GENETIC AND ENVIRONMENTAL FACTORS AFFECTING PERFORMANCE TRAITS OF STRAIGHTBRED ANGUS AND FRIESIAN-SIRED CALVES

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ABSTRACT

Genetic and environmental parameters for calf growth traits were determined from data collected over a 5-year period at the Whatawhata Hill Country Research Station, Hamilton, using least squares mixed model procedures. From a total of 497 female and 460 male calves sired by 29 Friesian bulls and from Friesian, Friesian-Jersey, Angus and Friesian-Angus dams, paternal half-sib heritability estimates were close to zero for both sexes of calf. Higher heritabilities were calculated by the same method using records from 179 female and 161 male straightbred Angus calves, the progeny of 17 bulls, and giving females first and males second were: birth weight, -0.14 and 0.44; pre-weaning growth rate, 0.19 and 0.29; and weaning weight, 0.25 and 0.40. Because of large standard errors, the differences between calf sexes were not conclusive.

Genetic correlations between birth weight and pre-weaning growth rate and birth weight and weaning weight calculated for the Angus males were 1.06 and 1.07, respectively, and the genetic correlations between pre-weaning growth rate and weaning weight calculated for all individuals except the Friesian-sired female calves ranged from 0.88 to 1.06. Other genetic correlations were not obtained because negative sire components of variance precluded their estimation.

The ranges of the phenotypic correlations were: birth weight and pre-weaning growth rate, 0.07 to 0.43; birth weight and weaning weight; 0.25 to 0.61, and pre-weaning growth rate and weaning weight, 0.85 to 0.98.

An investigation of cow - calf weight relationships using 340 Angus and 404 Friesian cow - calf pairs showed that heavier Friesian cows gave birth to significantly heavier calves, such that every 10 kg increase in cow liveweight was associated with an approximate 0.40 kg increase in calf birth weight.

Regressions of weaning weight on dam liveweights showed that heavier Angus cows weaned significantly heavier male calves by approximately 0.45 kg per 10 kg increase in cow weight. The other associations for the remaining animals were considerably smaller and non-significant.

The findings of this study suggest that where Friesian sires are used, genetic improvement in calf growth characters would be slow and less effective than in Angus cattle. The genetic parameters for the Angus breed compare favourably with the majority of published estimates while comparable findings for dairy breeds and dairy x beef crossbreds are few in number.

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CHAPTER ONE

INTRODUCTION

The formulation of selection plans in livestock production systems requires knowledge of the genetic parameters of productive traits. Because genetic parameters apply only to the population from which they are estimated, the practice of using parameters from one location in another can be questioned despite the fact that estimates of genetic parameters for the same traits in different populations at different times often show a similarity. Existing plans for the improvement of New Zealand beef cattle are essentially based on genetic parameters reported in American literature. While there is considerable need for better integration of genetic improvement schemes with farming systems, there is also a need for further estimation of genetic parameters for productive traits of cattle used for beef production under local pastoral management if better selection programmes are to be adopted.

In beef cattle, measurable productive traits include those associated with reproductive efficiency, growth capacity and efficiency, carcass quality and meat quality. The increasing demand for beef of high quality, the current emphasis on the efficiency of production and the availability of additional breeds of cattle have contributed to the need to evaluate and compare numerous breeds and crosses between established breeds for performance characteristics, as well as to assess the potential for selection within the more promising recently imported breeds.

In New Zealand a considerable amount of research interest has centred on the production of beef from what have been traditionally regarded as dairy breeds and from beef x dairy crossbreds. The main objective of this present study was to estimate genetic and environmental (and phenotypic) parameters for birth weight, pre-weaning growth rate and weaning weight of straightbred Angus and Friesian-sired calves under hill country management at the Whatawhata Hill Country Research Station of the Ministry of Agriculture and Fisheries, Hamilton.

In a beef production system, gains in efficiency through using small cows tend to be offset by the lower growth rates of their offspring. A second objective in this work was to assess the likely effects of cow size on calf birth and weaning weights in straightbred Angus and straightbred Friesian cattle through investigations of cow - calf weight relationships.

CHAPTER TWO

REVIEW OF LITERATURE

I. The Application of Genetic Principles

Genetic differences between individuals within and among the populations provide a basis for genetic improvement. The concept of heritability in both the narrow sense and the broad sense was defined by Lush (1940) and has more recently been discussed by Touchberry (1973). Heritability in the narrow sense includes as heredity only the average effects of genes; in the broad sense heritability refers to the functioning of the whole genotype. Heritability in the narrow sense can be used for predicting the response to a single generation of selection.

Selection or restriction of population size may cause heritability to change. It has been noted that gene effects have to be very large in relation to the phenotypic standard deviation before genetic variances are likely to change substantially in the first few generations of selection (Hill, 1974).

The relative efficiencies of some heritability estimators for sample populations have been given by Hill (1974). Heritabilities for beef traits are commonly obtained using the paternal half-sib method. Often suitable records are not available to enable the application of other methods. Paternal half-sib estimates lie between heritability in the narrow sense and heritability in the broad sense as the estimates obtained contain the additively genetic variance and a fraction of the epistatic variance. These estimates are usually regarded as approximating heritability in the narrow sense rather than in the broad sense. Lush (1940) and Koch (1972) have discussed the possible biases that may arise from environmental correlations.

For long-term improvement, multi-trait selection is most efficiently carried out by the selection index approach, the genetic basis for which has been given by Hazel (1943). Such an index requires knowledge of the genetic and phenotypic correlations between traits and the heritability, standard deviation and relative economic value for each trait. Examples of selection indexes of various forms for beef cattle include those of L.L. Wilson et al. (1962; 1963), Armstrong et al. (1965), Petty et al. (1965), Swiger et al. (1965), Vesely and Robison (1972), Dickerson et al. (1974), Koch et al. (1974a; 1974b) and McClintock and Cunningham (1974).

The problem of defining selection objectives for beef cattle is indeed complex. Notably, the bull, the cow, and the slaughter animal are each expected to perform different functions. Furthermore, the beef processing industry is faced with the difficulty of catering for a wide range of consumer preferences (Barton, 1970a; 1974). Many authors have discussed selection criteria for beef cattle (Carter, 1966; Cartwright, 1970; Dickerson, 1970; Rae and Barton, 1970; Dickerson et al., 1974; Lindhé, 1974; Preston and Willis, 1974; Bishop et al., 1975; among others).

Birth weight and pre-weaning growth rate (and therefore weaning weight) are influenced by the direct maternal effects of the dam. In a review of factors associated with milk production of beef cows, Barton (1970b) has emphasized the importance of this factor in affecting early growth of beef calves. The correlations he reported between dams' milk production and the growth rates of calves are generally high, but tend to decrease later in lactation. Koch (1972) pointed out that total maternally-related variation had been shown to account for 15 to 20% of the variation in birth weight, and 29 to 38% of the variation in liveweight gain from birth to weaning (i.e., pre-weaning growth rate). The studies reveiwed by that author indicate that maternal effects on birth weight and pre-weaning growth rate are of low -to - medium heritability.

The composition of genotypic relationships between relatives for a maternally influenced trait are given in Table 2.1. The components between relatives shown, other than among paternal half-sibs will, for maternally influenced traits, be affected by the sign and magnitude of the covariance between the genetic components for maternal effects and the genetic components for growth rate. Dickerson (1947) discussed the apparent antagonism between direct maternal and transmitted influences which may slow genetic progress in swine. The way in which maternal effects influence heritability estimates obtained by different methods was also discussed. Evidence presented later suggests that similar antagonisms may be important in beef cattle.

Table 2.1 Genetic components of relationships between relatives for a maternally influenced trait
(Additive and dominance deviations. Adapted from Willham, 1963)

Variances and covariances	$\sigma^2_{A_o}$	$\sigma^2_{D_o}$	$\sigma_{A_oA_m}$	$\sigma_{D_oD_m}$	$\sigma^2_{A_m}$	$\sigma^2_{D_m}$
Genotypic variance of P_x	1	1	1	0	1	1
Dam-offspring	½	0	1¼	1	½	0
Sire - offspring	½	0	¼	0	0	0
Paternal half-sib	¼	0	0	0	0	0
Maternal half-sib	¼	0	1	0	1	1

A_o = additive genetic effects for growth rate .
A_m = additive genetic effects for maternal ability.
D_o = dominance effects for growth rate.
D_m = dominance effects for maternal ability.
P_x = phenotypic expression for a trait.

II. Birth Weight, Preweaning Growth Rate and Weaning Weight as Productive Traits of Beef Cattle

A. Birth weight

Birth weight is of economic importance as it is related to both calving difficulty and subsequent performance of the calf and the cow.

It is well established that dystocia is an important factor contributing to calf losses at or near birth (Wiltbank et al., 1961; Anderson and Bellows, 1967; Monteiro, 1969; Laster and Gregory, 1973). Furthermore, the subsequent reproductive performance of cows experiencing dystocia is impaired (Brinks et al., 1973; Laster et al. 1973 ; Laster and Gregory, 1973).

In studies to date, calving difficulty has generally been scored according to the kind or extent of assistance given to cows at calving, that is by hand assistance, the use of foetal extractors or surgery. Factors shown to be related to calving difficulty according to Brinks et al. (1973) are age of dam, sex of calf, weight and shape of calf, gestation length, breed, mating system, sire of calf, pelvic area of dam and weight of dam. Of these, age of dam and calf birth weight have been shown by Laster (1974) to be the most important factors. Anatomical abnormalities of the calf contributed little to the incidence of dystocia (Terrington et al.1960; Anderson and Bellows, 1967).

Calving difficulty has become of increasing concern with the recent use of large sire breeds in matings with smaller dam breeds. Turton (1964) noted that in Britain, where Charolais bulls were used, breed of dam was an important factor affecting the incidence of calving difficulty.

Laster et al. (1973) found that calves whose sires were Charolais, Simmental, Limousin and South Devon were associated with significantly more calving difficulty (30 to 35%) than those sired by Hereford, Angus and Jersey bulls (6 to 16%) following matings with Hereford and Angus cows. Other studies in general agreement include those of Sagebiel et al. (1969) and the large-scale breed evaluation programmes presently in progress in New Zealand (Carter et al., 1975) and at the United States Meat Animal Research Center (U.S.MARC) in Nebraska (Smith et al., 1976), which have shown a markedly high incidence of dystocia in 2-year-old dams. It is noteworthy that in comparing the incidence of dystocia amongst 2-year-old dams between the study of Smith et al. (1976) and Carter et al. (1975), the ranking differs for the performance of exotic sire breeds (i.e., Simmental, Charolais, Limousin and South Devon) in the two countries.

There is relatively little information on comparisons of straightbred cattle of different breeds for this characteristic. Smith et al.(1976) found the incidence of dystocia to be 18% and 12% for the Hereford and Angus breeds, respectively. In the study of Carter et al.(1975) the percentage incidence of dystocia among Hereford dams less the percentage incidence of dystocia among Angus dams amounted to 22% for the 2-year-olds and 4% for the older dams.

