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PELVIC MEASUREMENTS AND FACTORS AFFECTING CALVING DIFFICULTY IN BEEF HEIFERS

BY

UMAR PAPUTUNGAN

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To

My famil

and

My teach

ABSTRACT

A series of studies on pelvic measurements and factors affecting calving difficulty (dystocia) in beef heifers was undertaken (1) to estimate repeatability of pelvic diameters measured by the Rice pelvimeter, (2) to identify the major factors contributing to dystocia, and (3) to evaluate the effect of sire birth weight on maternal performance and calving difficulty of female progeny (F1).

The repeatabilities of pelvic measurements with or without the operator effect were moderate ranging from 0.40 to 0.50. The correlation between horizontal and vertical pelvic diameters was also moderate (0.68). Between-operator variance was much smaller than the residual variance for each measurement. The area of pelvic opening (horizontal pelvic diameter x vertical pelvic diameter) as measured by experienced operators was significantly larger than that measured by inexperienced operators (257.5 ± 1.1 cm^2 vs. 246.9 ± 1.1 cm^2). The results suggested that in order to increase the accuracy of measurements, pelvic diameters should be estimated based on the average of at least two measurements.

The heifer's body condition score, calf's sire's birth weight, birth date and weight of calf, ratio of calf birth weight to pelvic dimensions and ratio of pelvic horizontal diameter to hip height of heifers all had significant effects on dystocia. However, sex of calf did not have a significant influence on dystocia. Generally, the variables measured on

heifers before calving accounted for a higher proportion of variation in dystocia than those measured after breeding.

Finally, the influence of low and high birth weight sires on maternal performance and calving ease of female progeny indicated that sires with high birth weight produced heifer progeny (F1) that were heavier at birth, weaning and calving at two-year of age compared with the progeny of low and medium birth weight sires. Heifer progeny from sires with high birth weight also had higher incidence of dystocia compared with heifers sired by low birth weight. Sire birth weight was not found to have a significant effect on hip height and pelvic dimensions of their heifer progeny.

The grand progeny (F2) of sires with high birth weight were also heavier at birth (P<0.05), but lighter (P<0.05) at weaning (194 vs. 208 kg).

The genetic correlation between direct and maternal effects ($r_{A.M}$) for birth weight was -0.04; however, the genetic correlation between direct and maternal grandsire effects for birth weight was positive and moderate ($r_{S.MS}$= 0.60). The results of this study indicated that while selection of low birth weight sires would reduce the incidence of calving difficulty as a direct effect, it would not have any adverse effect on maternal performance and calving ease of the female progeny.

Thus, based on the relative importance of major factors affecting dystocia, it is suggested that selection of bulls with low to moderate birth weight as breeding sires for mating with normal size heifers with at least moderate pelvic diameters, height and body condition score at calving, would be effective in reducing the incidence and severity of dystocia in beef heifers.

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CHAPTER 1

GENERAL INTRODUCTION

1.1. PHENOTYPIC ASPECTS OF CALVING DIFFICULTY

Parturition in cattle is a complicated process influenced by genetic and environmental factors. Observable features in the preparative stage of parturition are initiated by the increasing elasticity and relaxation of the cervix, vagina and pelvic ligaments, ascribed to oestrogen action, and followed by the passage of the fetus (Meijering 1984).

Under normal conditions, parturition should be completed without human interference, leaving a healthy cow with a viable calf. However, a significant proportion of calving is assisted with varying degrees of difficulty. It is, therefore, generally accepted that a case of calving difficulty (dystocia) is broadly defined as a delivery requiring assistance (Meijering 1984). Scoring procedures for calving difficulty as well as score transformation based on the frequencies of normal and difficult calving (Tong et al. 1977) have been developed.

A dramatic increase in the incidence of dystocia was associated with vulval constriction and irregular labour, when heifers normally kept under range conditions, were confined and intensively observed (Dufty 1972). Erb et al. (1981) reported that low levels of oestrogen in blood of the dam during the last three weeks of pregnancy were associated with difficult calving. The contribution of the oestrogen level to the occurrence of calving difficulty, however, was more pronounced in older cows than in heifers (Erb et al. 1981).

Size of dam as measured by weight and height is influenced by genetic and environmental factors (Benyshek and Little 1982); however, neither has been a good predictor of calving problems, because larger cows also give birth to heavier calves (Laster 1974). It appears, therefore, that selection for size of dam alone as a means of reducing the incidence of calving difficulty would be ineffective because of a correlated response with the size of fetus.

Obstruction of calf expulsion because of the large fetus size relative to the pelvic opening of the dam, generally referred to as feto-pelvic incompatibility (FPI), seems to be the most important cause of dystocia especially in first calving heifers (Bellows 1971; Rice and Wiltbank 1972; Makarechian and Berg 1983; Morrison et al. 1985; Johnson et al. 1988). Therefore, the internal pelvic dimensions, commonly measured as vertical pelvic diameter (perpendicular distance between the symphysis pubis and the sacral vertebrae) and horizontal pelvic diameter (largest distance between the right and left shafts of the ilia) can be applied on the living animal to predict dystocia (Deutscher 1985).

The horizontal pelvic diameter has relatively low correlation with the vertical pelvic diameter (0.32, reported by Bellows et al. 1971 and 0.54, reported by Naazie et al.

1989). Vertical and horizontal pelvic diameters or pelvic area (vertical x horizontal pelvic diameters) are used as predictive variables in predicting the incidence of dystocia. Naazie et al. (1989) reported that dam weight at calving was also an important factor affecting calving difficulty. However, there have been few studies on the prediction of dystocia based on pelvic measurements and other traits (Deutscher 1985). Meijering (1984) reported that pelvic measurements taken before or after calving may not accurately reflect the size of the pelvic opening during fetus expulsion. This indicates that time of measurement (after breeding and before calving) for internal pelvic diameters, weight and hip height, and the accuracy (repeatabilities) of pelvic measurements of heifers may affect their predictive values as far as dystocia is concerned. In addition, the accuracy (repeatabilities) of the pelvic diameters have not been adequately studied.

1.2. GENETIC ASPECTS OF CALVING DIFFICULTY

A method of determining whether a particular trait can be genetically transmitted from parents to their offspring is to estimate its heritability (h^2) which ranges from 0.0 to 1.0 and is usually applicable only to the populations from which it was estimated (Van Vleck et al. 1987; Jain and Prabhakaran 1992). If the heritability of a trait is high, a large proportion of the parents' superiority or inferiority relative to the population average can be transmitted to their offspring and selection, therefore, will be effective in changing the trait (Legates and Warwick 1990).

The estimates of heritability for calving difficulty as a trait of dam were 0.47±0.18 (Naazie et al. 1991) and 0.32±0.04 (Burfening et al. 1978b), while the heritability for calving difficulty as a trait of calf was 0.37±0.15 (Naazie et al. 1991).

For the size of dam's pelvic opening, the estimates of heritability of the vertical pelvic diameter, horizontal pelvic diameter and pelvic area were 0.43±0.13, 0.58±0.14 and 0.53±0.14, respectively (Benyshek and Little 1982); 0.43-0.57, 0.75-0.83 and 0.60-0.67, respectively (Morrison et al. 1984); 0.56, 0.36 and 0.61, respectively (Green et al. 1984); 0.30, 0.42 and 0.36, respectively (Holzer and Schlote 1984); and 0.99±0.21, 0.50±0.19 and 0.77±0.20, respectively (Naazie et al. 1991). The relatively high heritability estimates of pelvic diameters indicate that pelvic opening can be changed by selection. Philipsson et al. (1979) reported that dystocia had strong genetic correlation with birth weight (r_G=0.90). Burfening et al. 1978a, 1979, 1981), however, reported low to moderate genetic correlations between dystocia and birth weight (r_G=0.24 to 0.42).

A consistent use of low birth weight (direct effect) and large pelvic dimensions (maternal effect) would yield a rapid reduction in first calving problems (Bar-Anan et al. 1976;

Bar-Anan 1979). However, Philipsson (1976) and Thompson et al. (1981) reported that low birth weight sires would produce smaller heifer calves which run an increased risk of dystocia. There have been few studies on the relationship between direct effect of bull on birth weight, pelvic structures and calving performance of his female progeny and the maternal component associated with dystocia in his daughters.

Thus, the hypothesis that sires with low birth weight produce small calves which develop into small heifers and which have a greater incidence of calving difficulty still needs to be elucidated.

1.3. PROBLEMS OF CALVING DIFFICULTY

In the beef cattle industry, calving difficulty (dystocia) causes serious economic losses due to the increased mortality of both dam and calf, low fertility and the reduction in calf performance, and extra labour required from the farmer and veterinary assistance (Laster and Gregory 1973; Patterson et al. 1979; Philipsson et al. 1979; Meijering 1980).

Bellows et al. (1987) reported that calving difficulty (dystocia complex) was the most important cause of calf death, with 50.9 % of all deaths falling into this category. In cases of extremely difficult calving, cows have to be emergency-slaughtered. Philipsson (1976) reported that about 3.5 % of emergency-slaughter cases were caused by dystocia and about

6.2 % of those were caused by stillborn calf among Friesian heifers.

Menissier (1975) studied the effect of degree of difficult calving on non-return rate after first insemination and reported a range of 5 % to 15 % non-return when dystocia was terminated by moderate traction and 25 % to 45 % after caesareans (Meijering 1984).

The cost of veterinary assistance in calving difficulty depends on the kind of obstetric aid given, which is in turn dependent on the severity of dystocia (Meijering 1980). Philipsson (1976) reported that the frequency of veterinary assistance in dystocia cases was about 20 % in Friesian heifers.

Some producers cull heifers with small pelvic opening when selecting replacement heifers in order to reduce dystocia. However, the accuracy (repeatability) of the pelvic measurements has not been adequately studied. In addition, the relative importance of factors affecting calving performance is not well established. Considering these problems, a series of studies were undertaken 1) to estimate the accuracy (repeatability) of measurements of pelvic diameters, 2) to identify the major factors contributing to calving difficulty and 3) to study the effect of sire birth weight on maternal performance and calving ease of the female progeny (F1).

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CHAPTER 2

REPEATABILITY ESTIMATES OF PELVIC MEASUREMENTS BY RICE PELVIMETER[1]

2.1. INTRODUCTION

Calving difficulty (dystocia) results in serious economic losses in beef cattle, particularly in first calving heifers. This is mainly because the heifers are still growing and therefore their pelvic opening is too small for the easy passage of the calf during parturition. The frequency and severity of dystocia are influenced by the interrelated factors such as size and conformation of fetus (Bellows et al. 1982; Comerford et al. 1987; Laster 1974; Makarechian et al. 1982; Naazie et al. 1989; Rutter et al. 1983), sex of calf (Rice and Wiltbank 1972), age, size and the condition of the cow at calving (Bellows et al. 1971; Makarechian and Berg 1983), and size of the pelvic opening of dam and abnormal position of fetus (Bellows et al. 1971; Dufour et al. 1981; Johnson et al. 1988; Makarechian and Berg 1983; Meijering 1984; Rice and Wiltbank 1972). However, the large size of the fetus relative to that of the pelvic opening termed as feto-pelvic incompatibility (FPI) has been found to be the major cause of dystocia in heifers (Bellows et al. 1971; Deutscher 1985; Dufour et al. 1974; Rice and Wiltbank 1972).

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[1]A version of this chapter has been published. U. Paputungan, M. Makarechian and M.F. Liu 1993. Canadian Journal of Animal Science 73:977-980.

Measuring the pelvic area of the dam as a tool in selecting replacement heifers to identify and cull heifers which are likely to encounter dystocia at parturition is gaining popularity among some veterinarians and producers, even though pelvic area alone has been shown to explain only a small proportion of the variation in dystocia compared with calf birth weight (Rice and Wiltbank 1972; Bellows et al. 1971; Rutter et al. 1983; Deutscher 1985; Johnson et al. 1988). The Rice pelvimeter, a caliper-type instrument (Lane Manufacturing, Co., Denver, Colorado) is preferred by producers for rapid measurements in internal pelvic diameters (Deutscher 1985). Although measuring pelvic diameters is widely practised, the accuracy and repeatabilities of these measurements using the Rice pelvimeter are not well established.

