNAL AREA WITH FOUR
EXTERNAL MEASUREMENTS AND BODY WEIGHT

Lot	Correlations							
	1 ^a	2 ^b	3 ^c	4 ^d	5 ^e	6 ^f	7 ^g	8 ^h
1	.561	.464	.414	.094	.427	.384	-.019	.364
2	.504	.466	.633	.240	.270	.360	.074	.165
3	.658	.108	.588	.346	.717	-.054	.439	.106

^aAnterior pelvic area & cow weight.

^bPosterior pelvic area & cow weight.

^cAnterior pelvic area & hip width.

^dAnterior pelvic area & pin width.

^eAnterior pelvic area & rump length.

^fPosterior pelvic area & hip width.

^gPosterior pelvic area & pin width.

^hPosterior pelvic area & rump length.



TABLE IX
MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING ANTERIOR AREA
FROM CERTAIN EXTERNAL MEASUREMENTS

Equation Number	Constant ^b	Coefficient of Variables in Equation				R ²
		Hip Width	Pin Width	Rump Length	Body Weight	
LOT 1						
1	-14.13	.2272	-.8289	1.5550	.1460	.349
2	-24.80	2.0790	-.4261	2.3897		.227
3	17.78	.8273	-.9115		.1598	.328
4	115.74	.0150		1.6130	.1414	.341
5	-11.79		-.7890	1.6342	.1501	.349
6	25.21	3.3336	-.4982			.174
7	-.11		.1765	3.5972		.183
8	-30.39	1.9372		2.4060		.225
9	7.45	.6178			.1552	.318
10	35.89		-.7614		.1798	.321
11	-23.74			1.6180	.1917	.341
LOT 2a						
1	78.19	3.1953	-.5470	-1.3320	.0178	.436
2	67.56	3.6276	-.5732	-1.1680		.426
3	41.18	2.9661	-.9106		.0150	.423
4	-69.71	3.0663		1.6374	.0182	.431
5	109.37		.3216	-.0379	.0603	.256
6	35.10	3.3607	-.8938			.415
7	76.78		.7804	1.6514		.083
8	71.37	3.5018		-1.4838		.421
9	33.63	2.6098			.0144	.408
10	107.65		.3086		.0601	.256
11	106.66			.1864	.0612	.254
LOT 2b						
1 ^a	-53.62	1.6006	.1263	2.3126	.0398	.607 ^a
2	-76.57	1.7615	.2263	3.3789		.565
3 ^a	-20.96	2.3002	.6168		.0675	.545 ^a
4 ^a	-52.02	1.6151		2.3380	.0399	.606 ^a
5 ^a	-19.42		.3819	2.9523	.0436	.567 ^a
6 ^a	-40.62	3.5056	1.4299			.371 ^a
7	-41.05		.5209	4.2034		.517
8 ^a	-73.90	1.7884		3.4309		.565 ^a
9	-11.10	2.4132			.0697	.540
10 ^a	49.65		1.2564		.0863	.452 ^a
11 ^a	-13.61			3.0483	.0441	.566 ^a

TABLE IX (continued)

Equation Number	Constant ^b	Coefficient of Variables in Equation				R ²
		Hip Width	Pin Width	Rump Length	Body Weight	
LOT 3						
1	41.99	1.6257	.3216	-.1621		.076
2	38.50	1.5618	.3037			.076
3	39.79	1.6350		-.0742		.075
4	35.73		.3582	1.5525		.033

^ap < .05.

^b"Constant" refers to the constant term in a regression equation, computed by subtracting from the mean of the dependent variable the product of the mean of each independent variable and the regressions of the dependent variable on that independent variable.