Dystocia has generally been associated with higher birth weights. From survey data in Britain, Kilkenny and Stollard (1976) reported that on average, calves born at assisted calvings weighed 3.5 kg more than calves born without assistance and calves born dead were 4.1 kg heavier than live-born calves. Smith et al.(1976) found that the regression of calving difficulty on birth weight was homogenous over all the breed groups studies. An overall 1.6% increase in the incidence of dystocia for each kilogram increase in birthweight was reported, although the regression expressed as the percentage increase in dystocia per killogram increase in birth weight, were 3.3, 1.5, 0.9 and 0.5 for the 2-year, 3-year, 4-year and 5-year and over age-of-dam classes, respectively. In a previous study involving some of the same data, but with a larger proportion of young cows, Laster et al.(1973) obtained an overall regression of a 2.3% increase in dystocia per kilogram increase in birth weight. Smith et al.(1976) noted that in cows experiencing difficult births, calves were 2.2 kg heavier than calves born without difficulty, and that this difference appeared to be consistent among sire breeds. Several other studies have found that heavier birth weights were associated with a higher incidence of dystocia (Rice and Wiltbank, 1970; Bellows et al., 1971; Nelson and Hubber, 1971; Crowley, 1965; Monteiro, 1969).

Several studies have indicated that birth weight is correlated with other factors affecting dystocia. In a statistical model excluding the influence of birth weight, Laster et al.(1973) found that sex of calf, age of dam, sire breed and dam breed were all significant sources of variation affecting dystocia. On the inclusion of birth weight in the statistical model, all these sources of variation, apart from age of dam, were no longer significant suggesting that they were linearly related to birth weight. In an analysis of survey data using the same approach, A. Wilson et al. (1976) found that country of birth, season of birth, sire of calf, sex of calf and birth rank remained significant factors affecting dystocia of Chianina-sired calves when birth weight was accounted for in the model. Large management differences and errors associated with estimating rather than accurately weighing were suggested as being possible factors contributing to these results. These authors considered that the disappearance of breed-of-dam effects on the inclusion of birth weight in the model may have been a reflection of differences in calf birth weights and/or correlated differences in mature size.

Smith et al.(1976) found that after average within-breed differences in birth weight were removed, between-sire variability in dystocia level remained highly significant. These authors noted that the nature of the remaining variation was not known, but suggested that calf shape may account for part of it.

In the study of Willham et al.(1970) , multiple linear regressions of calving difficulty on birth weight, cow weight, birth weight/cow weight, pelvic measurements, gestation length, birth date and hip width were found to be of limited value for predicting calving difficulty. Coefficients of determination for these factors were 0.33, 0.29, 0.26 and 0.16 for Angus, Hereford, Holstein and Brown Swiss dams in straight-breed and reciprocal-cross matings.

A number of other workers have also investigated the relationships between various cow and calf measurements and dystocia. In the study of Laster (1974), measurements of calf shape (shoulder width, hip width, chest depth, wither height and back length) independent of birth weight were not related to dystocia. Pollak et al. (1974) found a phenotypic correlation between calf size and calving difficulty of 0.33 in a study in which dairymen scored calf size in Holsten cattle, also indicative of no close relationship. Several studies have provided evidence to suggest that foeto-pelvic disproportion is an important cause of calving difficulty in heifers (Bellows, 1968; Sloss, 1970; Crowley, 1965; Amir et al. 1967; Bellows, 1968; Monteiro, 1969). Also,it was considered by Laster (1974) that pelvic size and other cow measurements are of little value in predicting dystocia.

A higher incidence of dystocia has been observed with bull calves compared with heifer calves (Anderson and Bellows, 1967; Bellows et al.1969; Bellows et al.1971; Brinks et al.1973; Carter et al.,1975; Smith et al., 1976; Tong et al.,1976). Smith et al.,(1976) have noted interactions of sex of calf with age of dam and with sire breed for this characteristic. Male calves tended to be associated with more calving difficulty in young cows and for sire breeds associated with higher mean dystocia levels. Similar interactions were showen by Carter et al., (1975). The superiority of birth weights for male over female calves was 2.7 kg. amd 2.0 kg. in the American and New Zealand studies, respectively.

Estimates of the heritability of calving difficulty have been low with all estimates being less than 0.25 (Brinks et al.1973; Hansen, 1974; Pollak et al.,1974; Cundiff et al., 1975; Tong et al.,1976). Tong et al.,(1976) found with Charolais-sired calves that heritability estimates for this trait ranged from 0.064 to 0.1 depending on the definition of ease of calving. The findings of some studies suggest that the heritability of dystocia tends to increase with the level of incidence (Hansen, 1974; Tong et al., 1976).

Sagebiel et al.(1969) found that crossbreeding increased dystocia at the birth of female calves. The higher incidence of dystocia was associated with a significant amount of heterosis for birth weight.

A moderately-sized negative genetic correlation between dam effects and calf effects was determined by Bar-Anan et al.(1976) in Israeli-Fresian heifers. The effect did not occur in older cows. It was noted than this occurrence could be explained if a sire producing large calves caused calving difficulty in his heifer mates but the sires' heifer and cow daughters would be large giving rise to a lower incidence of calving difficulty than would be otherwise expected from the genetic relationship between the calves of the sire and the calves of his daughters.

The correlations between gestation length and birth weight reported by Anderson and Plum (1965) and Preston and Willis (1974) range from 0.15 to 0.52, generally being higher for male calves than for female calves. Smith et al.(1976) noted that breed of sire significantly influenced the regression of birth weight on gestation length,which tended to be the greater for the larger sire breeds. It was also indicated that such regressions should not be interpreted as an accurate estimate of growth rate late in the gestation period. Differences in gestation length often appear to be associated with differences in birth weights between breeds and sexes (e.g., Carter et al., 1975; for review see Preston and Willis, 1974).

Burfening et al.(1973) found that from a study of 1,546 field records from the American Simmental Association, the standard partial regression of calving ease on birthweight and gestation length were 0.19 and 0.04 , respectively. The correlations among variables were 0.18 for calving ease and birth weight, 0.24 for gestation length and birth weight and 0.05 for calving ease and gestation length.

Bar-Anan (1971) estimated a phenotypic correlation of 0.29 between the growth rate of bulls and the frequency of calving difficulty in their female half-sibs.

This relationship was further investigated by Hansen (1974) in the Red Danish and Black Pied Danish breeds, and in contrast to the above study, genetic and phenotypic correlations obtained indicated that growth rate and ease of calving were favourably associated. Correlations were small and did not differ significantly from zero. It was concluded that there did not appear to be a risk for increasing calving difficulties through growth-rate selection in these two breeds. Lindström (1974), analysed data from Ayrshire and Finn cattle and found selection for high liveweight at the end of a performance test results in higher birth weights. This author suggested the use of a selection index through which birth weight could be maintained at a constant level.

Weighted average estimates of the genetic and phenotypic correlations of birth weight with post-weaning gain and with final slaughter weight given by Petty and Cartwright (1966) show favourable associations (0.30 - 0.64) with the genetic correlations being larger than the phenotypic correlations. Correlations of birth weight with pre-weaning growth rate and with weaning weight which are also positive are outlined in Section 4.

B. Pre-weaning growth rate and weaning weight

Genetic and phenotypic correlations between pre-weaning growth rate and weaning weight are close to unity. Their genetic and phenotypic associations with birth weight have been shown to differ, as birth weight, being a component of weights recorded later in the animal's life, is more closely related to weaning weight than it is to pre-weaning growth rate.

Pre-weaning growth rate is an important trait *per se* being a sizable component of final slaughter weight. It is often advantageous in the selection of bulls to predict future growth from early liveweight gains or weights. Weaning weight is commonly regarded as a predictor of future maternal performance, having a sufficiently high repeatability when expressed as a trait of the dam (see Petty and Cartwright, 1966).

Several studies have indicated that in rearing female replacement stock, calves should be grown at optimal rather than maximal rates. The findings reviewed by Koch (1972) and more recently the work of Cundiff *et al.*(1974b) provide evidence that maternal environment for gain from birth to weaning is negatively influenced by favourable maternal effects in the previous generation. Burfening and Kress (1973) found that cows' own 180-day weights and yearling weights were lowest when cows were reared as calves on immature dams, but their subsequent most probable abilities for 180-day calf weights were above average.

However, some conflicting evidence has been reported. For example, Koger and Crane (1974) found, from an investigation of 536 females in four breeding systems, that even though many of the heifers were fat and heavy at weaning there was no evidence to suggest that their subsequent performance was adversely affected.

The suggestion of unfavourable genetic associations between individuals' growth and maternal components and the apparent negative association between dams' and daughters' milking ability make the practice of screening heifer replacement stock on the basis of their own weaning weights questionable. Koch (1972) reported that there were moderate-to-large negative genetic correlations in most studies between maternal environment and calf effects for pre-weaning gain, although in one study of 4,060 Hereford calves in Nebraska, he estimated this genetic correlation to be close to zero. Following the findings of an earlier study, Koch and Clark (1955) suggested that selecting calves on the basis of their pre-weaning gains would be selecting for better genotypes for growth response combined with a slight overall adverse effect on maternal ability due to the large negative genetic correlation determined between these two traits. It was added that selecting cows for weaning weight of calf would place greater emphasis on maternal effects on growth response with regard to the genetic value of cows. Desse and Koger (1967) noted breed differences for this genetic association in Brahman and Brahman-cross cattle. A genetic covariance close to zero was obtained in a Brahman herd, but a negative estimate was determined in a Brahman-cross herd.

Unlike the genetic relationships described above, Koch and Clark (1955) reported high positive genetic correlations between maternal effects of dams and post-weaning growth ranging from 0.7 to 0.8. A negative genetic association of maternal ability with pre-weaning growth, but a positive genetic association between maternal ability and post-weaning growth have also been reported in Romney sheep (Ch'ang and Rae, 1972).

Average heritability estimates for pre-weaning growth rate and weaning weight (see Section 4) indicate that these traits should respond to selection. Weighted average estimates of genetic and phenotypic correlations for pre-weaning growth rate and weaning weight with post-weaning gains given by Petty and Cartwright (1966) are mostly low, but positive. Several authors have, however, reported some negative genetic correlations between weights recorded at or close to the time of weaning with carcass traits, but findings are often inconsistent (Dunn et al.,1970; Stout et al., 1970; Cundiff et al., 1971; Dickerson et al.,1974; L.L. Wilson et al.,1976).

III. Some Genetic Factors affecting Birth Weight, Pre-Weaning Growth Rate and Weaning Weight in Beef Calves

Factors affecting performance in animals can be regarded as having an additive or non-additive influence. The additive effects discussed in this section are mainly additive genetic effects while discussion of non-additive effects will cover interactions among genotypes and those interactions commonly referred to as genotype - environment interactions. Additive genetic differences arise between breeds, sexes, herds and between individuals within these categories.

In discussing breeds of cattle, Daly (1974) has defined breed as a group of animals of common origin possessing well fixed and distinctive characteristics not common to other members of the same species. From this definition it could be expected that sizable breed differences for productive traits should exist. Over the years there have been many reports of breed performance but few direct comparisons between breeds in the same environment. Mason (1971) reviewed the performance of many cattle breeds and indicated that there are important differences between breeds in many productive characters. Recently there has been an abundance of cross-breeding studies, some of which will be discussed in considering both additive and non-additive effects. Breed comparison studies in New Zealand have been reviewed by Carter (1975).

Breed differences may be utilized through crossbreeding, the possible benefits being through creating hybrid vigour to increase productivity over that of the mean of the parental breeds (a non-additive gain), by combining desirable attributes not available in any one breed (an additive effect) or with the objective of producing foundation stock for developing new breeds (Warwick, 1968; Cartwright, 1970). The latter involves both additive and non-additive advantages although the level of heterosis should decline following interbreeding. In more recent times new breeds which have been developed include the Santa Getrudis, Charbray, Droughtmaster, Bonsmara, Brangus and Bradford from crosses of animals of the *Bos taurus* and *B. indicus* species.