The objectives of this study were: 1) To evaluate the accuracy of measuring pelvic measurements using the Rice pelvimeter by estimating the repeatabilities of the pelvic measurements, 2) To study the effect of operator on pelvic measurements and 3) To estimate the correlation between pelvic dimensions.

2.2. MATERIALS AND METHODS

2.2.1. Animals

Pelvic dimensions of beef heifers were measured by Rice pelvimeter instrument in this study. Rice pelvimeter was constructed from stainless steel and calibrated in 0.25 cm on a scale which can be easily read when the pelvic diameters are measured through the rectum. This instrument is used by placing it inside the rectum of the animal and reading the pelvic measurement on the outside.

A total of 143 beef heifers from two breed groups (Beef Synthetic #1 and Dairy Synthetic) born in the spring of 1990 maintained at the University of Alberta Beef Cattle Research Ranch at Kinsella, Alberta, were used to estimate the repeatabilities of pelvic measurements. The Beef Synthetic #1 population was composed of approximately 31% Charolais, 36% Angus, 21% Galloway with small contributions from Brown Swiss (6%) and others (6%). The Dairy Synthetic population contained approximately 54% Dairy breeding from Holstein (22.1%), Brown Swiss (25.8%) and Simmental (6.1%) and the remainder (46%) from traditional beef breeds of Angus, Galloway, Hereford, and Charolais (see Appendix 1 for complete breed composition since 1962). A description of breeding and management practices of the herds is presented in Appendix 2, adapted from Berg et al. (1990). In order to study the effect of the operator on the accuracy of the measurements, a total of 30 non-pregnant beef heifers from the same breed groups were used.

2.2.2. Measurements

Repeated measurements of vertical pelvic diameter (VP) (perpendicular distance between the symphysis pubis and the sacral vertebrae) and horizontal pelvic diameter (HP) (largest distance between the right and the left shafts of the ilia) were taken on 143 bred beef heifers (18±0.5 months old at two months after breeding) four times by the same operator using the Rice pelvimeter (Lane Manufacturing, Co., Denver, Colorado) within a period of three weeks to estimate the repeatabilities of pelvic measurements.

In order to evaluate the effect of operator on pelvic measurements, four operators (two experienced and two inexperienced operators) measured the vertical and horizontal pelvic diameters of 30 non-pregnant beef heifers (19±0.30 months old) four times each during a period of 8 days using the same Rice pelvimeter. The operators who had never measured the pelvic diameter using pelvimeter before start of this study were defined as inexperienced operators, while those who had ever measured the pelvic diameter before start of this study were define as experienced operators. The pelvimeter was inserted into the rectum at the same depth and position for the consecutive measurements of pelvic diameters. Pelvic area (PA) was defined as the product of VP by HP.

2.2.3. Statistical analysis

Two linear models were used for analysis of the data. The first model included breed group and animal nested within breed group using 143 bred beef heifers, while the second model included breed group, animal nested within breed group, and operator effects using 30 open beef heifers with the equations, i.e.

$$Y_{ijk} = \mu + B_i + A_{ij} + \varepsilon_{ijk} \quad (1),$$

$$Y_{ijkl} = \mu + B_i + A_{ij} + O_k + \varepsilon_{ijkl} \quad (2),$$

where Y_{ijk} or Y_{ijkl} were the pelvic diameter measurements, μ was the overall mean, B_i was the effect of the i-th breed group, A_{ij} was the effect of the j-th animal within the i-th breed group, O_k was the effect of the k-th operator and ε_{ijk} or ε_{ijkl} were assumed as random errors.

The effect of breed group was assumed to be fixed, while animal and residual effects were assumed to be random. The effect of operator was first assumed to be random to estimate variance components and then was assumed to be fixed to compare experienced and inexperienced operators (Harvey 1985). Comparisons of the operator effects were analyzed using contrast method in PROC GLM (SAS Institute Inc. 1985). Variance components were estimated using PROC VARCOMP method=REML in SAS package (SAS Institute Inc. 1985).

The repeatability of each measurement which represents a pooled measure of the correlation between repeated measurements (Falconer 1989) was estimated by the intraclass correlation method (Becker 1967; Steel and Torrie 1980).

The first data set (143 heifers) was used to estimate the repeatabilities of pelvic measurements as the ratio of animal variance component to the sum of animal and residual variance components. For the second data set (30 heifers), in which the operator effect was also included in the model, animal variance component was divided by the total phenotypic variance (the sum of animal, operator and residual variance components) to evaluate the effect of operator on the repeatability estimates.

The correlation coefficients between pelvic dimensions (PV, PH and PA) were estimated on within breed group basis, first using PROC GLM to obtain residual, then using PROC CORR to obtain the residual correlation (SAS Institute Inc. 1985).

2.3. RESULTS AND DISCUSSION

2.3.1. Repeatabilities of internal pelvic measurements

Estimates of variance components and repeatabilities of pelvic measurements with or without the operator effect in the model are presented in Table 2.1. In general, the results showed that the repeatability estimates of pelvic measurements were moderate (0.53±.04 and 0.46±.04 for vertical and horizontal diameters, respectively), indicating that every time the trait is measured the operator may not get the same reading due to large error among consecutive measurements as indicated by large residual variance (Figure 2.1). These repeatability scores suggest that more than one measurement of pelvic diameters will increase accuracy.

The results also indicated that the operator variance component was very small relative to the residual variance component (0.02 vs. 0.39 for vertical pelvic diameter and 0.06

vs. 0.36 for horizontal pelvic diameters, Table 2.1). For the vertical pelvic measurement, the operator variance contributed only 2.3% of the total variance, while the residual variance contributed 44.3% of the total variance (Figure 2.2). In the case of the horizontal pelvic measurement, the operator variance contributed 6.7% of the total variance, while the residual variance contributed 40.0% of the total variance (Figure 2.2). Consequently, for the pelvic area as the product of vertical and horizontal diameters, the operator variance contributed 5.3% of the total variance, while the residual variance contributed 38.3% of the total variance (Figure 2.2).

The results of this study indicate that measuring the pelvic diameters using the Rice pelvimeter is not highly repeatable regardless of operator's effort. In addition, the small contribution of operator effect to the total phenotypic variance resulted in similar estimates of repeatability regardless of adjusting or not adjusting for operator effect (Table 2.1).

2.3.2. The effect of operator on the pelvic measurements

The effect of operator on the pelvic diameter measurements was highly significant ($P<0.01$) when the operator effect was assumed fixed (Table 2.2). The comparison between experienced and inexperienced operators revealed that the vertical pelvic diameter measured by experienced operators was significantly larger ($P<0.05$) than that measured by inexperienced operators (17.94±0.04 cm vs 17.68±0.04 cm). Consequently, the area of pelvic opening as measured by experienced operators was also significantly larger ($P<0.05$) than that measured by the inexperienced operators (257.46±1.08 cm^2 vs 246.94±1.08 cm^2). The inexperienced operators were probably more cautious and hesitant than the experienced operators in fully extending the Rice pelvimeter which resulted in smaller measurements. This indicates that inexperienced operators take a great deal of practice to establish consistency.

2.3.3. Correlation coefficients among pelvic dimensions

The coefficient of correlation between vertical and horizontal diameters was 0.68, and the coefficients of correlation of vertical and horizontal diameters to the pelvic area were 0.94 and 0.94, respectively ($P<0.01$). These high correlations were due to the estimation of pelvic area from vertical and horizontal pelvic diameters. The estimates obtained in this study were in agreement with those reported by Naazie et al. (1989) but higher than the estimates reported by Bellows et al. (1971). However, in all the studies, the association between horizontal and vertical pelvic diameters measured by the Rice pelvimeter was relatively moderate.

2.4. SUMMARY AND CONCLUSION

Pelvic measurements in beef heifers at the University of Alberta Beef Cattle Breeding Research Ranch at Kinsella were analyzed to: i) estimate the repeatabilities of the pelvic measurements using the Rice pelvimeter, ii) study the effect of operator on pelvic measurements and iii) estimate the correlation between pelvic diameters. Based on the results of this study, several conclusions were drawn as follow:

1). The repeatabilities of pelvic measurements using the Rice pelvimeter were moderate i.e. 0.53±0.04 and 0.46±0.04 for vertical and horizontal pelvic diameters, respectively without operator effect, and 0.53±0.07 and 0.53±0.07 for vertical and horizontal pelvic diameters, respectively including operator effect.

2). The area of pelvic opening measured by the experienced operators was significantly larger than that measured by the inexperienced operators.

3). The correlation between horizontal and vertical pelvic diameters was moderate (0.68) indicating that the two pelvic diameters are associated with each other and carry complementary information which respect to pelvic area.

It can be concluded that measuring the pelvic diameters by the Rice pelvimeter is not highly repeatable. In order to increase accuracy, the vertical and horizontal pelvic diameters should be estimated based on the average of at least two measurements.

TABLE 2.1. VARIANCE COMPONENT ESTIMATES AND REPEATABILITIES OF PELVIC MEASUREMENTS

Item	Pelvic		
	Vertical Pelvic Diameter (VP)	Horizontal Pelvic Diameter (HP)	Pelvic Area (VPxHP)
Data set of 143 heifers :			
Animal variance	0.35	0.30	271.29
Residual variance	0.31	0.35	225.86
Total variance	0.66	0.65	497.15
Repeatability [y]	0.53±0.04	0.46±0.04	0.55±0.04
Data set of 30 open heifers :			
Animal variance	0.47	0.48	406.01
Operator variance	0.02	0.06	38.15
Residual variance	0.39	0.36	276.18
Total phenotypic variance	0.88	0.90	720.34
Repeatability [y]	0.55±0.07	0.57±0.07	0.59±0.07
Repeatability [z]	0.53±0.07	0.53±0.07	0.56±0.07

[y] The animal variance divided by the sum of animal and residual variance.
[z] The animal variance divided by the total phenotypic variance.

TABLE 2.2. MEANS AND STANDARD ERRORS OF PELVIC MEASUREMENTS AMONG OPERATORS

Operator	n	Horizontal Pelvic Diameter (HP) (cm)	Vertical Pelvic Diameter (VP) (cm)	Pelvic Area (HPxVP) (cm^2)
1 +	30	14.23±.05 [a]	17.97±.06 [a]	256.10±1.52 [a]
2 +	30	14.43±.05 [b]	17.90±.06 [a]	258.82±1.52 [a]
3 -	30	13.85±.05 [c]	17.65±.06 [b]	245.03±1.52 [b]
4 -	30	14.02±.05 [d]	17.71±.06 [b]	248.86±1.52 [b]

(+) experienced operators; (-) inexperienced operators.
a,b,c,d Means within columns followed by different letters are significantly different (P<.05).