TABLE X

MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING POSTERIOR AREA
FROM CERTAIN EXTERNAL MEASUREMENTS

Equation Number	Constant	Coefficient of Variables in Equation				R ²
		Hip Width	Pin Width	Rump Length	Body Weight	
LOT 1						
1	4.05	1.1019	-1.8422	1.1737	.1179	.276
2	-5.39	2.5974	-1.5169	1.8477		.203
3	27.32	1.5548	-1.9046		.1283	.265
4	-21.32	.6302		1.3025	.1075	.240
5	14.77		-1.6488	1.5576	.1375	.268
6	-49.77	3.5675	1.5727			.174
7	25.44		- .7639	3.3563		.139
8	-25.33	2.0928		1.9059		.178
9	4.48	1.1170			.1188	.226
10	58.96		-1.6224		.1658	.245
11	-12.88			1.5243	.1199	.237
LOT 2a						
1	113.79	.8837	- .9817	- .6587	.0565	.245
2	80.17	2.2514	-1.0616	- .1382		.150
3	95.04	.7704	-1.1614		.0551	.242
4	122.47	.6522		-1.2059	.0672	.231
5	122.19		- .7414	- .3006	.0683	.232
6	76.35	2.2198	-1.0997			.150
7	85.85		- .2220	1.6116		.027
8	89.20	2.0181		- .7240		.134
9	85.51	.3160			.0544	.219
10	112.45		- .8447		.0669	.232
11	127.50			- .8179	.0663	.224
LOT 2b						
1	93.22	-1.4812	3.9305	- .0098	.0071	.241
2	89.09	-1.4524	3.9484	.1810		.240
3	93.06	-1.4842	3.9284		.0070	.241
4	142.12	-1.0314		.7798	.0113	.033
5	61.54		3.6940	- .6019	.0036	.200
6	91.01	-1.3590	4.0129			.239
7	59.76		3.7055	- .4987		.200
8	135.93	- .9823		1.0890		.029
9	155.81	- .7652			.0212	.024
10	38.93		3.5157		.0050	.194
11	117.62			.3261	.0086	.013

TABLE X (continued)

Equation Number	Constant	Coefficient of Variables in Equation				R ²
		Hip Width	Pin Width	Rump Length	Body Weight	
LOT 3						
1	-100.96	.6178	1.5224	3.2136		.190
2	-29.36	1.8845	1.7779			.144
3	-83.98	.6618		3.6295		.154
4	-103.34		1.5363	3.8652		.185

were found between any external measurements and posterior pelvic area in the experiment used for this study.

Only in Lot 2b were combinations of external measurements found to account for more variation in anterior pelvic area than did simple correlations. In this lot all equations gave significant R^2 values with the exception of equations two, seven, and nine. In no case did any combination of external measurements account for a significant amount of variation in posterior area, although greater amounts of variation could be accounted for this way than by any individual measurement except body weight.

A great deal of variation is shown among lots when either simple correlations or multiple regressions are used. The number of observations that make up Lot 2a is considerably smaller than the numbers in Lots 1 and 2b. This may account for some part of the variation. Another possible explanation for a part of the variation is the difference in growth rates of the individual animals in the experiment. Other than these two reasons no obvious explanation could be found for the variation among the lots.

Internal area could not be accurately predicted from external measurements; only approximately 60 percent of the variation in internal area could ever be accounted for by variation in external measurements.

IV. SEPARATION OF INTERNAL AREA INTO GROUPS BY USE OF CALVING DIFFICULTY

Thirteen animals of 36 experienced calving difficulty in Lot 1. In Lots 2a and 2b, respectively, six animals of 14 and 13 of 28 animals experienced difficulty at parturition. A summary of calving difficulties and calf measurements is given in Table XI.

An attempt was made to determine if internal pelvic area (anterior and posterior) had been responsible for placing these heifers into groups having calving difficulty and groups having no difficulty. Least-squares analysis was the method used in this determination; since calving difficulty was a discrete variable, an analysis of this type was necessary. Also, other factors were fitted with calving difficulty in an analysis of this type. These factors were sire of the calf, a discrete variable, and the continuous variables, birth weight of the calf, head width of the calf, shoulder width of the calf, circumference of the calf's shoulders, hip width of the calf, and hip circumference. The results of these determinations are given in Tables XII, XIII, and XIV for Lots 1, 2a, and 2b, respectively.

No models were fitted that gave any separation of pelvic area for heifers having difficulty and those having no difficulty. As far as differentiation by difficulty there were no R^2 values that even approached significance at the $P < .05$ level.