A. Additive effects

Sex-of-calf differences for birth and weaning weights are well established (Petty and Cartwright, 1966, Pleasants, 1974, Preston and Willis, 1974 and Nicoll, 1975) and will not be discussed in detail here other than to state that bull calves have heavier birth and weaning weights than heifer calves while at weaning, steer calves are heavier than heifer calves, but lighter than bull calves.

There is an accumulating body of evidence from New Zealand studies of breed differences in which animals were managed in the same environment. Carter (1974) reported some provisional results on the performance of 1,031 Angus, Hereford and Angus-Hereford reciprocal cross calves. Hereford calves were born later owing to longer gestation periods and had higher birth weights than Angus calves. Average birth weights for the two breeds were 29.4 kg and 25.4 kg, respectively. Calves out of Angus dams had higher pre-weaning gains and weaning weights compared to calves out of Hereford dams, perhaps indicating the superior milking ability of the Angus cow. Birth weights for the reciprocal cross calves were intermediate between the two parental breeds and weaning weights were superior to either parental breed.

In an improved tussock environment at the Tara Hills High Country Research Station, Davis (1973, 1974) and Stevenson (1975) have shown that Angus calves were lighter at birth, but gained more rapidly to weaning than Hereford calves. In contrast to the study of Carter (1974), Hereford calves were slightly heavier than Angus calves at weaning. Friesian calves had higher birth weights and grew considerably more rapidly to weaning than either Angus or Hereford calves. Crossbred animals generally ranked between the performance of the parental breeds for birth weight and pre-weaning growth rate.

In a study of 7,771 straightbred Hereford and 16,666 straightbred Angus calves recorded in the New Zealand Beef Cattle Weight Gain Performance Recording Scheme, Nicoll (1975) found that Hereford calves were on average 3.1 kg heavier at weaning than Angus calves even though they were weaned on average 2.2 days younger.

The superiority of the Friesian in birth weight and pre-weaning growth rate relative to the Angus and Friesian-Angus reciprocal crosses was evident in an experiment in the years 1968 to 1970 at the Whatawhata Hill Country Research Station (Hight et al.,1973). Progeny results for the individual calf breeds are summarized in Table 2.2 and are of particular relevance to

Table 2.2 Cow and calf performance in reciprocal crossbreeding studies with Friesian and Angus cattle at the Whatawhata Hill Country Research Station (from Hight et al.,1973)

Sire breed Dam breed	Friesian Friesian	Angus Friesian	Friesian Angus	Angus Angus
No. calves weaned	96	79	96	103
% calves dying to weaning	7	3	9	10
Mean birth weight (kg)	35	33	30	26
Mean weaning weight (kg)	181	176	155	143

the present study. The data indicate the superiority of the Friesian dam, and the Friesian sire for birth and weaning weights. It is also noteworthy that calf losses to weaning were highest for the straightbred Angus and Friesian x Angus[1] calves, intermediate for the straightbred Friesian calves and lowest for Angus x Friesian calves.

Preliminary results from a trial in which Angus, Hereford and Friesian bulls were mated to 490 Angus cows reported by Carter (1975) have shown that Hereford x Angus calves were heavier at birth than Friesian x Angus and Angus calves by 0.4 kg and 2.1 kg respectively. Hereford x Angus calves had a 5-day longer mean gestation period than the other calf breeds. Friesian x Angus calves were heaviest and Hereford x Angus calves the lightest at weaning. Everitt et al. (1975) reported that Simmental x Friesian calves grew at a similar rate (0.62 kg/day) to Friesian calves (0.61 kg/day) to 16 weeks of age (approx.) while Hereford x Friesian calves grew more slowly (0.57 kg/day). At 215 days of age the average calf weights were 151.7 kg, 148.6 kg and 141.2 kg for the Simmental-, Friesian-, and Hereford-sired calves, respectively.

Everitt and Jury (1972) assessed the comparative performance following matings of Charolais, Hereford and Friesian sires to Jersey dams and from records of straightbred Angus and straightbred Friesian cattle in the same dairy herds for birth traits. In order of superiority, mean birthweights for the various breeds of calf were Friesian (38.2 kg), Charolais x Jersey (32.7 kg), Friesian x Jersey (30.3 kg), Hereford x Jersey (27.9 kg), Angus (27.4 kg) and Jersey (23.4 kg). Charolais x Jersey calves had the longest mean gestation length (286 days) followed by Hereford x Jersey (284 days) followed by the Friesian x Jersey, Friesian and Jersey calves (281 days).

In a study of 2,134 Chianina-sired calves in Britain A. Wilson et al. (1976) presented least squares means for the effect of breed of dam on birth weight. In order of superiority the ranking was Friesian (+2.92), Ayrshire-Friesian crosses and Hereford-Friesian crosses (+1.44), Ayrshire (-0.61) and Jersey (-5.59) in terms of birth weight in kilograms.

The breed evaluation studies currently in progress in New Zealand previously noted (Carter et al., 1975) have involved the mating of sires of several breeds to Hereford and Angus cows at three research locations. Bulls of each of the Angus, Hereford, Friesian, Jersey, South Devon, Charolais, Limousin, Blond d'Aquitaine, Simmental, Maine Anjou and Charolais breeds were mated artificially. Cow and calf performance reported by Carter et al. (1975)

[1] Crosses are of the form A x B where A is the sire breed and B is the dam breed

included results for some 3,000 calves born in years 1972 to 1974 by a total of 121 sires and are in part shown in Table 2.3. In general the figures in Table 2.3 show that the exotic breeds offer more rapid pre- and post-natal growth at the expense of an increased incidence of calving difficulty, particularly in younger dams. The data presented by those authors also indicate that losses to weaning, mostly of calves out of 2-year-old dams, are greater following the use of the large exotic sires over Angus and Hereford dams. Calves out of Angus dams were on average 2.0 kg. lighter at birth, were associated with 4% fewer calving difficulties and were born following gestation periods 3 days shorter than calves out of Hereford dams. Calves of Angus dams grew faster, being on average 6 kg. heavier than calves of Hereford dams at 6 months of age. The high 6-month weights of Friesian-sired calves following relatively lower birth weights compared to the other breeds supports other findings previously discussed which have shown high growth rates of Friesian or Friesian-sired calves.

Similar data were reported on 2,368 calves born out of Hereford and Angus dams at U.S.MARC (Smith et al., 1976) sired through artificial insemination by 32 Hereford, 35 Angus, 33 Jersey, 27 South Devon, 20 Limousin, 26 Charolais and 27 Simmental bulls. Birth and weaning data are presented in Table 2.4. One notable feature is the higher birthweights and longer gestation periods reported in the American study compared with those reported in New Zealand by Carter et al. (1975). The superior pre-weaning growth rates and 200-day weights of the Charolais- and Simmental-sired calves are in agreement with the New Zealand trials. Straightbred Angus calves grew more rapidly than straightbred Hereford calves and attained higher 200-day weights. Similarly, calves of Angus dams were heavier at weaning following more rapid pre-weaning growth than calves of Hereford dams.

Pahnish et al. (1969) showed in their crossbreeding studies in which the Charolais, Hereford and Angus breeds were represented, that the Hereford ranked second to the Charolais in calf birth weight by both breed of sire and breed of dam. The Angus however, ranked second to the Charolais for pre-weaning growth rate and weaning weight, also by both breed of sire and breed of dam.

Most studies indicate that Hereford and Angus calves attain similar weaning weights. There appear to be no consistent ranking for these two breeds for this trait in American literature as several studies have shown the superiority of the Angus (Meade et al., (1959); Gaines et al., (1966); Gregory

Table 2.3 Some cow and calf performance characters in New Zealand breed evaluation trials[1] (adapted from Carter et al. 1975)

Sire Breed	Dystocia (%)		Gestation length (days)	Birth weight (kg)	6-month weight (kg)
Angus	5	(31)	278	28.1	157
Hereford	3	(47)	280	29.5	164
Friesian	5	(38)	278	30.6	175
Jersey	1	(0)	280	25.4	156
South Devon	9	(56)	283	32.4	171
Charolais	18	(50)	283	33.5	178
Limousin	9	(31)	285	30.8	168
Blond d'Aquitaine	12	(25)	287	32.8	174
Simmental	13	(77)	284	32.8	177
Maine Anjou	12	(75)	283	33.7	175
Average	9	(45)	282	30.8	169

[1] Gestation lengths, birth weights and 6-month weights are pooled over all dam ages - The percentage dystocia for dams 3 years of age are presented followed by those for 2 year old dams in parentheses.

Table 2.4 Some cow and calf performance characters in breed evaluation trials at the United States Meat Animal Research Center. (adapted from Smith et al., 1976)

Breed Group	Dystocia (%)	Gestation length (days)	Birth weight (kg)	Pre-weaning average daily gain (kg/day)	200-day weight (kg)
Straightbred calves					
Hereford	18 (51)	285.5	34.7	0.74	182
Angus	12 (37)	281.6	31.0	0.79	190
Calves of Hereford and Angus dams					
Hereford-Angus crosses	11 (41)	282.9	33.7	0.80	194
Jersey-sired	5 (15)	281.8	29.4	0.77	183
South Devon-sired	27 (68)	285.6	35.8	0.79	194
Limousin-sired	24 (72)	288.1	36.2	0.80	197
Charolais-sired	34 (74)	285.9	38.6	0.84	207
Simmental-sired	29 (66)	286.2	38.0	0.83	204
All calves of Hereford dams	24 (59)	286.4	35.9	0.77	190
All calves of Angus dams	17 (50)	283.3	33.9	0.83	199

[1] Data are pooled over all age of dam groups -- Additional figures are shown for dystocia percentages for 2-year-old dams in parentheses

et al.,(1966a, 1966b)) while others indicate the superiority of the Hereford (Damon et al., 1959; Melske et al.,1964). Birth weights of Shorthorn cattle appear to be intermediate between those of Angus and Hereford cattle and weaning weights are of similar order to the other two breeds (see Preston and Willis 1974).

Within-breed differences between lines are well known. Brinks et al. (1967) reported significant line-of-dam influences on the average daily gains of bull calves, but sire line had no effect. Wangus and Brinks (1971) found line of sire significantly affected most probable producing ability for weaning weight while Burfening and Kress (1973) reported that breeding line of cow significantly affected most probable producing ability for both birth weight and 180-day weight.

Humes et al.(1973) reported both significant line-of-sire and line-of-dam differences among pre-weaning gains of heifer calves and significant line-of-dam differences for pre-weaning gains of bull calves. [illegible] line-of-dam rather than line-of-sire differences would be expected since line-of-dam effects [illegible] maternal as well as genetic influences on pre-weaning gains.

In beef cattle studies the effect of herd is often accounted for in experimental analyses as being a combination of both genetic and environmental differences. Consequently genetic differences between herds for beef traits [illegible] not well known. However, Cundiff et al. (1975) studied the performance of [illegible] calves sired by 51 bulls from 18 Angus herds [illegible] 44 bulls from 18 Polled-Hereford herds through artificial breeding at U.S.MARC. Effects of herd origin were significant for birth weight and 200-day weight and accounted for 3.9% and [illegible] of the total variation in each trait, respectively.