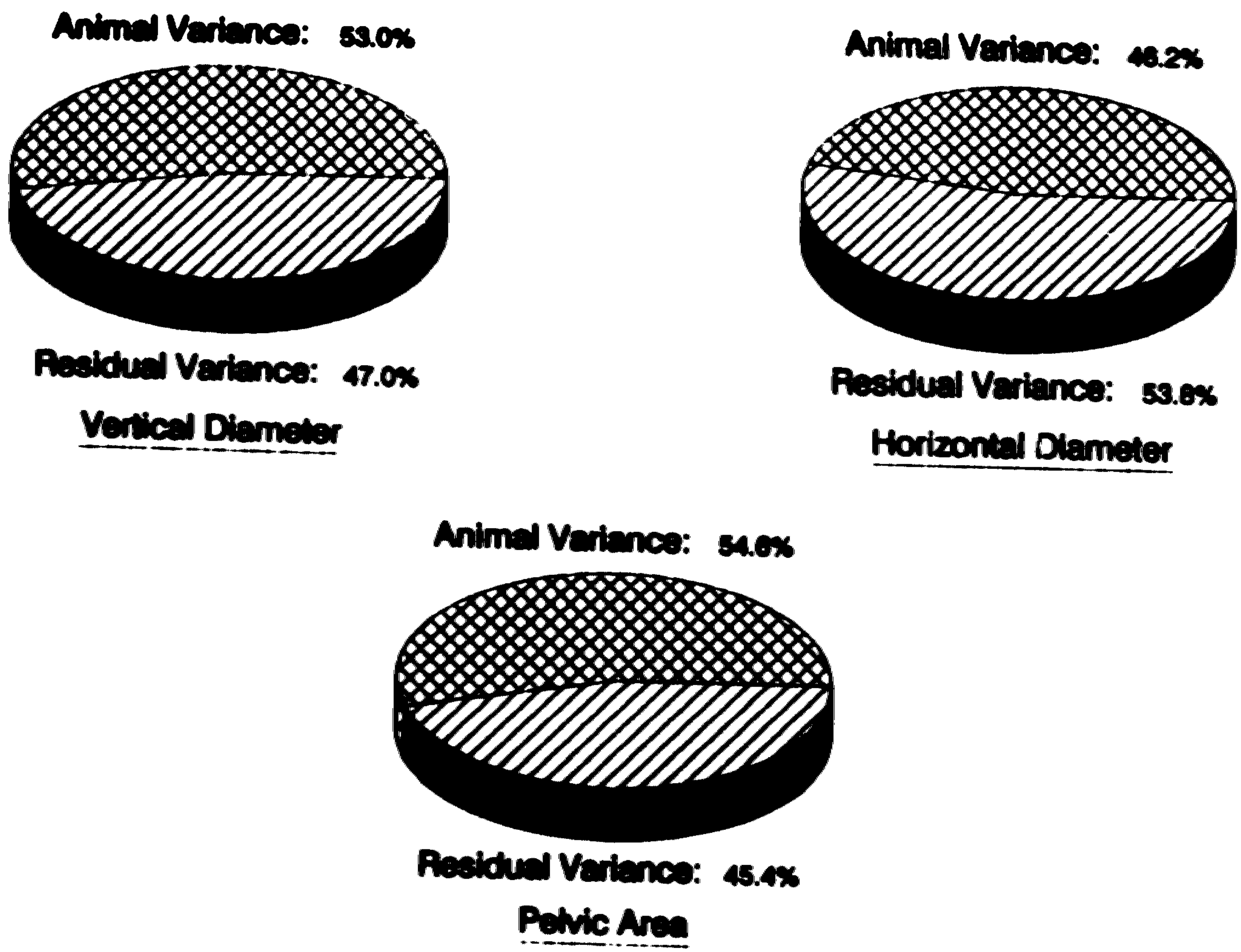

Figure 2.1. Partition of Animal and Residual Variance Components of Pelvic Measurements

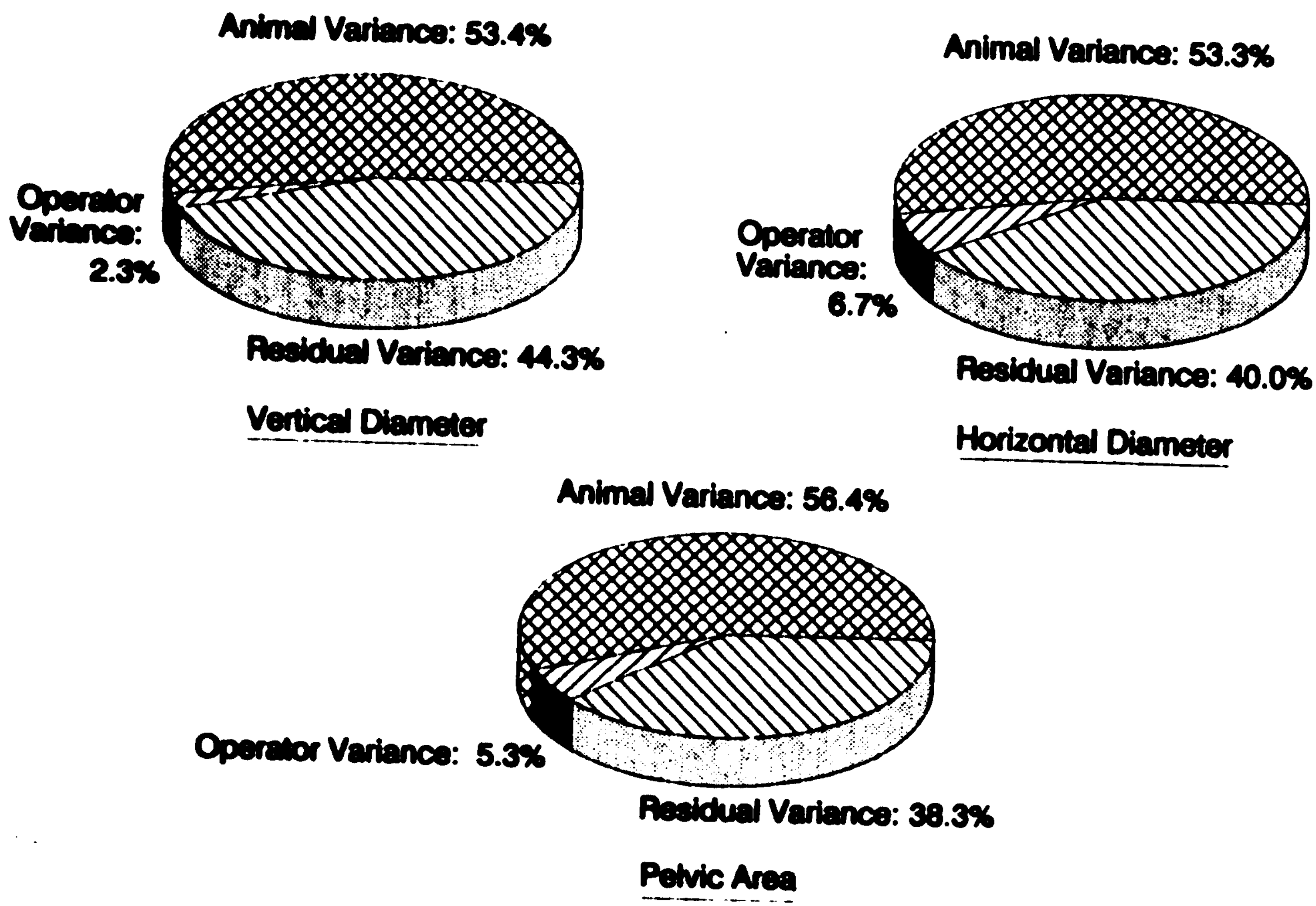

Figure 2.2. Partition of Animal, Operator and Residual Variance Components of Pelvic Measurements

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CHAPTER 3

SOURCES OF VARIATION IN CALVING DIFFICULTY[1]

3.1. INTRODUCTION

The importance of calving difficulty (dystocia) in primiparous heifers as a cause of calf mortality and morbidity (Bellows et al. 1987; Laster and Gregory 1973), increased management cost (Meijering 1984) and low fertility in later parities (Brinks et al. 1973; Laster et al. 1973; Philipsson et al. 1979) is well documented.

Published reports indicate that the small pelvic area of primiparous heifers is an impediment to normal parturition (Williams 1968; Bellows et al. 1971; Rice and Wiltbank 1972; Makarechian and Berg 1983; Johnson et al. 1988). There have been several studies dealing with factors affecting calving difficulty with conflicting results. For example, calf birth weight was reported to be the most important factor influencing calving difficulty and there was little or no correlation between pelvic measurements and calving performance (Rutter et al. 1983; Naazie et al. 1989; Van Donkersgoed et al. 1990). Morrison et al. (1985) reported that pelvic measurements accounted for 22.1% of the variation in calving difficulty score, although the effect of calf birth weight on calving difficulty was much more important than

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pelvic measurements.

Several researchers have identified feto-pelvic incompatibility (FPI) as a major cause of dystocia (Bellows et al. 1971; Johnson et al. 1988; Rice and Wiltbank 1972; Deutscher 1985). However, pelvic measurements taken before or after calving may not reflect the size of the pelvic inlet during fetus expulsion (Meijering 1984). The impact of changes in pelvic dimensions, hip height and weight of heifers during the period of pregnancy on calving difficulty has not been explicitly explored.

The objectives of this study were to identify the major factors contributing to calving difficulty and to compare the influence of pelvic diameters, weight and height of heifers measured after breeding and before calving on dystocia in beef heifers calving at two years of age.

3.2. MATERIALS AND METHODS

3.2.1. Data collection

Calving records of 107 heifers (born in the spring of 1990) from the University of Alberta Beef Cattle Research Ranch at Kinsella, Alberta were used in this study. The heifers were from two breed groups, 57 Beef Synthetic #1, and 50 Dairy Synthetic heifers. The genetic compositions of the breed groups are given in Appendix 1. Details of the breeding and herd management are described in Appendix 2, adapted from Berg et al. (1990).

The heifers were mated with 7 yearling bulls (number of heifers mated with each bull ranged from 8 to 26) in single sire groups within each breed for a period of 45 days and were maintained together until calving under conventional management. Bulls with extreme birth weights were not used for breeding.

The pelvic diameters, hip height and body weight of the heifers were first measured two months after the end of the breeding season (18±0.50 months old). Horizontal (largest distance between the right and the left shafts of the ilia) and vertical (perpendicular distance between the symphysis pubis and the sacral vertebrae) pelvic diameters (pelvic area = horizontal x vertical diameters) were measured by a single operator using the Rice pelvimeter. The vertical pelvic and horizontal pelvic diameters, hip height (the vertical distance from the ground to the top of the hip) and heifer weight were also measured two months before start of calving season (22±0.50 months old).

Breed group, heifer's body condition score, sex of calf, calf birth date, calf birth weight and sire birth weight were also considered in the study in order to evaluate their effects on calving difficulty.

Calving difficulty was scored on a 0 to 5 scale, where 0 indicates normal calving without human assistance, score 1 indicates slight assistance relieved with simple traction, score 2 indicates puller used easy with moderate assistance, score 3 indicates puller used hard with intensive assistance, score 4 indicates extreme traction requiring veterinary assistance to relieve the dystocia without danger to the dam or calf and score 5 indicates the most difficult calving, requiring surgical intervention (Smidt and Huth 1979). Since there was only one calving difficulty of score 3, it was treated as a calving difficulty of score 2. There was no calving difficulty of scores 4 or 5 in the data set.

Heifer's body condition (fatness) was scored at calving on a scale of 1 (very thin) to 5 (grossly fat) according to Lowman et al. (1973). There was no condition score of 5 in the data set.

3.2.2. Statistical analysis

Calving difficulty scores of heifers were first transformed using Snell transformation to provide homogenous residual variation over subclasses and approximately normally distributed residual deviations (Tong et al. 1977). Analyses were performed on the Snell transformed calving scores.

The data were analyzed by covariance analysis using SAS package (SAS Institute, Inc. 1985) with the following basic model :

$$Y_{ijkl} = \mu + B_i + S_j + C_k + \Sigma X_t + \varepsilon_{ijkl}$$

where Y_{ijkl} was Snell transformed calving score, μ was the overall mean, B_i was the effect of the i-th breed group, S_j was the effect of the j-th sex of calf, C_k was the effect of the k-th body condition score, X_t was effect of the t-th continuous independent variable and ε_{ijkl} was a random error.

Eight submodels all based on the above basic model were performed in order to identify and compare the contributions of all original variables, some original variables measured two months after the end of the breeding season and two months before start of calving season when the other variables were dropped from the model and the contributions of the ratios of some variables on the variations in calving difficulty (Table 3.1).

The contribution of a factor to calving difficulty was estimated as the percentage of the sum of squares (due to the factor after adjusting for the other factors in the model) in the corrected total sum of squares (Type III in SAS Institute, Inc. 1985). This was equivalent to the reduction in the coefficient of determination (R^2) after dropping that factor from the model.

3.3. RESULTS AND DISCUSSION

3.3.1. Means of heifer traits measured after breeding and before calving

The means of pelvic dimensions, hip height and weight of heifers measured before calving increased in the two breed groups during pregnancy, following a similar growth pattern (Table 3.2). Generally, the means of pelvic diameters, hip height and weight of Dairy Synthetic heifers were higher than those of Beef Synthetic #1 heifers ($P<0.05$). The heifer's traits measured after breeding and before calving, however, had considerable variation, as indicated by the large standard errors (Table 3.2).