In Lot 2a, when difficulty, sire of the calf, and calf measurements were fitted together there was some indication of separation of

TABLE XI
SUMMARY OF ASSISTED CALVINGS AND MEANS AND STANDARD
ERRORS OF CALF MEASUREMENTS

	Lot 1	Lot 2a	Lot 2b
No. of parturitions	36	14	28
No. of assisted parturitions	13	6	13
Calf measurements	Mean Standard Error	Mean Standard Error	Mean Standard Error
Birth weight of calf	(cm.) (cm.)	(cm.) (cm.)	(cm.) (cm.)
Head width	57.52 $\pm$.1667	60.11 $\pm$.3382	57.32 $\pm$.1744
Shoulder width		11.838 $\pm$.1362	11.364 $\pm$.0694
Shoulder circumference		16.455 $\pm$.3281	15.564 $\pm$.1635
Hip width		68.561 $\pm$ 1.0676	63.717 $\pm$.7556
Hip circumference		17.011 $\pm$.2313	16.421 $\pm$.1488
		67.75 $\pm$.7342	67.232 $\pm$.9583

TABLE XII
EFFECTS OF BIRTH WEIGHT, CALVING DIFFICULTY, AND SIRE ON ANTERIOR
AND POSTERIOR PELVIC AREAS, LOT 1

Equation Number	Constant	Birth Weight ^a	Least-Squares Constants for Discrete Variables								R ²	
			Difficulty (0)	Difficulty (2)	Difficulty (3)	Sire 1	Sire 2	Sire 3	Sire 4	Sire 5		Sire 6
<u>Anterior Area</u>												
1						-8.7699	-2.2484	-14.6580	25.9863	6.0163	-6.3263	.209
2			3.8272	11.0303	-14.8575							.091
3			4.1414	9.1232	-13.2646	-10.2963	-3.1783	-9.5406	25.3068	5.3368	-7.6284	.252
4	161.73	-.0000	3.8272	11.0303	-14.8575							.091
<u>Posterior Area</u>												
1						-6.0257	2.1320	-5.1066	20.5430	-4.6369	-6.8158	.084
2			2.1208	6.9126	-9.0334							.033
3			2.9663	7.5306	-10.4969	-7.1926	1.4625	-.8813	19.6069	-5.2730	-8.0225	.252
4	151.19	-.0000	2.1208	6.9126	-9.0334							.091

^aThe regression of both areas on birth weight was zero.

TABLE XIII
STATISTICS RELATING ANTERIOR AND POSTERIOR PELVIC AREAS TO VARIOUS
CONTINUOUS AND DISCRETE VARIABLES, LOT 2a

Equation Number	Constant	Regression Coefficients				Least-Squares Constants				R ²			
		Birth Weight	Head Width	Shoulder Width	Hip Circumference	Difficulty (0)	Difficulty (2)	Difficulty (3)	Sire 1		Sire 2	Sire 3	Sire 4
Anterior Area													
1						6.7432	-2.7191	-4.0241	-1.184	17.4648	-15.4937	-1.8527	.392
2						.1126	-3.0691	3.1817				.099	
3						4.3394	-1.2879	-3.0515	-1.5342	15.0636	-14.3207	.7913	.409
4						-4.4533	-5.8217	10.2750	-1.8782	14.1902	-14.8236	2.5116	.515
5	161.98	.2292				-6.1011	-3.5563	9.6574	-5.1354	2.6014	-8.8147	11.3487	.783
6	82.06					-7.6824	-4.7172	8.8754	-4.5492	7.0841	-14.1754	11.6405	.540
7	63.80					-1.3115	-3.0793	1.7902	-1.5576	8.7367	-16.2862	9.1071	.520
8	81.76					1.2891	-3.0793	1.7902	-1.0209	14.9767	-13.8803	-.0755	.411
9	52.66					3.2464	-4.6656	1.4192					.179
10	197.65					1.2891	-3.0793	1.4192					.506
11	96.45					4.9266	-2.2348	2.2052					.140
12	69.64					-1.5095	-6.957	2.2052					.136
13	135.69					4.9266	-2.2348	2.2052					.196
14	123.05					3.7982	-1.0140	-2.7842					.456
15	280.04					12.4075	-3.8181	-8.5894					.734 ^a
16	111.18								-5.3264	2.4659	-6.9327	9.8132	.494
17	73.26								-3.2481	9.5858	-13.6870	7.3493	.479
18	98.30								-2.7989	8.1284	-12.7832	7.4537	.393
19	88.72								.4451	17.9597	-15.7621	-2.6427	
19	187.38												
Posterior Area													
1						3.6240	-5.2270	1.6030	-8.0443	17.6489	-14.1114	4.5068	.639 ^a
2						-2.7471	-7.7718	10.5189					.093
3						4.3394	-1.2879	-3.0515	-10.6759	13.3424	12.7942	10.1277	.739 ^a
4						-6.3732	-10.0713	16.4445					.148
5	161.98	.2292				-5.2917	-7.9789	13.2706	-10.9633	12.6128	-13.2143	11.5648	.808 ^a
6	76.62					-3.0726	-7.9044	10.9770	-12.2061	8.0471	-10.4546	14.6136	.801 ^a
7	107.31					-11.1291	-5.8257	16.9548	-10.9185	12.7004	-12.7825	11.0006	.739 ^a
8	18.59					-8.8691	-7.7272	16.5963	-10.7019	6.3367	-14.9706	19.3358	.865 ^a
9	59.23					1.1085	-6.6272	5.5187	-12.9174	13.7218	-14.7173	13.9129	.790 ^a
10	97.85					-2.955	-4.2660	4.5615					.131
11	104.49					4.9810	-5.5887	2.6077					.179
12	184.81					.6980	-3.5330	2.8350					.114
13	102.53					7.9554	-6.0674	-1.8880					.127
14	234.63								-8.2839	-17.0552	-13.6791	4.9078	.146
15	123.54								-10.0319	11.9246	-10.8517	8.9590	.127
16	115.77								-7.5835	18.8091	-14.3773	3.1517	.685 ^a
17	166.28								-10.9717	7.4524	-11.1511	14.6704	.641 ^a
18	59.83								-10.3847	15.5940	-12.9968	7.7875	.734 ^a
19	106.57												.660 ^a
19													