B. Non-additive effects

(1) Crossbreeding. Existing breeds may be regarded as being mildly-inbred lines differing in gene frequencies, in the average level of heterozygosity, and in epistatic combination effects of genes on performance (Dickerson, 1973). Crossbreeding is a means by which both additive and non-additive genetic differences may be exploited. If both additive and non-additive genetic effects are important then improvement will be maximized by combining crossbreeding with selection among and within breeds (Dickerson, 1970).

Non-additive gains from crossbreeding can be measured in terms of realized heterosis. Heterosis is usually determined as the percentage superiority of F_1 reciprocal crosses over the average performance of parental breeds. A higher percentage of heterosis is usually associated with reproductive and maternal traits which, in most animal species, are considered to be of low heritability.

Mason (1966) in reviewing the literature considered the major heterotic gain in beef cattle would be in improved calf viability. More recent studies have shown that worthwhile heterotic gains in beef cattle are obtainable for growth traits.

Rollins et al. (1969) and Koger (1973) have noted the importance of determining estimates of heterosis in cattle covering the kinds of variation in environments typical of beef cattle operations where such estimates are applied. There is now an extensive literature on heterosis from crossing, much of which has been reviewed by Koger et al. (1973) and Preston and Willis (1974).

Koger (1973) pointed out that there is a tendency for estimates of heterosis to be biased upwards in environments unfavourable to one or more of the parent breeds represented in crosses. It was suggested that under these conditions, knowledge of the performance of crossbreds relative to other stock would provide the beef cattle industry with more useful information rather than knowledge of the amount of heterosis obtained. That author has also noted that it is not always clear whether a heterotic response to crossbreeding is due to complementarity of traits, heterozygosis at the gene level, or inbreeding depression in the straightbred parents.

Following a review of many studies, Koger (1973) showed that for reproductive and growth traits, the mean level of heterosis for B. indicus - B. taurus crosses was approximately 2.5 times that for crosses among the B. taurus breeds. This advantage was considered to be attributable to both the relative superiority of B. indicus - B. taurus crosses as well as the poor performance of one or more of the purebreds in trials involving B. indicus crosses. Overall heterotic advantages through crossbreeding were shown to be 10 to 20% for crosses among B. taurus breeds in favourable environments and 30 to 50% for B. indicus - B. taurus crosses bred and raised in unfavourable climatic conditions.

Estimates of heterosis from crosses of the traditional British beef breeds (Hereford, Angus, Shorthorn) for birth weight are of the order of 0 to 4% (Gregory et al.,1965; Gaines et al.,1966; Sagebiel et al., 1967; Pahnish et al., 1969; Rollins et al.,1969; Long and Gregory, 1974; Smith et al., 1976). In New Zealand, the data of Carter (1974) indicated there to be 4.7% heterosis for this trait from crossbreeding experiments with Angus and Hereford cattle. A higher heterosis for these breeds has been reported for pre-weaning growth rate and weaning weight. Some studies have indicated that heterosis for these traits is of the order of 3 to 6% (Gregory et al.,1965; Gaines et al.,1966; Sagebiel et al.,1967; Carter, 1974; Smith et al.,1976). Higher estimates of the order of 6 to 11% have been reported by other workers (Rollins et al.,1969; Long and Gregory, 1974). Pahnish et al. (1969) suggested that differences in environments may have contributed to the inconsistencies reported between studies.

Rollins et al. (1969) found more hybrid vigour was expressed from crossing Hereford and Shorthorn cattle than from the other 2-breed crosses amongst the Shorthorn, Hereford and Angus breeds. The average superiority of the Hereford-Shorthorn, Hereford-Angus and Shorthorn-Angus reciprocal crosses was 2.2 kg, 0.1 kg, and 0.2 kg for birth weight and 10.2 kg, 7.0 kg, and 6.5 kg for weaning weight, respectively. Pahnish et al. (1969) and Sagebiel et al.(1974) included the Charolais breed in reciprocal crosses with Angus and Hereford cattle. In these studies heterosis was greater in crosses of the two British breeds than of the Charolais-British crosses.

There does not appear to be any consistent trend showing higher levels of heterosis from breed crossing for either sex of calf, as conflicting results have been reported (Gregory et al., 1965; Pahnish et al.,1969; Long and Gregory, 1974).

Martin (1971) noted that several studies have shown little heterotic advantage in crossing beef with dairy breeds compared to results obtained from crosses of beef breeds or crosses of dairy breeds. Hight et al. (1973) reported 3.5% heterosis for birth weight after crossing Friesian with Angus cattle at the Whatawhata Hill Country Research Station. Percentage heterosis was slightly lower for weaning weight (2.2%) and was considered to be small compared to the large maternal differences observed.

Several studies have shown that crossing inbred lines of the same breed results in heterosis for calf weights. In a comparison of line-cross performance with the mean performance of 3 Hereford lines, Flower et al. (1963) found an average hybrid advantage of 0.1% in birth weight and 4.6% in weaning weight.

Stonaker (1963) suggested the presence of homogametic heterosis following a study of 1,229 Hereford calves born in 9 years in which 15% heterosis was detected in weaning weight of female calves and 8% in male calves. In general agreement, is the study of Brinks et al. (1967) ; from crossing five Hereford lines, heterosis in birth weight, pre-weaning growth rate and weaning weight was 3.8%, 10.6% and 9.4% in heifer calves and 3.0%, 5.6% and 5.1% in bull calves, respectively. Urick et al. (1968) also found that female calves showed a greater heterotic response than male calves. They reported the difference was small for birth weight (3.7% versus 3.0%), but quite large for weaning weight (9.0 versus 4.9%). Conflicting evidence was given by Humes et al. (1973) who found that from crossing three inbred lines in which the average level of inbreeding was 14%, heterosis for birth weight and pre-weaning growth rate was -8.2% and -3.2% in heifer calves and 2.6% and 8.2% in bull calves, respectively.

Owing to the large maternal influence on calf growth, heterosis for maternal performance of crossbred or line-cross replacement females could be expected to be more important to the commercial cattleman than the heterotic effect for growth in F_1 calves. Cundiff et al.(1974b) estimated maternal heterosis from the difference between progeny of British crossbred and British straightbred dams sired by the same bulls of another breed. From a total of 975 calf records, effects of maternal heterosis were 1.7% for birth weight, 3.6% for 135-day weight and 4.7% for 200-day weight. The effects of heterosis were shown to reflect greater and more persistent milk production from crossbred dams. Linear regression studies indicated there to be a tendency for maternal heterosis effects on pre-weaning growth rate to decline with increasing age of dam. This effect appeared to be largely due to the Angus-Shorthorn reciprocal cross dams. In their study the effect of maternal heterosis on 200-day weight was greater under a management system in which cows first calved as 2-year olds (5.8%) than under a management system where females had their first calf as 3-year-olds (3.0%).

Cundiff et al. (1974a) indicated that the cumulative effect of individual and maternal heterosis from breed crossing amounted to 23% for weight of calf weaned per cow in the breeding herd.

Similar effects have been reported in line crossing experiments. Brinks et al.(1972) reported heterosis estimates for maternal effects on birth weight and weaning weight in Herefords of 1.5% and 4.7%, respectively. Burfening and Kress (1973) also found some positive heterosis from line crossing, the most heterosis being observed in crosses between lines which were the most divergent in the traits studied. Average heterosis for the cow's own birth weight and 180-day weight were relatively small; -0.7% and 2.6%, respectively. Maternal heterosis effects on the cow's most probable producing ability for birth weight and for weaning weight were both estimated as 1.6%.

Far greater maternal heterosis can be expected from Brahman x British breed crosses (e.g. Koger et al., 1975b), but such findings are of limited relevance to the present study.

The performance of breed-or line-crosses is often partitioned into those components attributable to general and specific combining abilities (see Falconer, 1960). There is little evidence to suggest that differences of specific combining ability can be used to any large extent in beef cattle, although there are very few reports in the literature.

In a study of 751 calves of the Hereford, Angus and Shorthorn breeds and all six reciprocal cross combinations Gregory et al. (1965) found that estimates of heterosis in birth weight, pre-weaning growth rate and weaning weight for Hereford-Shorthorn and Hereford-Angus combinations were almost twice those for the Angus-Shorthorn animals, although these differences were mostly non-significant. Non-significant sire x breed-of-dam interactions for both sexes of calf were reported for all traits studied indicating no important differences of specific combining ability for sires within a breed.

Damon et al. (1961) reported significant specific combining ability for 180-day weight by testing for the significance of breed-of-sire x breed-of-dam effects among crossbreds. The results of their experiments showed that the more widely divergent breeds such as the Hereford and Brahman breeds combined with a superior level of specific combining ability than did crosses of more similar breeds such as the Angus and Hereford. Koger et al. (1975a) found non-significant sire x breed-of-dam interaction effects for birth weight and 205-day weight from Brahman-British and British crossbreds with interest in applications to progeny testing. Genetic correlations between paternal half-sib families from different dam breed classes were estimated. An average value of 0.96 was obtained suggesting that sires would be ranked similarly in terms of the performance of their offspring, when mated to the various breeds of dam studied. In their reciprocal crossbreeding studies, using Friesian and Angus parental breeds, Hight et al. (1973) reported non-significant sire-within-breed x dam breed effects on all calf traits studied. Differences of specific combining ability for birthweight were shown by Brown et al. (1967) but it was not stated whether the differences were significant.

Cundiff et al. (1974b) at the Fort Robinson Beef Cattle Research Station in Nebraska found that specific effects of maternal heterosis were significantly greater ($P<.01$) in Hereford-Shorthorn reciprocal crosses than in Angus-Shorthorn reciprocal crosses.

(2) Genotype - environment interaction. A problem in selecting animals arises if the breeding values of individuals do not rank in the same order of superiority or the relative magnitudes of the differences in performance between groups differs markedly from one environment to another. Ideally selection should be carried out in environments which allow the most accuracy in predicting adaptability to environment. If interactions between heredity and environmental influences are important then animals should be evaluated in the environment in which they will be used. Alternatively it may be necessary to determine how much of the improvement made in one environment will be carried over if animals are transferred to a new location.

Where genotype-environment interactions have been considered in beef cattle, most studies have simply indicated the presence or absence of significant interaction effects. There is generally little evidence to suggest that interactions associated with a change of rank under different environmental conditions are of importance in beef cattle (Warwick, 1972; Preston and Willis, 1974).

Much interest has centered on the possibility of there being major interactions of breeds or sires within breeds with locations. Significant sire x region effects on birthweight (Edwards et al., 1966) and significant sire x station effects on pre-weaning growth rate (Cunningham and Henderson, 1965) have been reported. Other authors have found non-significant sire x station effects for these traits (Woodward and Clark, 1950).

Aken et al.(1976) studied the records of 228 bull calves sired by 17 Fleckvieh and 3 Gelbvieh sires. Offspring were born in West Germany (144 calves) and in Texas (84 calves). A significant breed-of-sire x location interaction was reported for adjusted 364-day weight. No change in the ranking for the breeds was noted, but the breed differences were smaller in Texas. When the sire-within-breed x location interaction was substituted for the breed x location interaction, the effect was non-significant.

Nunn et al. (1974) reported a significant sire x region interaction effect on weaning weight. The interaction variance however accounted for less than

2% of the total variance, although sire rankings were seen to change from region to region.

Breed x year effects were shown to be significant for birth weight in the studies of Ellis et al.(1965) and Turner and McDonald (1969). The latter authors also found this interaction to have a significant effect on pre-weaning growth rate and weaning weight. Gregory et al. (1965) observed no significant interactions of breed of sire with year and of breed of dam with year on pre-weaning traits.