3.3.2. Important factors affecting calving difficulty

The frequency of normal calving in this study was 74% (Table 3.3). The percentage of normal calvings in this study was within the range of the frequency of normal calving of these breed groups (Makarechian et al. 1982; Naazie et al. 1989).

Comparisons of the total variation in calving difficulty scores explained by the models which included the variables measured after breeding with the models which included the same variables measured before calving indicated that, in general, the variables measured before calving accounted for a somewhat higher proportion of variation in calving difficulty than those measured after breeding (Table 3.4).

The total variation in calving difficulty (Table 3.4), accounted for in this study, was 35.5% which was higher than that previously reported by Naazie et al. (1989).

Breed group, heifer's body condition score, sire birth weight, calf birth weight and the ratios of calf birth weight to pelvic area had significant effects on calving performance in all models used in this study. However, calf birth date, heifer's weight and the ratio of horizontal pelvic diameter to hip height significantly affected calving performance only when the heifer's traits were measured before calving, while only hip height had significant effect on calving performance when measured after breeding (Table 3.4). Naazie et al. (1991) reported that hip height was genetically correlated with calving difficulty (-0.31 ± 0.25).

Calf birth weight was the most important variable affecting calving difficulty (P<0.01), explaining over 11% of the variation in calving difficulty scores (Table 3.4). The important contribution of calf birth weight to variation in calving difficulty score observed in this study was in agreement with other reports (Berg 1979; Ruttle et al. 1982; Johnson et al. 1988; Naazie et al. 1989; Morrison et al. 1985; Van Donkersgoed et al. 1990).

The ratio of calf birth weight to pelvic area, which can be considered a measure of feto-pelvic incompatibility, accounted for a higher fraction of variation in calving difficulty score compared with birth weight (Table 3.4). The effect of ratio of calf birth weight to pelvic area in this study was in agreement with the reports by Bellows et al. (1971) and Rice and Wiltbank (1972). Pelvic area alone did not have a significant influence on calving difficulty score when combined with calf birth weight, body condition scores and heifer weight (Model 1, Table 3.4). However, pelvic area and hip height had a significant effect on calving difficulty when calf birth weight, body condition score and heifer weight were dropped from the model (Model 7, Table 3.4), indicating confounding of these effect with calf birth weight, body condition score and heifer weight.

The heifer's weight and hip height had a significant effect on calving difficulty and body condition score accounted for over 11% of the variation in calving difficulty when calf birth weight was excluded from the model (Models 5 and 6, Table 3.4) which was in agreement with the results of other studies (Makarechian and Berg 1983; Naazie et al. 1989).

The least squares means of calving difficulty score of heifers with body condition scores of 1 and 4 (extremely thin and fat) were maximum and heifers with a body condition score of 3 (desirable condition) had the lowest level of calving difficulty score (Table 3.5). Model 1 and 2 were taken to represent the least square means of Snell transformed calving scores by breed groups and body condition scores which are similar in the other models. The low incidence of calving difficulty among heifers with body condition score of 3 indicates the importance of optimum condition for the process of parturition.

The Beef Synthetic #1 heifers had a higher level of calving difficulty compared to the Dairy Synthetic heifers ($P<0.05$, Table 3.5). The significant effect of breed group on calving difficulty in this study was in agreement with other studies (Liboriussen 1979; Makarechian et al. 1982; Naazie et al. 1989; Gregory et al. 1991). Liboriussen (1979) reported

Simmental and Charolais breeds had the highest incidence of calving difficulty among European beef and dual-purpose breeds. The Beef Synthetic #1 contained about 31% Charolais, while Dairy Synthetic contained only about 6% Simmental.

Heifers delivering in the early spring tended to have more calving difficulty compared with those delivering later, as the partial regression coefficient of calving difficulty score on calving date was negative ($P<0.05$). This may be a result of a longer period of feed supplementation which had greater effect on improving the body condition of heifers calving later in the season (Makarechian and Berg 1983).

The results of this study indicate that the incidence and severity of calving difficulty in first calving heifers could be significantly reduced by the following strategy: (1) Using sires with low birth weight which would result in calves with low birth weight, (2) Using heifers with relatively well developed pelvic openings, and (3) Keeping heifers in good body condition (score of 3) during pregnancy.

3.4. SUMMARY AND CONCLUSION

Records on birth date, sex and birth weight of calf, body condition score, hip height, body weight and internal pelvic diameters of heifers measured after breeding and before calving in two breed groups were used to identify the major factors contributing to calving difficulty and to compare the influence of pelvic diameters, weight and height of heifers measured after breeding and before calving on calving difficulty in beef heifers.

Based on the results of this study, several conclusions could be drawn as follows:

1). The incidence of calving difficulty was increased by heavy birth weights of calf and small heifer's pelvic dimension relative to her hip height and calf birth weight.

2). The ratios of heifer's variables measured two months before calving generally accounted for somewhat higher proportion of variation in calving difficulty compared with those measured after breeding.

3). The frequency of dystocia was significantly different in the two breed groups. Beef Synthetic heifers had more difficult calving than Dairy Synthetic heifers.

Based on the relative importance of the major factors affecting calving difficulty, the incidence and severity of calving difficulty in first calving heifers could be reduced by the following strategies: 1) Using sires with low birth weight which would result in calves with low birth weight, 2) Using heifers with relatively well developed pelvic opening, and 3) Keeping heifers in good body condition score (score of 3) during pregnancy.

TABLE 3.1. NUMBER OF VARIABLES MEASURED AFTER BREEDING AND BEFORE CALVING IN EACH MODEL CONTRIBUTING TO THE VARIATIONS IN CALVING DIFFICULTY IN BEEF HEIFERS

Variables	
<u>Model 1</u>	<u>Model 2</u>
Breed Group	Breed Group
Body condition score	Body condition score
Calf birth date	Calf birth data
Calf birth weight	Calf birth weight
Pelvic area (After Breeding)	Pelvic Area (Before Calving)
Hip height (after Breeding)	Hip height (Before Calving)
Weight (After Breeding)	Weight (Before Calving)
<u>Model 3</u>[Y]	<u>Model 4</u>[Y]
Breed Group	Breed Group
Body condition score	Body condition score
Calf birth date	Calf birth date
Pelvic hor./Hip height (AB)	Pelvic hor./Hip height (BC)
Pelvic vert./Hip height (AB)	Pelvic vert./Hip height (BC)
Weight / Hip height (AB)	Weight / Hip height (BC)
Calf b.wt / Pelvic area (AB)	Calf b.wt / Pelvic area (BC)
<u>Model 5</u>	<u>Model 6</u>
Breed Group	Breed Group
Sex of calf	Sex of calf
Body condition score	Body condition score
Calf birth date	Calf birth date
Sire birth weight	Sire birth weight
Pelvic area (After Breeding)	Pelvic area (Before Calving)
Hip height (After Breeding)	Hip height (Before Calving)
Weight (After Breeding)	Weight (Before Calving)
<u>Model 7</u>	<u>Model 8</u>
Breed Group	Breed Group
Body condition score	Body condition score
Sire birth weight	Sire birth weight
Pelvic area (After Breeding)	Pelvic area (Before Calving)
Hip height (After Breeding)	Hip height (Before Calving)

[Y]AB = After Breeding; BC = Before Calving.

TABLE 3.2. LEAST SQUARE MEANS AND STANDARD ERRORS OF HEIFER TRAITS TAKEN TWO MONTHS AFTER BREEDING AND TWO MONTHS BEFORE CALVING

			After breeding	Before calving
Breed[y]	n	Variable [a]	Mean ± S.E.	Mean ± S.E.
SY#1	57	Pelvic horizontal (cm)	13.1 ± 0.07	15.7 ± 0.12
		Pelvic vertical (cm)	15.8 ± 0.08	18.5 ± 0.09
		Pelvic area (cm^2)	207.8 ± 2.11	291.5 ± 3.33
		Hip height (cm)	126.3 ± 0.51	129.7 ± 0.51
		Heifer weight (kg)	389.1 ± 4.36	442.1 ± 5.17
SD	50	Pelvic horizontal (cm)	13.6 ± 0.08	16.3 ± 0.13
		Pelvic vertical (cm)	16.3 ± 0.08	19.0 ± 0.10
		Pelvic area (cm^2)	222.4 ± 2.25	309.7 ± 3.55
		Hip height (cm)	130.7 ± 0.45	133.9 ± 0.55
		Heifer weight (kg)	403.6 ± 4.65	454.8 ± 5.52

[y]**SY#1** = Beef Synthetic #1, **SD** = Dairy Synthetic.
[a]significantly different ($P<0.05$) between two breed groups for all variables measured after breeding and before calving.

TABLE 3.3. DESCRIPTION OF CALVING DIFFICULTY SCORES, THEIR FREQUENCIES AND SNELL TRANSFORMED SCORES IN BEEF HEIFERS

Calving description	Difficulty score	n	Frequency %	Snell transformed calving score
Normal	0	79	74	0
Slight assistance	1	13	12	60
Puller used, easy or hard	2	15	14	100

TABLE 3.4. VARIATIONS IN DYSTOCIA EXPLAINED BY VARIABLES MEASURED ON BEEF HEIFERS AFTER BREEDING AND BEFORE CALVING

Variable	Change in R^2 (%)	
	After breeding	Before calving
	Model 1	Model 2
Breed Group	3.52 *	3.61 *
Body condition score	4.99 *	6.10 *
Calf birth date	2.33	2.95 *
Calf birth weight	12.87 **	15.97 **
Pelvic area	0.68	0.04
Hip height	1.36	1.05
Weight	0.18	1.37
Total variation explained	35.51	36.17
	Model 3	Model 4
Breed Group	3.40 *	2.93 *
Body condition score	4.90 *	5.16 *
Calf birth date	2.30	3.13 *
Pelvic horizontal / Hip height	2.13	2.94 *
Pelvic vertical / Hip height	0.00	0.02
Weight / Hip height	1.08	1.53
Calf birth weight / Pelvic area	13.15 **	17.57 **
Total variation explained	35.61	37.29
	Model 5	Model 6
Breed Group	6.73 **	7.58 **
Sex of calf	1.70	2.59
Body condition score	11.10 **	13.47 **
Calf birth date	3.48 *	4.37 *
Sire birth weight	4.00 *	3.69 *
Pelvic area	1.93	0.03
Hip height	4.67 *	1.97
Weight	2.05	3.07 *
Total variation explained	26.62	28.44
	Model 7	Model 8
Breed Group	6.89 **	5.99 **
Body condition	9.30 *	11.07 **
Sire birth weight	3.45 *	2.70
Pelvic area	5.31 *	0.46
Hip height	3.94 *	0.95
Total variation explained	22.48	17.97

* $P < 0.05$.
** $P < 0.01$.

TABLE 3.5. LEAST SQUARES MEANS AND STANDARD ERRORS OF SNELL TRANSFORMED CALVING SCORES BY BREED GROUPS AND BODY CONDITION SCORE OF HEIFERS

Item [y]		Snell calving scores ± S.E. [z]	
	n	Model 1	Model 2
Breed: Beef Synthetic	57	42.01 ± 8.11 [a]	42.36 ± 7.88 [a]
Dairy Synthetic	50	23.89 ± 7.65 [b]	24.76 ± 7.57 [b]
Body condition scores:			
1	7	48.01 ±13.16 [c]	48.37 ±12.97 [c]
2	56	22.57 ± 4.25 [cde]	23.48 ± 4.19 [cde]
3	40	11.88 ± 5.51 [e]	10.40 ± 5.41 [e]
4	4	49.35 ±23.03 [cd]	51.98 ±22.72 [cd]

[y] Score: **1** = extremely thin; **2** = thin; **3** = moderate; **4** = fat; **5** = extremely fat.

[z] LSMEANS from PROC GLM in Model 1 and Model 2, Snell calving score: **0**=normal delivery to **100**=Puller used, easy or hard.

a,b,c,d,e, Means within a column and subclass bearing different letters are significantly different (P<.05).

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CHAPTER 4

EFFECT OF SIRE BIRTH WEIGHT ON MATERNAL PERFORMANCE AND CALVING DIFFICULTY OF FEMALE PROGENY (F1)

4.1. INTRODUCTION

Calving difficulty and associated problems are a major cause of loss in beef cattle production. Several studies have confirmed the fact that increased incidence of calving difficulty is associated with increased birth weight (Bellows et al. 1971; Burfening et al. 1981; Meijering 1984; Naazie et al. 1989).