^ap < .05.

heifers into groups based on pelvic size. However, these results are not consistent with the results from Lots 1 and 2b in which there were no significant results. It will be remembered that the number of animals in Lot 2a is small compared to the other two lots and this could be partly the cause of the separation in this lot.

Considering all lots and individuals studied, it was not possible to predict calving difficulty on the basis of maternal pelvic size.



CHAPTER V

SUMMARY

Repeated pelvic measurements were made on 107 purebred Angus and Hereford heifers at the Alcoa Farms research unit of The University of Tennessee. The objectives were to determine the repeatability and accuracy with which such measurements could be made, to show the change in pelvic size as heifers approach parturition, to determine if some relationship exists between internal pelvic area and certain external measurements of the pelvis, and to determine the effect of size of the maternal pelvic area on calving difficulty. Measurements were made over a two-year period of time, and data were collected on calving difficulty at the time of parturition.

Product-moment correlations and multiple regression equations were used to show relationships and the effects of combinations of measurements.

From the data it was concluded that:

1. Repeatability of measurements was high, and these measurements could be used with confidence.
2. The increase in size of the pelvic area as a heifer matured from one year of age until she calved as a two-year-old did not follow a consistent pattern. Therefore, measurements of a yearling heifer could not be used to predict pelvic size when the heifer reached two years of age.

3. Internal area could not be accurately predicted from external measurements because only approximately 60 percent of the variation in internal area could ever be accounted for by variation in external measurements.
4. Internal pelvic area could not be used to predict calving difficulty, as there were no significant differences of area between those heifers having difficulty and those heifers having no difficulty.

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LITERATURE CITED

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APPENDIX

APPENDIX

CALVING DIFFICULTY EVALUATION

Cow No.:
Cow Breed:
Date of Parturition:

Sex of calf:
Birth weight:
Sire of calf:

Please check the statements which describe the birth of this calf:

- A. Calved without help.
 - 1. Stillborn.
 - 2. Alive at birth.
- B. Calf had to have head or neck or legs straightened before it could be born.
 - 1. No other help needed.
 - 2. Needed help after being straightened.
- C. Calf had to be pulled.
 - 1. Coming head first.
 - 2. Coming rear-feet first.
 - 3. Pulled by 1 person without block and line.
 - 4. Pulled by 2 or more persons or with help of block and line.
 - 5. Dead when delivery started.
 - 6. Alive when delivery started.
 - a. Alive at end of delivery.
 - b. Dead at end of delivery.
- D. Embryotomy.
- E. Caesarean section.
 - 1. Dead at end of delivery.
 - 2. Alive at end of delivery.