Many studies have shown a non-significant sire x sex interaction for calf growth traits (Bradley et al.,1966; Tanner et al.,1969; Thrift et al., 1970) while others (L.L. Wilson et al. 1969) found this kind of interaction to be significant. Also indicative of within-breed genotype x sex interactions are those studies in which higher heritabilities have been reported for either sex of calf (see section 4).

In a study of Hereford and Brahman cattle, Ellis et al.(1965) found a significant breed x sex interaction effect on birth weight. Smith et al. (1976) reported significant sire breed x sex effects on birth weight, but not on pre-weaning growth rate or weaning weight in their breed comparison studies. The significant interaction in the birthweight analysis however, accounted for less than 1% of the variance.

Age of dam is known to be an important factor affecting weaning weight. Non-significant sire breed x age-of-dam effects on weaning weight were reported by Cundiff et al., (1966) and by Sellers et al. (1969). Smith et al.(1976) reported a significant effect for this interaction on pre-weaning gains and 200-day weight. It was suggested that the interaction may have occurred because the breeds with greater growth potential responded more to the increasing milk production with increasing age of dam.

Warwick et al. (1964) noted there were significant genotype x nutritional plane effects on pre-weaning growth rate using identical twin pairs. In a study of both identical and fraternal twin Hereford cattle, Kress et al. (1971) found that set x diet interactions were seldom a significant source of variation affecting 10 live animal body measurements including body weight. Burnside et al.(1972) and Batra et al. (1973) studied Holstein fraternal twin calves and found no evidence for significant feed ration x twin pair interaction effects for any of the live animal measurements considered. Macleod et al. (1970) noted an absence of interactions between breeds and rations for weight gains of Holstein and Jersey calves fed two quantities of whole milk and two feed supplements.

Findings related to genotype-environment interactions for beef traits are inconclusive as experimental results are not always in agreement. Few studies have determined whether interactions are attributable to changes in the ranking of animals or arise from changes in the magnitudes of differences between individuals. Preston and Willis (1974) reviewed the evidence for physiological explanations for breed adaptability. These authors point out that while it has been accepted by some that there are real differences between B. taurus and B. indicus cattle in their adaptibility to different climatic conditions, there is little evidence suggesting that this view should always be adopted.

IV Estimates of the Heritabilities of and Genetic and Phenotypic Correlations among Birth Weight, Pre-weaning Growth Rate and Weaning Weight

When the heritability of a maternally influenced trait is the regression of the sum of the additive genetic values on phenotypic value as defined by Dickerson (1947), then:

$$\text{Heritability } (h^2) = \frac{\sigma^2_{A_o} + 1.5\,\sigma_{A_oA_m} + 0.5\,\sigma^2_{A_m}}{\sigma^2_P}$$

where the terms are defined as in Table 2.1 (Willham, 1963).

The most common method used to determine heritability estimates of birth weight, pre-weaning growth rate and weaning weight in cattle has been the paternal half-sib method followed by parent-offspring regression. Estimates calculated by the paternal half-sib method contain only the additive genetic variance for growth (and a small portion of the epistatic variance) and therefore, do not account for maternal effects (Willhamm 1963). The method also involves the multiplication of the sire variance component by four. Thus, sampling errors and environmental biases may be large. It has been suggested that selection of sires may cause bias in the heritability estimates (Neville, 1962; Carter, 1971) although little is known of the magnitude or direction of such bias.

There is an extensive literature on estimates of genetic parameters for beef calf traits in the British beef breeds (Angus, Hereford and Shorthorn), but relatively little information on other beef breeds, dairy breeds or beef x dairy crosses. A majority of estimates is from American sources and there have been very few estimates based on New Zealand data.

Some published estimates of the heritabilities of birth weight, pre-weaning growth rate and weaning weight among the traditional British beef breeds and also for the Friesian breed and various crossbreds, are presented in Tables 2.5, 2.6 and 2.7, respectively. Estimates obtained before 1969 are represented by the summary values given by Petty and Cartwright (1966) and by Preston and Willis (1974). The summary values have been determined from wide-ranging estimates. However, heritability estimates for these traits, most of which have been obtained for grazing management, are predominately moderately high, with those for birth weight tending to be higher than those for pre-weaning growth rate and weaning weight.

The higher heritability estimates for pre-weaning gain and weaning weight from the regression of offspring on sire than for the regression of offspring on dam shown in Petty and Cartwright (1966), appear to be consistent with the suggestion that the maternal performance of dams in milking ability is negatively associated with the influence of the maternal environment in which the dams were reared.

The estimates obtained in New Zealand (Carter, 1971; Baker et al., 1975) are in good agreement with the summary values presented, with the exception of being lower for birth weight.

Heritability estimates for the Friesian breed vary. The findings of Afifi and Soliman (1971) and Mason et al. (1972) are generally in good agreement with the estimates for the beef breeds. Vial (1962) reported near zero and negative estimates for birth weight and pre-weaning gain, respectively and Hodges obtained a low estimate (0.12) for average daily gain to nine months of age.

The findings of Stout et al. (1970) and L.L. Wilson et al.(1976) (see Table 2.7) suggest that differences between individuals in weaning weight that are attributable to genetic differences between sires are of similar importance where calves are from high milk-producing beef x dairy dams as where calves are from beef-bred dams.

Table 2.5 Some published estimates of the heritability of birth weight in cattle

Location	Breed[1]	Method of[2] estimation	No. calf records	Heritability estimate	Authors
		Summary values			
[a]U.S.A	A,H,S	PHS		0.44	Petty and Cartwright (1966)
[b]U.S.A	A,H,S	Parent-offspring regression		0.44	Petty and Cartwright (1966)
[c]Worldwide	Many	Various		0.38	Preston and Willis (1974)
		Other estimates			
Britain	BF		158	0.01	Vial (1962)
Nebraska	A,H	PHS	995	0.10	Cundiff et al.(1975)
Arkansas	A	d	932	0.17	Brown and Galvez (1969)
United Arab Republic	F		783	0.23	Afifi and Soliman (1971)
New Zealand	A,H	PHS	e	0.28	Baker et al. (1975)
Arkansas	H	d	789	0.36	Brown and Galvez (1969)
Montana	A	PHS	2113	0.39	Nelsen and Kress (1976)
Georgia	H	Sire-offspring regression	180	0.41	Chapman et al.(1972)
Nebraska	H	PHS	3462	0.53	Koch et al. (1973)
North Carolina	H	PHS	1692	0.67	Vesely and Robison (1971)

[1]A = Angus, H = Hereford, S = Shorthorn, F = Friesian, BF = British Friesian

[2]PHS = paternal half-sib method

[a]Weighted average of 21 estimates

[b]Weighted average of 4 estimates

[c]Preferred value from 54 estimates

d = combined estimate from maternal and non maternal components

e = 131 sires

Table 2.6 Some published estimates of the heritability of pre-weaning growth rate in cattle

Location	Breed[1]	Method of estimation[2]	No. calf records	Heritability estimate	Reference
		Summary values			
[a]U.S.A.	A,H,S	PHS		0.34	Petty and Cartwright (1966)
[b]U.S.A.	A,H,S	Parent-offspring regression		0.07	Petty and Cartwright (1966)
[c]Worldwide	Many	Various		0.27	Preston and Willis (1974)
		Other estimates			
[d]Britain	BF	PHS	148	< 0	Vial (1962)
Nebraska	H	Parent offspring regression	2956	0.10	Koch *et al*.(1974b)
Nebraska	A,H	PHS	915	0.10	Cundiff *et al*. (1975)
[e]Britain	BF	PHS	986	0.12	Hodges *et al*. (1961)
Nebraska	H	PHS	3462	0.17	Koch *et al*.(1973)
Britain	BF	PHS	669	0.20	Mason *et al*(1972)
Montana	A	PHS	2113	0.29	Nelsen and Kress (1976)
Canada	A,H	PHS	84021	0.32	Kennedy and Henderson (1975a)

[1] A = Angus, H = Hereford, S = Shorthorn, BF = British Friesian

[2] PHS = paternal half-sib method

[a] Weighted average of 20 estimates

[b] Weighted average of 4 estimates

[c] Preferred value from 35 estimates

[d] Daily gain from 7 to 84 days of age

[e] Daily gain to 9 months of age.

Table 2.7 Some published estimates of the heritability of weaning weight[1] in cattle

Location	Breed[2]	Method of estimation[3]	No. calf records	Heritability estimate	Reference
		Summary values			
[a]U.S.A.	A,H,S	PHS		0.32	Petty and Cartwright (1966)
[b]U.S.A	A,H,S	Parent-offspring regression		0.12	Petty and Cartwright (1966)
[c]Worldwide	Many	Various		0.30	Preston and Willis (1974)
		Other estimates			
Nebraska	A,H	PHS	915	0.05	Cundiff et al. (1975)
Nebraska	H	Parent-offspring regression	2956	0.12	Koch et al. (1974b)
Nebraska	A,H	Sire-offspring regression		0.14	Cundiff et al. (1975)
[d]Britain	BF	PHS	149	0.18	Vial (1962)
Nebraska	H	PHS	3462	0.20	Koch et al. (1973)
[e]New Zealand	A,H	PHS		0.20	Baker et al. (1975)
Montana	H	PHS	5999	0.23	Nelsen and Kress (1976)
[f]New Zealand	A	Sire-offspring regression		0.25	Carter (1971)
Montana	A	PHS	2113	0.27	Nelsen and Kress (1976)
Nebraska	A,H,A-H	PHS	1036	0.30	Dickerson et al. (1974)
Canada	A,H	PHS	84021	0.32	Kennedy and Henderson (1975a)
Georgia	H	Sire-offspring regression	180	0.34	Chapman et al. (1972)
Pennsylvannia	HxA-Ho	PHS	646	0.35	L.L.Wilson et al. (1976)
South Dakota	H	PHS	679	0.40	Dinkel and Busch (1973)
North Carolina	H	PHS	1692	0.50	Vesely and Robison (1971)
United Arab Republic	F	PHS	783	0.55	Afifi and Soliman (1971)
Hawaii	A	PHS	2550	0.72	Francoise et al. (1973)
Hawaii	H	PHS		0.82	Francoise et al. (1973)

1 Weaning weight or weight recorded close to the time of weaning
2 A = Angus, H = Hereford, F = Friesian, BF = British Friesian, Ho = Holstein
3 PHS = paternal half-sib method
a Weighted average of 30 estimates
b Weighted average of 8 estimates
c Preferred value from 35 estimates
d 84 - day weight
e 131 sires
f 84 sires

Table 2.8 Some published estimates of genetic and phenotypic correlations among birth weight, pre-weaning growth rate and weaning weight

Location	Breed[1]	No. calf records	Genetic correlation	Phenotypic correlation	Reference
		Birth weight and pre-weaning growth rate			
U.S.A	A,H,S		0.38[a]	0.23[b]	Petty and Cartwright (1966)
Nebraska	H	1,693	0.28[e]	0.27[e]	Koch *et al.* (1973)
Nebraska	H	1,769	0.10[f]	0.18[f]	Koch *et al.* (1973)
		Birth weight and weaning weight			
U.S.A	A,H,S		0.58[b]	0.39[c]	Petty and Cartwright (1966)
North Carolina	H	1,692	0.49	0.42	Vesely and Robison (1971)
Nebraska	H	1,693	0.53[e]	0.43[e]	Koch *et al.* (1973)
Nebraska	H	1,769	0.41[f]	0.35[f]	Koch *et al.* (1973)
Nebraska	A,H,S	166	0.84[e]	0.64[e]	Dunn *et al.* (1970)
Nebraska	A,H,S	134	0.91[f]	0.51[f]	Dunn *et al.* (1970)
		Pre-weaning growth rate and weaning weight			
U.S.A.	A,H,S		0.98[d]	0.97[d]	Petty and Cartwright (1966)
Montana	A,H	3,492	0.94 to 0.97		Nelsen and Kress (1976)
Nebraska	H	1,693	0.95[e]	0.98[e]	Koch *et al.* (1973)
Nebraska	H	1,769	0.96[f]	0.98[f]	Koch *et al.* (1973)
Canada	A,H	61,688	1.00	0.98	Kennedy and Henderson (1975b)

[1] A = Angus, H = Hereford, S = Shorthorn

[a] Weighted average of 8 estimates

[b] Weighted average of 9 estimates

[c] Weighted average of 10 estimates

[d] Weighted average of 6 estimates

[e] Female calves

[f] Male calves

Some authors have reported higher heritability estimates for female calves than for male calves (Carter and Kincaid, 1959; Pahnish et al., 1961; Blackwell et al.,1962; Robertson et al.,1963; Francoise et al., 1973; Koch et al., 1973; Nelsen and Kress, 1976) although the differences, often quite large, have mostly been reported to be non-significant.