Selection directed towards increased size and growth rate in beef cattle has been achieved mainly by the use of sires with potential for high growth rate. Unfortunately, correlated responses to selection for growth rate include increased birth weight and higher level of calving difficulty (Koch et al. 1982). Increasing use of large and rapid growing bulls on smaller breeds has also contributed to the higher incidence of calving difficulty (Schaeffer and Wilton 1977; Liboriussen 1979).

A reduction in calf birth weight as a result of using sires with low birth weight would reduce the incidence of calving difficulty in first calving heifers (Bar-Anan 1979; Makarechian and Berg 1983). On the other hand, female progeny sired by bulls with low birth weight may be smaller in size, less productive and grow slower than the population average, resulting in a higher incidence of dystocia in heifers calving at two years of age (Philipsson 1976; Thompson et al. 1981). In contrast, Meijering and Postma (1985) reported that selection of low risk sire for dystocia would have a favourable influence on both direct and maternal effects of dystocia.

The objectives of this study were to evaluate the influence of sire birth weight on calving performance and maternal traits of their female progeny.

4.2. MATERIALS AND METHODS

4.2.1. Experimental design

Records of weight (from birth to calving), height, pelvic diameters and calving difficulty score of 407 two-year old heifers from three breed groups, 162 Beef Synthetic #1 (SY#1), 158 Beef Synthetic #2 (SY#2), and 87 Dairy Synthetic (SD), accumulated over six years at the University of Alberta Beef Cattle Research Ranch at Kinsella, Alberta, Canada were available for this study.

The SY#1 population is a composite of Charolais, Angus, and Galloway. The SY#2 population is composed of approximately 67% Hereford, 10% Dairy, and the remainder from other beef breeds. The SD population is composed of approximately 67% Dairy breeding (Holstein, Brown Swiss, and Simmental) and the remainder from the breeds used to develop SY#1. Details of the composition of the three breed groups are described in

Appendix 1.

The heifers were mated with bulls in single-sire mating groups within each breed group during a breeding season of 45 days. The heifers themselves were sired by 78 sires (number of heifers sired by each bull ranged from 2 to 18) in single sire mating groups, while heifers' calves (grand-progeny of the original sires) belonged to 55 sire families (Table 4.1). The heifers were maintained together under conventional management following breeding. Details of the herd management and breed group compositions have been described by Berg et al. (1990).

Records on birth date and birth weight, sex, weaning and yearling weights of the grand progeny (F2) and birth weight of their sires were also available. Calving performance of the heifers was scored on a scale of 0 to 5 (0 = normal or unassisted and 5 = the most difficult delivery requiring surgery) (Table 4.2).

Heifers and their progeny were weighed within 24 hours after calving. Pelvic diameters and hip height were measured five to six months after calving to allow the pelvic inlet to involute to the normal state. The horizontal and vertical pelvic diameters were measured using a Rice pelvimeter, caliper-type instrument (Lane Manufacturing Co. Denver, Colorado). Pelvic area was estimated as the product of vertical and horizontal pelvic measurements.

4.2.2. Statistical Analysis

4.2.2.1. Sire birth weight on calving performance and maternal traits

The original sires were grouped into high, medium and low classes according to their birth weight within breed group and year in order to identify and to divide the heifer progeny from sires with three classes of birth weight as follows: High = sires with birth weight heavier than one half standard deviation above the mean, Medium = birth weight within one half standard deviation of the mean, and Low = birth weight lower than one half standard deviation of the mean (Figure 4.1).

Sire birth weight classes were included in the model as a fixed effect in analyzing the data on growth and calving performance of female progeny (F1) and performance of their grand-progeny (F2).

Calving difficulty scores were transformed using Snell transformation as described by Tong et al. (1977) (Table 4.2). The data were analyzed by covariance analysis using SAS package (SAS Institute, Inc. 1985), according to the following basic model :

$$Y_{ijklm} = \mu + C_i + B_j + P_k + \Sigma X_l + e_{ijklm} \qquad (1)$$

where Y_{ijklm} denotes each record of the dependent variable, μ = the overall mean, C_i = fixed effect of the i-th year, B_j = fixed effect of the j-th breed group, P_k = fixed effect of the k-th sire birth weight class, X_l = effect of the l-th independent continuous variable, and ε_{ijklm} = random error.

The age of heifer was used as a covariate in analyzing the data on heifer's weight, height and pelvic dimensions. In analyzing calving difficulty scores of heifers, age and weight of the heifers at calving as well as birth weight of the bull which bred the heifers were used as covariates. In analyzing the performance of grand-progeny (F2), age of heifer at calving, sex of calf and birth weight of the bull mated to the heifer were also included in the model.

Comparisons of the effects of sire birth weight on the performance of heifers and their calves were performed by the separation of least squares means.

4.2.2.2. Heritabilities and genetic correlation

Sire and grandsire variance components and covariance between sire and grandsire effects for birth weight were estimated using the procedure described by Burfening et al. (1981) with the following model:

$$Y_{ijkl} = \mu + C_i + B_j + P_{k(j)} + \varepsilon_{ijkl} \quad (2)$$

where Y_{ijkl} denotes the record of dependent variable, namely calf birth weight, μ = the overall mean, C_i = fixed effect of the i-th year, B_j = fixed effect of the j-th breed group, $P_{k(j)}$ = random effect of the k-th sire or maternal grandsire within the j-th breed group, and ε_{ijkl} = random error.

The estimates of variance components of additive direct ($\sigma^2_{A_o}$), additive maternal ($\sigma^2_{A_m}$) effects and covariance between additive direct and additive maternal effects (σ_{AoAm}) were calculated by equating variance components of sire (σ^2_s), maternal grandsire (σ^2_g) and covariance component between sire and maternal grandsire effect ($\sigma_{s,MGS}$) to their biological causal components (Koch 1972; Willham 1972; Burfening et al. 1981; Jain 1992).

The heritabilities of additive direct effects estimated from sire variance component (h^2_s) and maternal grandsire variance component (h^2_g), the heritability of additive maternal effect (h^2_m) and total heritability (h^2_t), as well as the genetic correlation between the direct and maternal effects (rAoAm) were estimated according to Burfening et al. (1981). The genetic correlation between sire and maternal grandsire effects ($r_{s,MGS}$) was estimated according to Philipsson (1976).

4.3. RESULTS AND DISCUSSION

4.3.1. Responses to sire birth weight for maternal performance and calving difficulty of female progeny (F1)

The phenotypic correlation coefficients between sire birth weight and his progeny's weight at different stages of growth from birth to two-year of age ranged from 0.36 to 0.42 ($P<0.01$). Sire birth weight had a negative correlation with the vertical pelvic diameter ($r=-0.36$, $P<0.01$) and a low positive association with calving difficulty score of his female progeny ($r=0.12$, $P<0.05$).

The phenotypic association between sire birth weight and the birth weight of his grand progeny was positive ($r=0.2$, $P<0.01$), whereas sire birth weight had a negative association with his grand progeny's weaning weight ($r=-0.37$, $P<0.01$). The association between sire birth weight and yearling weight of his grand progeny, however, was positive but small ($r=0.14$, $P<0.05$).

The least squares means of the traits measured on female progeny (F1) of sires and their offspring (F2) by sire birth weight classes are presented in Tables 4.3 and 4.4. Sires with high birth weight produced female progeny with higher birth weight, weaning and postweaning weights compared with the progeny of low birth weight sires. However, sire birth weight did not have a significant effect on heifer progeny's pelvic dimensions and hip height (Table 4.3), although sire birth weight had a negative correlation with the vertical pelvic diameter.

Heifer progeny from high birth weight sires had a higher incidence of calving difficulty compared with those from low birth weight sires (Table 4.3). High incidence of calving difficulty in heifer progeny sired by the high birth weight bulls could be explained by the fact that although these heifers were heavier compared to the other two groups at calving, the ratios of birth weight of their calves to their own pelvic dimensions were larger (Table 4.4), resulting in higher incidence of dystocia compared with the progeny of low birth weight sires. Feto-pelvic incompatibility (FPI) is recognized as one of the most important causes of dystocia in two-year old heifers (Rice and Wiltbank 1972; Meijering 1984). The result of this study is in agreement with that reported by Meijering and Postma (1985), who found that selection of low risk sires for dystocia would improve calving performance both as direct and maternal traits.

The grand-progeny of sires with high birth weight were heavier at birth compared with those from by low birth weight sires (34.8 vs. 33.3 kg). However, the trend in growth rate was somewhat reversed after birth as the grand-progeny of low birth weight sires tended to be heavier at weaning compared to the grand-progeny of sires with high birth weight (193.8 vs. 207.9 kg) as the difference approached significance at 5% level of probability (Table 4.4). This is probably due to the negative genetic correlation between direct and maternal effects on weaning weight (Hohenboken and Brinks 1971; Koch 1972; Trus and Wilton 1988), as genetic correlation between birth weight and weaning weight is positive and relatively high (Bourdon and Brinks 1982). Therefore, although grand-progeny from sires with high birth weight would have higher potential for pre-weaning gain, due to the negative genetic correlation between direct and maternal effects on weaning weight, their dams (daughters of high birth weight sires) would not be able to produce as much milk as daughters of low birth weight sires. The negative phenotypic association between sire birth weight and weaning weight of his grand progeny in this study confirms this interpretation.

Heifer progeny from sires with high birth weight calved approximately five days later than those from medium and low birth weight sires (P<0.05, Table 4.4). Bourdon and Brinks (1982) also reported a positive but low association between age at first calving and growth rate.

4.3.2. Genetic aspects of direct, maternal and maternal grandsire effects on birth weight

The estimate of sire variance component (σ^2_s) for birth weight (Table 4.5) was somewhat larger than that of the maternal grandsire variance component (σ^2_g). The results of this study are in agreement with those of Burfening et al. (1981) and Philipsson (1976), who found sire variance component (σ^2_s) to be larger than maternal grandsire variance component (σ^2_g) for birth weight.

The estimated variance component of direct effect (σ^2_{A}) for birth weight was larger than that of maternal effect (σ^2_{Ar}) (Table 4.5). Burfening et al. (1981) and Trus and Wilton (1988) also found the variance component of direct effect (σ^2_{Ac}) for birth weight to be larger than that of maternal effect (σ^2_{Ar}). The results give higher heritability estimates of direct effect (h^2_s and h^2_g) compared with the heritability estimate of maternal effect (h^2_m) (Table 4.6). The higher heritability estimate of direct effect suggests that birth weight is influenced more by genotype of the calf than by the genotype of the dam.

Although direct and maternal heritability estimates obtained from experimental data in this study tended to be lower compared with other reports (Trus and Wilton 1988; Bourdon and Brinks 1982), the total heritability (h^2_T) was within the range of 0.20 to 0.30 reported in the literature.

The heritability estimate of add..ive direct effect estimated from sire variance component (h^2_S) for birth weight was somewhat larger than that estimated from maternal grandsire variance component (h^2_G) (Table 4.6). These estimates are also in agreement with those reported by Burfening et al. (1981).

The estimate of genetic correlation between direct and maternal effects on birth weight was -0.04 (Table 4.6). The genetic correlations between direct and maternal effects on birth weight in other reports were within the range of -0.20 to -0.50 (Philipsson 1976; Burfening et al. 1981; Trus and Wilton 1988). On the other hand, Koch (1972) reported a positive genetic correlation between direct and maternal effects for birth weight.

The estimate of the genetic correlation between sire and maternal grandsire effects for birth weight was positive and moderate ($r_{S.MG}$=0.60). This is in agreement with the estimates reported by Meijering and Postma (1985) and Trus and Wilton (1988). The result suggests that the maternal grandsire effect on birth weight is dominated by direct inheritance (Meijering and Postma 1985).

With respect to the relationship between birth weight and calving difficulty, the results suggest that low birth weight sires produce smaller heifers than the average heifer progeny (F1), but these heifers are likely to have less incidence of calving difficulty, as using low birth weight sires results in smaller second generation progeny (F2) than average of F2 at birth.

Since the most difficult births occur due to a high birth weight of the calf to be delivered relative to the birth canal (pelvic opening), particularly in the first calving heifers, and the female progeny from high birth weight sires had more incidence of dystocia compared with the female progeny from low birth weight sires, the use of sires with low birth weight or small breed for mating with primiparous heifers should be effective in reducing the incidence of dystocia. In addition, since the female progeny from low birth weight sires generally have lower growth rates and may have less desirable conformation, these disadvantages may be offset by the use of sires with medium birth weight for mating with cows in the second or later parities which have less incidence of calving difficulty (Figure 4.2).

4.4. SUMMARY AND CONCLUSION

Records on growth and maternal performance of 407 two-year old heifers mated in single sire matings and birth weight and growth performance of their calves were used to study the influence of sire birth weight on calving performance and maternal traits of their female progeny. Based on results of this study, several conclusions were drawn as follows:

1. Sires with high birth weight produced heifer progeny (F1) that were heavier at birth, weaning and calving at two years of age compared with the progeny of medium and low birth weight sires.
2. Heifer progeny from sires with high birth weight also had higher incidence of calving difficulty compared with heifers sired by low birth weight.
3. Sire birth weight did not have significant effect on hip height and pelvic dimensions of their heifer progeny.
4. The grand progeny (F2) of sires with high birth weight were also heavier at birth ($P<0.05$), but lighter at weaning (194 vs. 208 kg).
5. The genetic correlation between additive direct and additive maternal effects (r_{AoAm}) for birth weight was -0.04; however, genetic correlation between sire and maternal grandsire effects was positive and moderate ($r_{S.MG}=0.60$).

The results of this study indicated that selection of low birth weight sires aimed at directly reducing the incidence of calving difficulty in heifers, could also result in lower incidence of dystocia among the female progeny without influencing the maternal performance of the female progeny. In fact,the maternal performance of female progeny of low birth weight sires was superior to that of high birth weight sires for weaning weight and age at calving.

Since the average for growth performance of the female progeny from low birth weight sires will likely be lower than that from high birth weight sires, the use of sires with low birth weight or small breed should be chosen only for mating with the primiparous heifers in order to minimize the possibility of excessive calf birth weight for reducing calving problems.

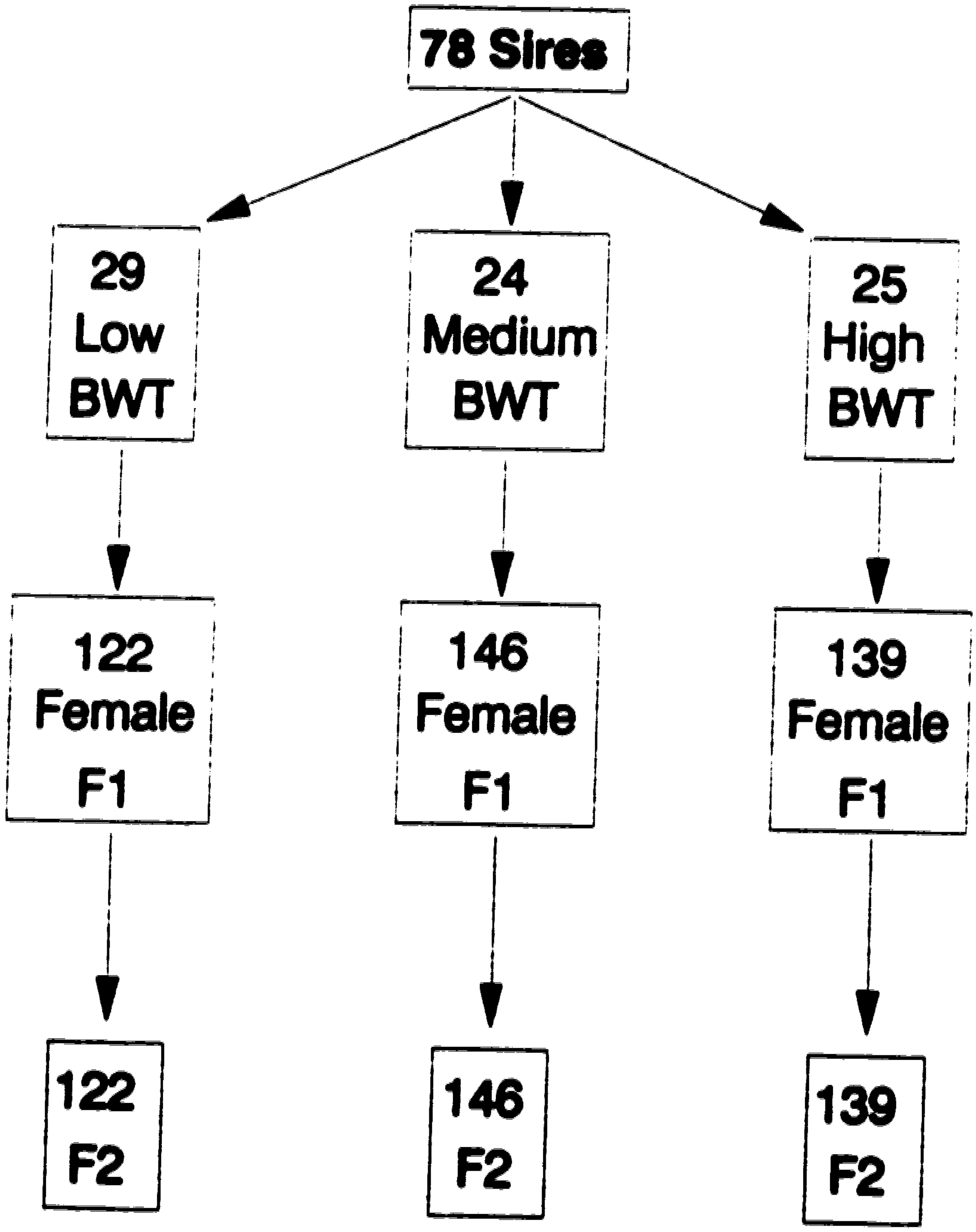


Figure 4.1. Design of the Effect of Sire Birth Weight (BWT) on Maternal Performance and Calving Difficulty of Female Progeny (F1)

TABLE 4.1. NUMBER OF ANIMALS BY BREED GROUP AND FAMILY RELATIONSHIP

Family relationship	Number of animals within breed group [a]			
	SY#1	SY#2	SD	Total
Sires (Heifers' parents) within category of sire birth weight [a]:				
High	13	7	5	25
Medium	9	9	6	24
Low	11	11	7	29
Heifers (Sires' progeny, F1) within category of sire birth weight :				
High	64	42	33	139
Medium	60	60	26	146
Low	38	56	28	122
Heifers' calves (Sires' grand progeny, F2):	162	158	87	407
Sires of heifers' calves:	23	21	11	55

[a]**SY#1** = Beef Synthetic #1, **SY#2** = Beef Synthetic #2, and **SD** = Dairy Synthetic.

High = Sire Birth Weight $\geq \bar{x} + ½$ s.d.

Medium = $\bar{x} - ½$ s.d. < Sire Birth Weight < $\bar{x} + ½$ s.d.

Low = Sire Birth Weight $\leq \bar{x} - ½$ s.d.

$\bar{x}$ = mean sire birth weight within breed group and year.
s.d. = standard deviation of sire birth weight within breed group and year.

TABLE 4.2. DESCRIPTION AND FREQUENCY OF CALVING DIFFICULTY AND SNELL TRANSFORMED SCORES

Calving description	Difficulty score	Snell score	n	Frequency, %
Normal	0	00.0	270	71.2
Slight assistance	1	48.0	51	12.5
Puller used, easy pull	2	66.4	36	8.8
Hard pull, veterinary [*] assistance, or Caesarean	3 ◆	100.0	30	7.4

[*] Assistance of a veterinarian was scored as 4 and Caesarean sections as 5.

◆ There were only five cases of 4 or 5 scores, therefore, those were combined with animals scored 3.

TABLE 4.3. LEAST SQUARES MEANS AND STANDARD ERRORS FOR WEIGHT, HEIGHT, PELVIC DIMENSIONS AND CALVING PERFORMANCE OF FEMALE PROGENY (F1) BY SIRE BIRTH WEIGHT

Sire birth weight	n	Trait	n	Trait *
	407	F1 Birth weight (kg)	355	F1 Weaning weight (kg)
High	139	40.1 ± 0.45 ^{a}	125	213.8 ± 2.11 ^{a}
Medium	146	36.1 ± 0.44 ^{b}	136	197.8 ± 2.01 ^{b}
Low	122	34.7 ± 0.48 ^{c}	94	191.6 ± 3.09 ^{b}
	355	F1 Yearling weight (kg)	355	F1 18 Mo weight (kg)
High	125	276.2 ± 2.72 ^{a}	125	409.4 ± 3.03 ^{a}
Medium	136	259.3 ± 2.59 ^{b}	136	390.6 ± 2.89 ^{b}
Low	94	256.7 ± 3.98 ^{b}	94	388.3 ± 4.44 ^{b}
	407	F1 Calving weight (kg)	406	F1 Hip height (cm)
High	139	449.5 ± 3.84 ^{a}	139	122.8 ± 1.90
Medium	146	433.6 ± 3.77 ^{b}	146	123.7 ± 1.80
Low	122	426.0 ± 4.03 ^{b}	121	126.7 ± 2.34
	407	F1 Pelvic horizontal (cm)	407	F1 Pelvic vertical (cm)
High	139	16.3 ± 0.08	139	17.5 ± 0.10
Medium	146	16.4 ± 0.07	146	17.4 ± 0.10
Low	122	16.3 ± 0.08	122	17.3 ± 0.10
	407	F1 Pelvic area (cm^2)	407	F1 calving score
High	139	286.0 ± 2.28	139	24.8 ± 3.01 ^{a}
Medium	146	285.8 ± 2.13	146	20.5 ± 2.92 ^{ab}
Low	122	281.5 ± 2.82	122	12.8 ± 3.16 ^{b}

*) a,b,c Means within a column of a trait followed by different letters are significantly different (P<0.05).

TABLE 4.4. LEAST SQUARES MEANS AND STANDARD ERRORS FOR BIRTH WEIGHT AND DATE, WEANING AND YEARLING WEIGHT, AND RATIO OF BIRTH WEIGHT TO DAM'S PELVIC DIMENSIONS OF GRAND PROGENY OF SIRES (F2) CLASSIFIED BY THEIR BIRTH WEIGHT

Sire birth weight	n	Trait *
	407	F2 Birth weight (kg)
High	139	34.8 ± 0.44 [a]
Medium	146	33.6 ± 0.43 [ab]
Low	122	33.3 ± 0.46 [b]
	407	F2 birth weight / F1 pelvic area (%)
High	139	12.3 ± 0.17
Medium	146	12.0 ± 0.16
Low	122	12.1 ± 0.21
	407	F2 Birth date (day) +
High	139	116.1 ± 1.21 [a]
Medium	146	111.2 ± 1.18 [b]
Low	122	111.3 ± 1.27 [b]
	306	F2 Weaning weight (kg)
High	88	193.8 ± 5.69 [a]
Medium	109	198.2 ± 4.79 [ab]
Low	109	207.9 ± 4.47 [b]
	298	F2 Yearling weight (kg)
High	85	406.1 ± 14.30
Medium	107	415.3 ± 11.92
Low	106	407.5 ± 14.80