Published estimates of genetic and phenotypic correlations among the three calf traits are given in Table 2.8. The high correlations between pre-weaning growth rate and weaning weight suggest that selection for either trait would have the same effect. The relationships between birth weight and weaning weight are characterized by the genetic correlation generally being higher than the phenotypic correlation. Both kinds of correlation however, show sizable positive associations. Genetic and phenotypic correlations of birth weight with pre-weaning growth rate are slightly lower than those between birth weight and weaning weight.

V. Relationships Between Cow and Calf Liveweights

The relationships between cow and calf liveweights are of economic importance to the beef cattle industry. In the genetic improvement of beef cattle, emphasis has been placed largely on attaining high growth rates by either choosing larger and more rapidly-growing breeds or selecing faster-growing animals within a breed. However, while fast growth in the young animal would appear to be desirable, the overall output/input ratic from a beef production system is of prime concern. Consequently it is of interest to investigate relationships between mature cow size and calf growth performance. It is to be expected however, that errors will arise in using cow liveweight as an indicator of cow size. In particular, the weight of a mature cow is known to fluctuate widely. Also, errors in recording cow liveweights are often difficult to avoid (Hughes, 1976).

Cow liveweight may be considered as having both a transmitted genetic effect and an environmental maternal effect on calf birth and weaning weights. Positive associations between cow liveweights and calf weights have been reported in most studies. Correlation estimates between cow liveweights and calf birth weights and between cow liveweights and calf weaning weights are shown in Tables 2.9 and 2.10, respectively. The correlations show no close relationships, although calf birth weights

Table 2.9 Published estimates of the correlation between dam liveweight and calf birth weight

Breed	No. cow-calf pairs	Correlation coefficient	Comment	Reference
Hereford	248	0.21		Gregory *et al*.(1950)
Beef Shorthorn	98	0.22		Knapp *et al*. (1940)
Hereford	502	0.24		Alexander *et al*. (1960)
Angus x Milking Shorthorn	463	0.24		Drewry *et al*. (1972)
Hereford	619	0.26		Singh *et al*. (1970)
Hereford	74	0.32		Gregory *et al*. (1950)
[a]	230	0.32	18-month weight	Sawyer *et al*. (1963)
Hereford	95	0.32		Vaccaro and Dillard (1966)
Angus	68	0.34		O'Mary and Millers (1976)
Charolais x Angus	49	0.36		O'Mary and Millers (1976)
Hereford	37	0.40	High nutritional plane	Tudor (1972)
Friesian	783	0.41		Afifi and Soliman (1971)
Hereford	95	0.41	First-calving 2-year-olds	Bellows *et al*. (1971)
Angus	103	0.42	First-calving 2-year-olds	Bellows *et al*. (1971)
[b]	173	0.43	[c]	Jeffery and Berg (1972)
[a]	230	0.44	$5\frac{1}{2}$-year dam weight	Sawyer *et al*.(1963)
Beef Shorthorn	402	0.49		Dawson *et al*. (1947)
Holstein	536	0.56		Foote *et al*. (1959)

[a] Not specified.

[b] Various breeds and crosses.

[c] Across breed and age of dam.

Table 2.10 Published estimates of the correlation between dam liveweight and calf weaning weight[1]

Breed	No. cow-calf pairs	Correlation coefficient	Comment	Reference
Hereford	69	-0.11		Gregory *et al.* (1950)
Hereford	[illegible]	0.03		Singh *et al.* (1970)
Hereford	9797	0.09	Fall weight of dam	Brinks *et al.* (1962)
Hereford	9797	0.12	Previous fall weight of dam	Brinks *et al.* (1962)
[a]	534	0.16		Urick *et al.* (1971)
Hereford	257	0.20		Gregory *et al.* (1950)
Hereford	9797	0.21	Spring weight of dam	Brinks *et al.* (1962)
Crossbred	394	0.22		Simpson *et al.* (1972)
[a]	176	0.29		Jeffery *et al.* (1971)
[b]	374	0.34		Hight *et al.* (1973)
Hereford	72	0.34		Tanner *et al.* (1965)
[a]	201	0.35		Jeffery *et al.* (1971)
Angus	20	0.51		O'Mary *et al.* (1959)

[1] Weaning weight or weight recorded close to the time of weaning

[a] Various breeds and crosses

[b] Friesian, Angus and Friesian-Angus crosses

appear to be more closely related to dam weights than do weaning weights.

Jeffery et al.(1971) compared dam weight at calf weaning with dam post-calving weight for their associations with pre-weaning growth rate of calves. Simple correlations between dam weight at weaning and pre-weaning growth rate were 0.29 and 0.35 in years 1966 and 1969, respectively. Correlations between post-calving weight of dam and pre-weaning growth rate were slightly higher being 0.33 and 0.44 for the two years, respectively. Although the associations of the two cow liveweights with pre-weaning performance were small it was suggested that the higher correlations with post-calving dam liveweight may have arisen due to a negative relationship between summer weight gain and milk yield.

Jeffery and Berg (1972) reported a positive association of dam weight with birth weight and with average daily gain of calf when considered first across breeds and secondly across ages of dam. Correlations were 0.43 and 0.34, respectively. When data were considered within the breed and age-of-dam categories, smaller positive and some negative associations were reported for these relationships.

Several other studies have shown negative associations between pre-weaning growth rates of calves and cow gains from calving to weaning. Such associations help to explain the low or negative correlations of cow weights with calf weaning weights. Gregory et al.(1950) reported negative correlations between pre-weaning growth rate and cow gains from calving to weaning of -0.12 and -0.34 at the two locations studied. On this finding these authors suggested that this could possibly be explained if cows making the smallest liveweight gains had more of their nutrients directed towards milk production giving rise to more rapid calf growth, while the cows making larger weight gains were putting more of their energy intake into body flesh.

Singh et al.(1970) noted that when cows lost weight during suckling, their calves grew more rapidly, and when cows gained weight, calves tended to grow more slowly. These authors showed that calves grew 0.03 kg faster per day for every 10% reduction in dams' liveweight. In general agreement are the studies of England et al. (1961), Brinks et al. (1962), Vaccaro and Dillard (1966) and Carpenter et al. (1973).

Hawkins *et al.*(1965) noted that in a study of 919 calves by 214 Hereford cows, cows that weighed less at weaning time weaned more calves and more total pounds of calf.

Sawyer *et al.*(1963) presented positive correlations of suckling daily gain with dam 18-month weight and dam 5½-year weight of 0.20 and 0.26, respectively. Singh *et al.* (1970) reported no significant effect of cow weight at parturition on pre-weaning average daily gains or weaning weight even though cow liveweights ranged from 385 to 725 kg. In the study of Singh *et al.* (1970), it was found that calves from cows weighing from 452 to 542 kg at parturition grew faster from birth to weaning than did calves from heavier or lighter cows, being indicative of a non-linear relationship. Nelson and Cartwright (1967) found that calf growth from birth to weaning was highest among Angus calves for dams averaging 570 kg liveweight, whereas Hereford calves grew most rapidly when dams averaged 600 kg. A more curvilinear relationship was determined among the Herefords.

According to Carpenter *et al.* (1973), mature size of cows fed individually to maintain equal fatness did not have a significant effect on weights and gains of 59 Charolais calves.

Urick *et al.* (1971) considered the relationship of actual cow weights and cow metabolic weight (liveweight $^{0.73}$) with measures of calf performance. Correlations were found to be essentially the same for actual and metabolic cow weights and those authors consequently chose to work with actual weights.

Some authors have expressed cow-calf weight relationships as a regression of calf weight on dam liveweight. Regressions of calf birth weight on dam liveweight are presented in Table 2.11. Noticeably all estimates are positive ranging from 0.16 to 0.37 kg increases in birth weight per 10 kg increases in dam weight. The higher correlation of birthweight with 18-month weight of dam than with 5½-year weight of dam reported by Sawyer *et al.* (1963) is in agreement with the finding of Vaccaro and Dillard (1966) that the association between dams' weight 90 days before calving and calf birth weight was highest for the youngest class of cow.

Table 2.11 Published estimates of the regression of calf birth weight on dam liveweight

Breed	No. cow-calf pairs	Regression (kg/10 kg)	Comment	Reference
[a]	173	0.16		Jeffery andBerg (1972)
Hereford	37	0.23	High nutrit-ional plane	Tudor (1972)
Hereford	90	0.25		Vaccaro and Dillard (1966)
[a]	377	0.26		Jeffery *et al.* (1971)
[b]	230	0.30	$5\frac{1}{2}$-year dam weight	Sawyer *et al.* (1963)
Friesian	[b]	0.34		O'Conner *et al.* (1968)
[b]	230	0.37	18-month dam weight	Sawyer *et al.* (1963)

[a] Various breeds and crosses
[b] Not stated

While Tudor (1972) reported significant positive relationships of dam weight with birth weight on a high nutritional plane, no significant association was found on a low nutritional plane.

The regressions of weaning weight (or calf weight close to the time of weaning) on dam liveweights presented in Table 2.12 show a consistent similarity, but are small in relation to the magnitudes of the liveweights. Breed differences were noted by Godley and Tennant, (1969) who found that weight of Angus dams had a significant effect on weaning weight but not for Hereford dams. Weight changes of Angus dams recorded over three periods did not significantly affect the weaning performance of their calves. However, Hereford cows that gained as little liveweight as 0.5 kg to as much as 125 kg from the beginning of the breeding season to weaning, weaned significantly heavier calves than did other cows with weight changes outside the range of 0.5 kg to 125 kg gains. Smith and Fitzhugh (1968), who studied 878 Angus progeny records, found that heavier dams had a tendency to wean heavier calves. Relationships were found to be homogeneous over the age of dam classes (2,3,4 to 5, 6 to 9, 10+).