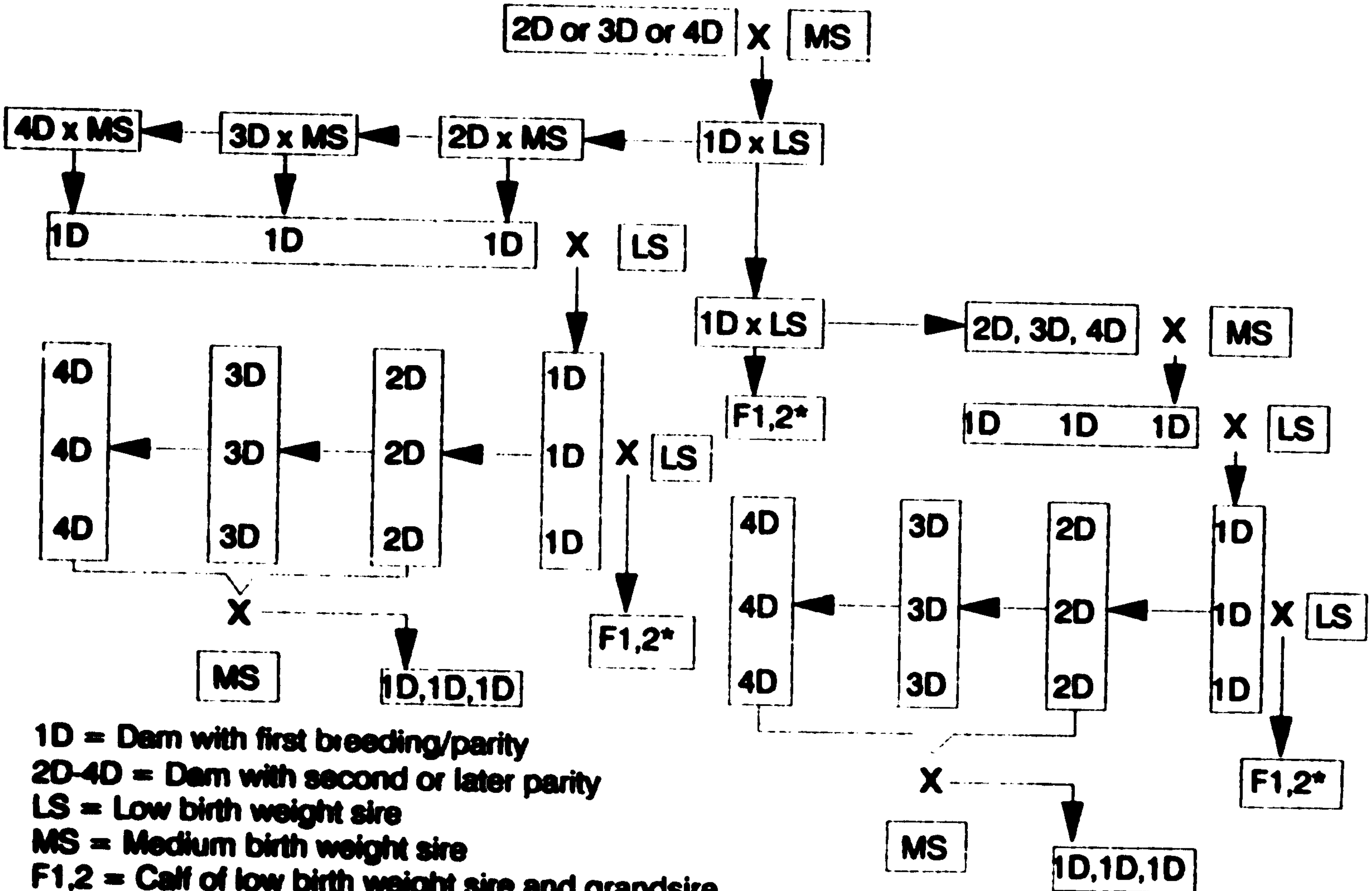
*) **a,b,c** Means within a column of a trait followed by different letters are significantly different ($P<0.05$).
+) Started from January 1.

TABLE 4.5. COMPONENTS OF VARIANCE AND COVARIANCE FOR BIRTH WEIGHT

Sire variance component (σ^2_{s})	1.10
Residual variance component (σ^2_{Es})	22.27
Maternal grandsire variance component (σ^2_{g})	0.67
Residual variance component (σ^2_{Eg})	22.41
Covariance between sire and maternal grandsire ($\sigma_{S,MG}$)	0.52
Genetic variance of additive direct effect (σ^2_{Ad})	4.40
Genetic variance of additive maternal effect (σ^2_{Am})	1.70
Covariance between genetic additive direct and maternal effects (σ_{AdAm})	-0.12

TABLE 4.6. HERITABILITY ESTIMATES, GENETIC CORRELATIONS OF DIRECT TO MATERNAL AND MATERNAL GRANDSIRE EFFECTS AND STANDARD ERRORS FOR BIRTH WEIGHT

Heritability of additive direct effect (h^2_A) estimated from σ^2_A	0.19±0.19
Heritability of additive direct effect (h^2_s) estimated from σ^2_s	0.12±0.15
Heritability of additive maternal effect (h^2_m)	0.10±0.17
Heritability of the total additive direct and maternal effects (h^2_T)	0.22±0.29
Genetic correlation between additive direct and maternal effects ($r_{A,M}$)	-0.04±0.92
Genetic correlation between additive direct and maternal grandsire effects ($r_{A,MG}$)	0.60±0.49



1D = Dam with first breeding/parity
2D-4D = Dam with second or later parity
LS = Low birth weight sire
MS = Medium birth weight sire
F1,2 = Calf of low birth weight sire and grandsire
* should be culled for the next breeding

Figure 4.2. Strategy for reducing dystocia using low birth weight sires in range beef cattle

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CHAPTER 5

GENERAL DISCUSSION

5.1. SUMMARY

The relationships between pelvic dimensions and the incidence of calving difficulty had been well documented (Rice and Wiltbank 1972; Burfening et al. 1978; Meijering 1984; Johnson et al. 1988; Siemens et al. 1991). However, the important factors affecting calving difficulty have not been consistent among the reports.

In this study, first attempts were made to evaluate the repeatability of the pelvic measurements in order to evaluate the accuracy of pelvic measurements using the Rice pelvimeter (Chapter 2). The results showed that the accuracy of pelvic measurements using the Rice pelvimeter was moderate within operator.

The influence of operators on the accuracy of pelvic measurements was also studied. The results indicated that the area of pelvic opening as measured by the experienced operators was significantly larger than that measured by the inexperienced operators. However, the relative variation between the operators compared to the residual variance was very small. The results of this study suggest that measuring the pelvic diameters using the Rice pelvimeter is not highly repeatable. Therefore, in order to increase accuracy, measurement by Rice pelvimeter should be based on the average of at least two measurements.

In order to identify the factors contributing to calving difficulty and to compare the influence of pelvic dimensions, weight and height of heifers measured after breeding and before calving, the contribution of each factor in variation of calving difficulty were studied (Chapter 3).

The means of pelvic dimensions, hip height and weight of heifers measured before calving in both breed groups (Table 3.2) were considerably larger and showed greater variation compared with those measured after breeding. The total variation in calving difficulty (Table 3.3), accounted for in this study, was higher than that previously reported by Naazie et al. (1989). This may be a different period of variable measurements and number of variables in the model. Calf birth weight, body condition score and the ratio of calf birth weight to pelvic area were the most important factors affecting the variation in calving difficulty. The low incidence of calving difficulty among heifers with body condition score of 3 indicated that adequate fat reserve was important for the process of parturition.

The important contribution of calf birth weight to variation in calving difficulty score (Table 3.3) was in agreement with other reports (Johnson et al. 1988; Naazie et al. 1989; Morrison et al. 1985; Van Donkersgoed et al. 1990). The large influence of the ratio of calf birth weight to pelvic area on calving difficulty score in this study was also in agreement with other studies (Bellows et al. 1971; Rice and Wiltbank 1972).

The results of other studies on the same population of cattle at Kinsella (Berg 1979; Makarechian and Berg 1983; Naazie et al. 1989) have shown that heifer's weight at calving was an important factor in calving difficulty. In this study, it was found that the heifer's weight and height alone made a significant contribution to calving difficulty only when calf birth weight was excluded from the model (Table 3.3).

The results of this study suggest that the incidence and severity of calving difficulty in first calving heifers could be significantly reduced by (1) using sires with low birth weight which would result in calves with low birth weight, (2) using heifers with relatively well developed pelvic opening, and 3) keeping heifers in good body condition (score of 3) during pregnancy.

The influence of sire birth weight on maternal performance and calving difficulty of the female progeny was also studied (Chapter 4). Based on this study, although the heifer progeny of sires with low birth weight were smaller at birth, weaning and calving at two years of age compared with those from high birth weight sires, their pelvic dimensions and hip height was not affected by the sire birth weight. The grand progeny (F2) of sires with high birth weight were also heavier at birth ($P<0.05$), but lighter at weaning (194 vs. 208 kg).

The genetic correlation between direct and maternal effects ($r_{[illegible]}$) for birth weight was -0.04; however, genetic correlation between sire and maternal grandsire effects on birth weight was positive and moderate($r_{[illegible]}$=0.60). This result was in agreement with other studies (Meijering and Postma 1985; Trus and Wilton 1988).

The results of this study indicate that selection for low birth weight sires aimed at directly reducing the incidence of calving difficulty in heifers, could also result in lower incidence of dystocia among the female progeny without influencing the maternal performance of the female progeny. In fact, the maternal performance of female progeny of low birth weight sires was superior to that of high birth weight sires for weaning weight and age at calving.

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APPENDIX 1

AVERAGE BREED PERCENTAGES AT THE UNIVERSITY BEEF CATTLE RESEARCH RANCH AT KINSELLA FROM 1962-1988 [a]

Breed	1962	1970	1974	1978	1982	1984	1986	1988
Beef Synthetic #1:								
Angus	41.4	37.6	36.0	35.7	36.8	36.9	36.2	35.6
Brown Swiss	-	4.7	4.2	4.5	5.2	5.0	5.3	5.7
Charolais	16.8	35.1	34.4	34.7	34.1	33.7	32.3	31.4
Galloway	40.3	20.3	21.4	21.7	20.6	20.7	20.1	20.9
Others	1.5	2.3	4.0	3.4	3.3	3.7	6.1	6.4
Beef Synthetic #2:								
Angus	-	-	-	-	11.1	10.0	15.3	12.1
Charolais	-	-	-	-	9.4	7.8	8.8	8.0
Galloway	-	-	-	-	7.4	4.4	6.7	5.1
Hereford	-	-	-	-	65.0	69.5	59.8	60.1
Others	-	-	-	-	7.1	8.3	9.4	14.7
Dairy Synthetic :								
Brown Swiss	-	17.5	30.1	27.3	22.5	23.7	22.7	25.8
Holstein	-	63.4	34.4	27.4	30.5	23.0	24.5	22.1
Simmental	-	-	-	9.4	7.2	12.1	8.9	6.1
Beef breeds*	-	19.1	35.5	35.9	39.8	41.2	43.9	46.0

* Includes mostly Angus, Galloway, Hereford and Charolais.

[a] Adapted from Berg et al. (1990).

APPENDIX 2

MANAGEMENT OF EXPERIMENTAL HEIFERS

The University of Alberta Beef Cattle Breeding Research Ranch is located at Kinsella, Alberta. The major objective of the breeding program has been selection for performance and productivity under commercial management conditions (Berg et al. 1990).

The studies (Chapter 2 and 3) were conducted during two consecutive years from July 1990 to July 1992, using 143 experimental beef heifers belonging to two breed groups, 82 Beef Synthetic #1 and 61 Dairy Synthetic. The heifer calves were born in April and May 1990 and were raised on the pasture until weaning in early October without creep feeding.

After calving, the heifer calves were given an injection of vitamin A, D and E supplements. The heifer calves were also vaccinated against clostridial diseases (Jasvax 8), infectious bovine rhinotracheitis (IBR) and parainfluenza 3 (PI3) at approximately two months of age (Bovishield/IBRPI3).

The breeding herds were on the range all year and depend on natural grazing except for 3-4 months in the winter when supplementary feed was provided. The level of supplementary feed depends on the pasture conditions and severity of winter. The heifers were fed with limited 2.3 kg concentrate and 2.3 kg hay per day. Straw bedding was also available.

Heifers were selected with emphasis on reproductive performance. All sound heifers had been exposed to a bull at approximately 14 months of age for up to 45 days during breeding season in July and August 1991. Bulls were selected based on pre- and post-weaning gain and used for breeding as yearlings with respect to average birth weight. Breeding was carried out in single sire groups up to about 26 heifers to a bull. Heifers which failed to conceive were culled and deleted from the final data set. In total, data on 107 calving heifers were used for analysis of calving performance.

Calving was in April and May 1992. Heifers calving for the first time were closely supervised by ranch staff. During calving season, the pregnant heifers showing signs of parturition were put in a calving pen and observed continuously. During parturition, the heifers which had the calf's forelimbs and head presenting at the vulva and ceased to complete birth normally until 3 hours were assisted. Calves of all heifers were weighed within 24 hours after calving.

APPENDIX 3

DERIVATION OF THE APPROXIMATE STANDARD ERROR OF REPEATABILITY AND HERITABILITY

The approximate standard error of the repeatability is derived based on General Formula of Error Propagation (Shapiro and Gross 1981; Stuart and Ord 1987).

The variance component analyses are available in computer programs e.g. using Maximum Likelihood (ML) or Restricted Maximum Likelihood (REML) procedures in SAS Package i.e. SAS VARCOMP (Statistical Analysis System Institute, Inc. 1985). The approximate asymptotic variances and covariances of these variance components are available from output (they are the inverse of information matrix in ML or REML estimation) or can be obtained from linear combinations of mean squares in generalized ANOVA estimation (Searle 1971, 1989).

In animal breeding, the variance components are used to construct or describe some genetic and environmental parameters, such as heritability, repeatability, intraclass correlation, etc. The constructed variables are then functions of these variance components each of which is subjected to sampling error. As a result, the constructed variables are also subjected to sampling error. It is, therefore, necessary to estimate the sampling error of the constructed variable (usually called standard error which is the square root of the sampling variance).

By definition, repeatability as a pooled measures of the correlation between repeated measurements within animals (Falconer 1989) can be estimated using intraclass correlation (Becker 1967; Steel and Torrie 1980) as:

$$\hat{r} = \frac{\hat{\sigma}^2_A}{\hat{\sigma}^2_A + \hat{\sigma}^2_O + \hat{\sigma}^2_E}$$

$$= \frac{\hat{\sigma}^2_1}{\hat{\sigma}^2_1 + \hat{\sigma}^2_2 + \hat{\sigma}^2_3}$$

$$= \frac{\hat{X}}{\hat{Y}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Then according to General Formula of Error Propagation, the approximate asymptotic variance of repeatability can be expressed as:

$$Var(\hat{r}) = Var(\hat{X})/\hat{Y}^2 + \hat{X}^2\, Var(\hat{Y})/\hat{Y}^4 - 2\hat{X}\, Cov(\hat{X},\hat{Y})/\hat{Y}^3 \quad \ldots(2)$$

where,

$$\hat{X} = \hat{\sigma}^2_A$$

$$\hat{Y} = \hat{\sigma}^2_A + \hat{\sigma}^2_O + \hat{\sigma}^2_E,$$

$$Var(\hat{X}) = Var(\hat{\sigma}^2_A),$$

$$Var(\hat{Y}) = Var(\hat{\sigma}^2_A) + Var(\hat{\sigma}^2_O) + Var(\hat{\sigma}^2_E) + 2Cov(\hat{\sigma}^2_A, \hat{\sigma}^2_O)$$

$$+ 2Cov(\hat{\sigma}^2_A, \hat{\sigma}^2_E) + 2Cov(\hat{\sigma}^2_O, \hat{\sigma}^2_E),$$

$$Cov(\hat{X},\hat{Y}) = Cov(\hat{\sigma}^2 A, \hat{\sigma}^2 A + \hat{\sigma}^2 O + \hat{\sigma}^2 E)$$

$$= Var(\hat{\sigma}^2 A) + Cov(\hat{\sigma}^2 A, \hat{\sigma}^2 O) + Cov(\hat{\sigma}^2 A, \hat{\sigma}^2 E).$$

Then the standard error of $\hat{r}$ is

$$\sigma(\hat{r}) = \sqrt{var(\hat{r})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The heritability is defined as :

$$\hat{h} = \frac{4\hat{\sigma}^2 s}{\hat{\sigma}^2 h + \hat{\sigma}^2 s + \hat{\sigma}^2 e}$$

$$= \frac{4\hat{\sigma}^2 2}{\hat{\sigma}^2 1 + \hat{\sigma}^2 2 + \hat{\sigma}^2 3}$$

$$= 4\frac{\hat{X}}{\hat{Y}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Then according to General Formula of Error Propagation, the approximate asymptotic variance of heritability can be expressed as:

$$Var(\hat{h}^2) = 4^2 \{Var(\hat{X})/\hat{Y}^2 + \hat{X}^2 Var(\hat{Y})/\hat{Y}^4 - 2\hat{X} Cov(\hat{X},\hat{Y})/\hat{Y}^3\} \ldots (5)$$

where,

$$\hat{X} = \hat{\sigma}^2 s$$

$$\hat{Y} = \hat{\sigma}^2 h + \hat{\sigma}^2 s + \hat{\sigma}^2 e,$$

$$Var(\hat{X}) = Var(\hat{\sigma}^2 s),$$

$$Var(\hat{Y}) = Var(\hat{\sigma}^2 h) + Var(\hat{\sigma}^2 s) + Var(\hat{\sigma}^2 e) + 2Cov(\hat{\sigma}^2 h, \hat{\sigma}^2 s)$$

$$+ 2Cov(\hat{\sigma}^2 h, \hat{\sigma}^2 e) + 2Cov(\hat{\sigma}^2 s, \hat{\sigma}^2 e),$$

$$Cov(\hat{X},\hat{Y}) = Cov(\hat{\sigma}_s, \hat{\sigma}_h + \hat{\sigma}_s + \hat{\sigma}_e)$$

$$= Var(\hat{\sigma}_s) + Cov(\hat{\sigma}_h, \hat{\sigma}_s) + Cov(\hat{\sigma}_s, \hat{\sigma}_e).$$

Then the standard error of $\hat{h}$ is

$$\sigma(\hat{h}) = \sqrt{var(\hat{h})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

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APPENDIX 4

THE SNELL TRANSFORMATION OF CALVING DIFFICULTY SCORE

Snell (1964) indicated two basic assumptions to analysis of variance methods i.e. i) the residual deviations are normally distributed and ii) the residual variances are homogeneous.

The Snell transformation score is a method of determining numerical scores for subjectively defined categorical data, particularly those concerning attitude scaling, in order to stabilize residual variation. A scoring procedure by Snell (1964) has some appealing properties i.e. the residuals are approximately normally distributed and the residual variances are homogeneous.

For a scale of calving difficulty categories in this study, the Snell transformed calving scores were estimated according to the procedure described by Tong et al. (1977).

For a scale of k categorical scores, points x_j (j=0,1,..k) is defined such that categorical score S_j corresponds to the interval x_{j-1} to x_j. The equations for the maximum likelihood estimates of the parameters x_j (j=0,1,2,...k) for the estimated boundary points of k categorical calving scores have been derived as follows:

(1) for j = k-1 :

$$\frac{N_{k-1}}{(e^{(\hat{x}_{k-1} - \hat{x}_{k-2})} - 1)} = (N_{k-1} + N_k)P_{k-1} - N_{k-1}$$

(2) for j=2,3,...k-2 :

$$\frac{N_j}{(e^{(\hat{x}_j - \hat{x}_{j-1})} - 1)} - \frac{N_{j+1}}{(e^{(\hat{x}_{j+1} - \hat{x}_j)} - 1)} = (N_j + N_{j+1})P_j - N_j$$

where $\hat{x}$ (j=1,2,...k) are estimate boundary points such that the score for category j, S_j corresponds to the mid-point between $\hat{x}_{j-1}$ and $\hat{x}_j$, P_j is the observed probability of observation in category j, and N_j is frequency of scale values in category j. Therefore, these two equations give estimates for the interval $(\hat{x}2 - \hat{x}1)$, $(\hat{x}3 - \hat{x}2)$, ...$(\hat{x}_{k-1} - \hat{x}_{k-2})$. Taking x1 = 0, values for all x_j (j=2,....k-1) are obtained.

For the two extreme categorical scores, scores are derived from the corresponding expected values under the two tails of the distribution. The scores for the first and last category are equal to:

$S1 = \hat{x}1-((-\log e\ P1)/Q1)$; and $Sk = \hat{x}_{k-1}+((-\log e\ P_{k-1})/Q_{k-1})$ where P1 is the probability of a value greater than x1 and Q1 = 1 - P1, and P_{k-1} is the probability of a value less than

x_{i} and $Q_{i} = 1 - P_{i}$.

Once the class boundaries x are estimated, mid-points between the first and last categories are estimated as follows :

$S_i = (x_i + x_{i-1})/2$.

Finally, the scores for S1, S2,............S_i are standardized to values between 0 and 100 by subtracting S1 from all S_i, then multiplying each score by $100/S_i$ for a score set of Snell transformed calving scores.

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APPENDIX 5

THE ESTIMATION OF ADDITIVE GENETIC DIRECT, MATERNAL AND MATERNAL GRANDSIRE EFFECTS

Estimates of the additive genetic variance of direct effects (σ^2_A), additive genetic variance of maternal effects (σ^2_M) and additive genetic covariance of direct and maternal effects (σ_{AM}) could be calculated by equating the sire variance component (σ^2_S), maternal grandsire variance component (σ^2_G) and covariance component between sire and maternal grandsire ($\sigma_{S.MG}$) to their biological causal component (Willham 1972) as follows:

$\sigma^2_S = 1/4\ \sigma^2_A$,

$\sigma^2_G = 1/16\ \sigma^2_A + 1/4\ \sigma_{AM} + 1/4\ \sigma^2_M$, and

$\sigma_{S.MG} = 1/8\ \sigma^2_A + 1/4\ \sigma_{AM}$.

The additive genetic variances and covariances were then calculated based on their biological causal components as follows:

$\sigma^2_A = 4\ \sigma^2_s$,

$\sigma_{AM} = 4\ \sigma_{S.MG} - 2\ \sigma^2_s$, and

$\sigma^2_M = 4\ \sigma^2_g - 4\ \sigma_{S.MG} + \sigma^2_s$.

The estimates of heritability of additive direct effect estimated from sire variance (h^2_s) and maternal grandsire variance component (h^2_g), the heritability of additive maternal effect (h^2_m) and total heritability (h^2_T), as well as the genetic correlation between additive direct and maternal effects ($r_{A,M}$) were estimated according to Burfening et al. (1981) as follows:

$$h^2_s = h^2_D = \sigma^2_S / \sigma^2_S + \sigma^2_{E_1},$$

where $\sigma^2_{E_1}$ = residual variance component from sire analysis,

$$h^2_M = 4\ \sigma^2_M / \sigma^2_M + \sigma^2_{E_2},$$

where $\sigma^2_{E_2}$ = residual variance component from maternal grandsire analysis,

$$h^2_T = \sigma^2_{AT} / \sigma^2_P,$$

where $\sigma^2_P = \sigma^2_A + \sigma_{A,AM} + \sigma^2_{AM} + \sigma^2_E$, and

$$\sigma^2_E = \sigma^2_{E_2} - 3/4\ \sigma^2_A - \sigma_{A,AM} - \sigma^2_{AM},$$

$$h^2_T = (\sigma^2_A + 3/2\ \sigma_{A,AM} + 1/2\ \sigma^2_{AM}) / \sigma^2_P, \text{ and}$$

$$r_{A,AM} = \sigma_{A,AM} / \sqrt{(\sigma^2_A)(\sigma^2_{AM})}.$$

The genetic correlation between sire and maternal grandsire effects ($r_{S,MGS}$), that is relevant in predicting the regression of maternal grandsire merit on direct genetic merit, was estimated according to Philipsson (1976) as follows:

$$r_{S,MGS} = (1/8\ \sigma^2_{AD} + \tfrac{1}{4}\sigma_{AD,AM}) / \sqrt{\tfrac{1}{4}\sigma^2_{AD}} . \sqrt{(1/16\ \sigma^2_{AD} + \tfrac{1}{4}\sigma^2_{AM} + \tfrac{1}{4}\sigma_{AD,AM})}.$$

Standard error of the genetic correlation was estimated according to Becker (1967) as follows:

$$S.E.(r_G) = [(1-r^2_G)/\sqrt{2}]\ [\sqrt{((S.E.(h^2_x)\ S.E.(h^2_y))/(h^2_x\ h^2_y))}].$$

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