Values in the literature for regressions of calf pre-weaning growth rate on dam liveweight are all positive. In a study of 1,011 Hereford cow and calf weights, Bennyshek and Marlowe (1973) found a linear regression coefficient after adjustment for environmental effects of 0.0046 kg increase in pre-weaning average daily gain per 10 kg increase in cow weight. Sawyer et al. (1963) reported regressions of suckling daily gain on 18-month weight and $5\frac{1}{2}$-year weights of dam of 0.0055 and 0.0040 kg per day per 10 kg change in cow weight, respectively. Jeffery and Berg (1972) determined a 0.0029 kg increase in average daily gain per 10 kg increase in post-calving weight of dam and McDonald and Turner (1969) indicated that there was a 0.004 kg increase in pre-weaning growth rate per 10 kg increase in dam weight across several breed groups. These latter results were considered to reflect both parental breed effects and cow weight effects on progeny performance.

Table 2.12 Published estimates of the regression of calf weaning weight[1] on dam liveweight

Breed	No. cow-calf pairs	Regression (kg/10 kg)	Comment	Reference
Hereford	[a]	0.44	Three herds	Edwards and Bailey (1975)
Hereford	385	0.49		Tanner et al. (1965)
Hereford	135	0.70		Neville (1962)
[a]	377	0.70		Jeffery et al. (1971)
[b]	173	0.70		Jeffery and Berg (1972)
Hereford	[a]	0.82	Two herds	Edwards and Bailey (1975)
Angus	518	0.85		Tanner et al. (1965)
Hereford	1011	0.70 - 1.10		Bennyshek and Marlowe (1973)
Hereford	20	0.97		Ewing et al. (1967)
[b]	577	1.18	Across sire breeds	McDonald and Turner (1969)
[c]		1.55		Hight et al. (1973)

[1] Weaning weight or weight recorded close to the time of weaning

[a] Not stated

[b] Various breeds and crosses

[c] Friesian, Angus and Friesian-Angus crosses

CHAPTER THREE

SOURCE OF DATA AND METHODS OF ANALYSIS

I. Source of Data

The data analyzed in this study were the records from various breeds and crosses of beef cattle at the Whatawhata Hill Country Research Station of the Ministry of Agriculture and Fisheries, Hamilton. The period covered was from the 1970 calving to the weaning in 1975.

The breeds of sire used were Angus and Friesian. Angus sires were mated only to Angus dams. Friesian sires were mated to the following five breeds of dam:

(i) Friesian
(ii) Friesian x Jersey (F_1)
(iii) Friesian x (Friesian x Jersey) (Backcross)
(iv) Angus
(v) Friesian x Angus (F_1)

Sires were chosen as being reasonable representatives of the Angus and Friesian breeds. A few sires were used in more than one year. Cows at spring calving were aged from 2 to 10 years. The culling of cows was on the basis of fertility status, weaning weight of calf, structural faults, temperament, age and disease.

All bull calves were castrated at birth. Liveweights recorded were calf birth weight (within 48 hours of birth), calf weaning weight, dam post-calving liveweight, dam pre-mating liveweight, and dam liveweight at weaning.

Pre-weaning growth rate was calculated as:

$$\text{Pre-weaning growth rate (kg/day)} = \frac{\text{weaning weight (kg)} - \text{birth weight (kg)}}{\text{age at weaning (days)}}$$

The year-round nutritional management practised over the period that the data were collected followed the principles set out by Hight (1968). From weaning, cows were run in two groups; the rising 3-year-olds and those over 3-years-of-age (mixed age). Late calving cows and those in poor condition from the mixed age group were later shifted to the preferentially fed rising 3-year-old group. The mixed age group was fed hay and roughage with a restricted amount of pasture in early autumn. A rising nutritional plane late in pregnancy and a higher level of feeding from calving to weaning were provided to the extent that feed supplies allowed.

At mating, in late October or early November, cows with calves at foot were randomly assigned to single-sire mating groups. Randomization was within age of dam and, for the cows to be mated to Friesian sires, within cow breed. Mating groups were shifted from paddock to paddock in order to provide a plentiful feed supply to the lactating cows. The periods over which cows were run in their mating groups and calf weaning dates are given in Table 3.1.

In years 1972 and 1973 post-calving nutritional treatments were imposed on cows to investigate the effects of differing levels of post-calving supplementary feeding on cow reproductive characteristics. Treatment classifications in 1972 were:

(i) Supplementary meal feeding for 14 days post-calving
(ii) Supplementary meal feeding for 21 days post-calving
(iii) Control animals fed pasture only
(iv) Those animals excluded from the experiment

In 1973, treatment were classified similarly, the only difference being that the supplementary meal feeding in treatment (ii) was from 14 to 28 days post-calving. Those animals excluded from the experiment in 1972 and 1973 and all animals in 1970, 1971 and 1974 were randomly assigned to paddocks from calving to mating.

Table 3.1 Periods over which cows were assigned to mating groups and weaning dates

Date cows and calves entered mating groups	Date cows and calves left mating groups	Date of weaning
10 Nov. 1970	29 Jan. 1971	22 Feb. 1971
10 Nov. 1971	25 Jan. 1972	13 March 1972
30 Oct. 1972	19 Jan. 1973	15 March 1972
26 Oct. 1973	2 Feb. 1974	28 Feb. 1974
27 Oct. 1974	6 Feb. 1975	19 Feb. 1975

Calf birth weights were classified according to year of record, sex of calf, sire breed, sire identification number, dam breed and age of dam. In addition to the above classification, pre-weaning growth rate and weaning weights were classified according to the post-calving influence of mating group. Age of dam was reclassified in the present study on the assumption that variation that could be attributed to this effect would be adequately accounted for using the classifications for which correction factors have been developed in the National Beef Recording Service (see Nicoll, 197[illegible]). The four classes are:

(i) 2-year-old dams

(ii) 3-year-old dams

(iii) 4-year-old dams

(iv) Those dams 5-years of age and older.

Sires and mating groups were treated as being nested-within-year. Birth date and age at weaning were treated as continuous covariates, the former affecting birth weight and the latter affecting both pre-weaning growth rate and weaning weight.

As all animals in any one year were weaned on the same day, the two covariates differed first in that they were opposite in sign when expressed as deviations from means, and secondly, the average age at weaning differed from year to year.

Data were edited for twin births, missing mating group number and for unknown sires where pregnant cows were brought to the Station in 1971. Fewer records were analyzed for the traits pre-weaning growth rate and weaning weight than for birth weight as a proportion of calves did not survive from birth to weaning, and the mating group classification was missing for some individuals.

In the Friesian-sired groups, 2-year-old dams giving birth to calves had been mated to different bulls from the older breeding females. Consequently it was necessary to analyze the records of Friesian-sired calves out of 2-year-old dams separately. The procedures of Weeks and Williams (1964) and Schaeffer (1975) were used to determine that the data were disconnected. Following preliminary analyses described in Chapter Four, population parameters for the straightbred Angus animals were obtained for only those records of calves out of dams aged 3-years and older. Estimates of heritability and genetic, environmental and phenotypic correlations were obtained for the following six separate groups:

Table 3.2 Identification numbers of sires and the number of offspring weaned per sire

Population: Sire breed	Dam age (years)	Year of birth of the calf	Sire identification no./No. offspring				
			Female calves				
Angus	3+	1970	23/4,	24/3,	25/2,	26/4	
		1971	33/5,	34/4,	35/5,	36/6	
		1972	45/11,	33/10,	46/11,	47/12	
		1973	47/9,	57/7,	58/6,	59/8	
		1974	62/9,	64/9,	65/13		
Friesian	2	1970	31/10,	32/7			
		1971	41/8,	42/8			
		1972	48/15,	50/14			
		1973	53/12,	54/13			
		1974	60/6,	61/9			
Friesian	3+	1970	27/13,	28/15,	29/13,	30/11	
		1971	37/15,	38/12,	39/23,	40/18	
		1972	41/20,	42/20	49/21,	51/13,	52/14
		1973	42/23,	49/21,	55/12,	56/27	
		1974	37/17,	66/11,	67/15,	68/19,	69/14
			Male calves				
Angus	3+	1970	23/2,	24/3,	25/5,	26/4	
		1971	33/5,	34/12,	35/6,	36/7	
		1972	45/10,	33/9,	46/13,	47/12	
		1973	47/11,	57/5,	58/7,	59/12	
		1974	62/8,	64/10,	65/8		
Friesian	2	1970	31/4,	32/2			
		1971	41/5,	42/4			
		1972	48/12,	50/6			
		1973	53/9	54/11			
		1974	60/3,	61/5			
Friesian	3+	1970	27/13,	28/14,	29/8,	30/13	
		1971	37/12,	38/15,	39/11,	40/13	
		1972	41/19,	42/19,	49/11,	51/20,	52/19
		1973	42/20,	49/24,	55/16,	56/23	
		1974	37/13,	66/22,	67/10,	68/20,	69/18

Table 3.3 Numbers of calves classified according to sire breed, dam breed, calf sex, age of dam and calf record

Dam breed	Female calves No. born	Female calves No. weaned	Male calves No. born	Male calves No. weaned
	Friesian-sired calves from 2-year-old dams			
Friesian	45	42	42	35
Friesian x Jersey			3	1
Friesian x (Friesian x Jersey)	31	28	16	12
Angus	8	8	3	
Friesian x Angus	30	24	19	13
	Friesian-sired calves from 3- to 9-year-old dams			
Friesian	128	121	141	135
Friesian x Jersey	77	75	83	81
Friesian x (Friesian x Jersey)	26	26	32	29
Angus	120	114	100	87
Friesian x Angus	32	31	21	21
	Angus-sired calves from 2-year-old dams			
Angus	18	17	25	18
	Angus-sired calves from 3- to 10-year-old dams			
Angus	143	138	159	149

Table 3.4 Means and standard deviations (S D) for the traits and covariates in the populations from which estimates of genetic, environmental and phenotypic parameters were obtained

Population		No. animals		Birth weight (kg)		Pre-weaning growth rate (kg/day)		Weaning weight (kg)		Day of birth (day of the year)		Age at weaning (days)	
Sire Breed	Dam age (years)	No. born	No. weaned	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
						Female Calves							
Angus	3+	143	138	26.4	3.8	0.72	0.09	150.6	25.3	256.8	21.1	171.3	21.2
Friesian	2	114	102	31.0	4.3	0.78	0.09	181.0	26.2	236.1	24.1	191.9	23.3
Friesian	3+	383	367	31.7	5.0	0.83	0.11	175.4	28.5	254.7	22.0	172.7	22.1
						Male Calves							
Angus	3+	159	149	28.3	4.0	0.77	0.11	163.5	29.2	254.9	21.5	174.9	21.4
Friesian	2	83	61	33.9	5.2	0.83	0.12	192.3	34.7	238.6	26.8	191.3	25.5
Friesian	3+	377	353	34.9	5.3	0.89	0.11	186.7	33.8	257.6	23.7	169.3	24.1

Table 3.5 Means and standard deviations (S D) of cow liveweights recorded post calving and at calf weaning time (kg) according to cow breed and sex of calf

Calf sex	No. cows calving	No. cows Weaning calves	Dam post-calving liveweight Mean	S D	Dam liveweight at calf weaning Mean	S D
			Angus cows			
Male	182	164	362.6	50.6	417.3	48.2
Female	158	153	361.1	53.3	414.0	49.3
			Friesian cows			
Male	213	168	392.6	67.7	430.1	68.0
Female	191	159	390.7	66.7	434.0	61.0

- Angus
  - Male calves from 3- to 10-year-old dams (i)
  - Female calves from 3- to 10-year-old dams (ii)
- Friesian-sired
  - Male calves
    - From 2-year-old dams (iii)
    - From 3- to 9-year-old dams (iv)
  - Female calves
    - From 2-year-old dams (v)
    - From 3- to 9-year-old dams (vi)

Included in Table 3.2 are the identification numbers of sires and the number of offspring weaned per sire which show that no more than five Friesian sires and four Angus sires were used in any one year, and that the numbers of offspring per sire differ widely. The number of calves classified according to sire breed, dam breed, calf sex, age of dam and calf record are shown in Table 3.3. Notably, in the Friesian-sired populations, by far the greater proportion of dams are of the higher milk-producing dairy or dairy x beef types.

The number of records, means and standard deviations for the three calf traits, namely, birth weight, pre-weaning growth rate and weaning weight and the two covariates, day of birth and age of weaning, classified according to the six separate groups given above, are presented in Table 3.4.

Cow-calf weight relationships were determined using records of the straightbred Angus and straightbred Friesian animals, pooled over all ages of dam. In Table 3.5 are means and standard deviations of cow liveweights recorded post calving and at weaning, according to sex of calf for the Angus and Friesian breeds.

II. Methods of Analysis

A. Estimation of genetic, environmental and phenotypic parameters

(1) Solution to the least squares equations. A general linear model can be written in matrix notation as:

$$Y = Xb + e \qquad \ldots (3.1)$$

where: Y = a known n x 1 observation vector (n is the total number of observations), X = a known n x p incidence matrix of 0's and 1's and continuous independent variables (p is the number of equations in the model).

b = an unknown p x 1 vector of parameters to be estimated

and e = an unknown n x 1 vector of normally and independently distributed random errors with an expected value of zero and a variance of $\sigma^2 I$ where I is an n x n identity matrix

Least squares estimation of b involves the finding of those values which minimise the sum of the squared deviations of the observed values from their expected values.

Since: $E(e) = 0$

and: $E(Y) = Xb$

then: $e'e = [Y-Xb]'[Y-Xb]$ ...(3.2)

By differentiating e'e with respect to b, equating to zero and substituting the estimate b for the parameter b, the resultant equations known as the normal equations are:

$[X'X]\, b = X'Y$ ...(3.3)

Solution of the normal equations requires that matrix X'X is of full rank. The methods used in this analysis for reducing the normal equations to full rank were the two outlined by Harvey (1960). They are:

(i) That for each factor in a model, the sum of the constant estimates equals zero,

and (ii) That for each factor in a model, one of the effects equals zero.

Methods (i) and (ii) above may be written in general terms as $\sum_i a_i = 0$ and $a_p = 0$, respectively.

Solution for the estimable functions of the unknown parameters involves the inversion of the X'X matrix. A computer routine was available which was suitable for inverting square matrices of limited dimensions (up to 35 x 35 approximately). Larger inverse matrices were obtained through the use of matrix partitioning procedures. Inversion with a single partitioning was carried out by partitioning the normal equations (3.3) as:

$$\begin{bmatrix} A_{rxr} & B_{rxs} \\ B'_{sx1} & C_{sxs} \end{bmatrix} \begin{bmatrix} b_{1\,rx1} \\ b_{2\,sx1} \end{bmatrix} = \begin{bmatrix} Y_{1\,rx1} \\ Y_{2\,sx1} \end{bmatrix} \quad \ldots(3.4)$$

Then:

$$Ab_1 + Bb_2 = Y_1 \quad \ldots(3.5)$$

and $$B'b_1 + Cb_2 = Y_2 \quad \ldots(3.6)$$

By solving for b_1 in equations (3.5), substituting into equations (3.6) and re-arranging, it can be shown that:

$$b_2 = [C-B'A^{-1}B]^{-1} \; [Y_2-B'A^{-1}Y_1] \quad \ldots(3.7)$$

from which the total reduction in sums of squares may be obtained through absorption as:

$$R(b_1, b_2) = b_2[Y_2-B'A^{-1}Y_1] + Y_1'A^{-1}Y_1 \quad \ldots(3.8)$$

where the order of the largest non-diagonal matrix to be inverted corresponds to the number of b_2 equations.

Alternatively where the full matrix inverse is required (see Section II.A.(2)), in terms of equations (3.4):

after defining $G = \begin{bmatrix} A & B \\ B' & C \end{bmatrix}$

and $G^{-1} = \begin{bmatrix} D & E \\ E' & F \end{bmatrix}$

the matrix inverse G^{-1} may be computed stepwise as:

$$F = [C-B'A^{-1}B]^{-1}, \quad \ldots(3.9)$$

$$E = -A^{-1}BF \quad \ldots(3.10)$$

and $$D = A^{-1}[I_1 - BF'] \quad \ldots(3.11)$$

where I_1 = an identity matrix of the same dimensions as A.

A second matrix partitioning was included for some larger interaction models, whereby if in equations (3.7), or alternatively in equations (3.9) the inverse of the $[C-B'A^{-1}B]$ matrix was obtained following the same computational steps used to calculate the inverse matrix G^{-1} (3.9 to 3.11).

(2) Estimation of mean squares, variance and covariance components and genetic, environmental and phenotypic parameters

The direct and indirect methods of Harvey (1960) were used in computing sums of squares from which mean squares were calculated. In testing for the significance of interactions involving nested factors, the use of the indirect method of obtaining sums of squares was preferred as these interactions were associated with a large number of degrees of freedom, thereby making the use of the direct method unsuitable. Furthermore, in testing for the significance of interactions involving nested factors, extensive use was made of compound parameters. The use of these arises as a simplification, since, for example in the 2-way classification with interaction, the same total sum of squares may be obtained due to fitting the interaction alone as can be calculated from fitting the main effects and the interaction. In other models, in which interactions involving nested effects were excluded, the direct procedure was applied requiring the calculation of complete inverse matrices.

An abbreviated form of the direct method of computing sums of squares is:

$$\hat{\beta}' Z^{-1} \hat{\beta}$$

where:

$\hat{\beta}'$ = a row vector of least squares estimates for a given set of equations

Z^{-1} = the inverse of the square segment of the inverse of the variance-covariance matrix corresponding, by row and column to this set of estimates

and $\hat{\beta}$ = a column vector of the least squares estimates for the given set of equations.

Using the general linear model (3.1) and the normal equations (3.3), the total reduction in sum of squares is:

$$R(b) = b'X^1Y$$

and the error sum of squares is:

$$\text{Error S.S.} = Y'Y - R(b)$$

Two methods of variance component estimation suitable for use in mixed models with unbalanced data are Method Two and Method Three of

Henderson (1953). Method Two, a short-cut method, is a well-defined procedure which may be used in mixed models in which there are no interactions between fixed and random factors and no nesting of fixed and random factors within each other (Henderson et al., 1974). As a consequence of these limitations, Method Two could not be used in the present case. Method Three, based on taking expectations of least squares reductions, yields unbiased estimates of variance components in mixed models and is not subject to the limitations of Method Two.

In main effect models, Method Three can be applied using the direct approach to compute the coefficients for the variance components in the expectations of mean squares (Harvey, 1970). This approach is an extension of the direct method for computing sums of squares and was adopted here in conjunction with the use of the restriction $\sum_i a_i = 0$, to reduce the normal equations to full rank.

Consider the mixed model:

$$Y_{ijkl} = \mu + a_i + b_{ij} + f_k + e_{ijkl} \qquad \ldots(3.12)$$

where: the a_i and the f_k are fixed and the b_{ij} random. The error mean square has the expectation σ^2_e, the error variance. The expectation of the mean square for the b_{ij} is:

$$E(MS_{b:a}) = \sigma^2_e + k_1 \sigma^2_{b:a}$$

Hence:

$$\hat{\sigma}^2_{b:a} = \frac{MS_{b:a} - \hat{\sigma}^2_e}{k_1}$$

The coefficient k_1 may be obtained using the formula:

$$k_1 = \frac{1}{r-p} \sum_i \left(\sum_j Z^{jj}_{b_i} - \frac{1}{q_i} \sum_j \sum_{j'} Z^{jj'}_{b_i} \right)$$

where: r = the number of AB subclasses,

p = the number of a_i classes,

q_i = the numbers of b_{ij} sub-classes within the a_i classes,

b_i refers to the reduced set of parameter estimates in the i^{th} a class and Z_{b_i} the portion of the inverse of the variance-covariance matrix corresponding by row and column to the set of b_i estimates.

Sampling errors of the sire-within-year and residual variance components were calculated using the method given by Kempthorne (1957).

Harvey (1970) indicated that covariance components can be estimated simultaneously with the variance components by computing reductions in sums of cross-products and utilizing the same variance-covariance matrices and the same coefficients for the covariance components as are used for the variance components in equating least squares reductions to their expectations.

In the present study, common variance-covariance matrices were utilized for the traits pre-weaning growth rate (GR) and weaning weight (WW) and the reductions in sums of crossproducts due to fitting the b_{ij} were computed using the direct method.

i.e. $\hat{\beta}'_{GR} Z^{-1} \hat{\beta}_{WW}$

For the correlations with birth weight (BW) a different variance-covariance matrix was used, the birth weight model was refitted, but only those calves weaned were included. Also, a second model for the other traits was fitted differing in that the regression on age at weaning was fitted rather than the regression on day of birth. The least squares estimates were then obtained from the corresponding models so that the formulae:

$$\hat{\beta}'_{BW} Z^{-1} \hat{\beta}_{GR}$$

and

$$\hat{\beta}'_{BW} Z^{-1} \hat{\beta}_{WW}$$

could be applied, for the b_{ij} classes.

Total reductions in sums of cross-products were obtained by multiplying the row vector of parameter estimates for one trait by the restricted X'Y column vector of equations (3.3) for another trait.

In the mixed model (3.12), if the b_{ij} are sires nested within years then the genetic and environmental variances and covariances based on the corresponding sire within year and error components of variance and covariance may be obtained from the expectations given in Table 3.5, assuming that inbreeding, epistasis and environmental correlations among half sibs are negligible.

The paternal half-sib estimate of heritability is then four times the intra-class correlation based on sires within year.

i.e. $h^2 = 4 \left[\dfrac{\hat{\sigma}^2_{b:a}}{\hat{\sigma}^2_{b:a} + \hat{\sigma}^2_{e}} \right]$

Approximate standard errors for the heritability estimates were calculated using the formula of Falconer (1960).

Table 3.6 Expectations of sire within year and error variance and covariance components in terms of genetic and environmental variances and covariances

Source	Expectations	
	Variance components	Covariance components
Sire within year	0.25 $var_G x$	0.25 cov_G (xy)
Error	0.75 $var_G x + var_E x$	0.75 cov_G (xy) + cov_E(xy)

$var_G x$ = additive genetic variance for trait x
$var_E x$ = environmental variance for trait x
$cov_G(xy)$ = genetic covariance between traits x and y
$cov_E(xy)$ = environmental covariance between traits x and y

Genetic, environmental and phenotypic correlations were estimated using the general formula:

$$r_{xy} = \frac{cov(xy)}{(var\ x\ .\ var\ y)^{\frac{1}{2}}}$$

in which the genetic, environmental and phenotypic covariances and variances were inserted to obtain the genetic, environmental and phenotypic correlations, respectively. The formula of Tallis (1959) was adopted to estimate approximate sampling errors for the genetic correlations.

(3) Fitting models to data

Models fitted in testing for the significance of the post-calving nutritional effects on pre-weaning growth rate and weaning weight in years 1972 and 1973 were:

(i) Angus calves from dams of all ages. The model fitted was:

$$Y_{ijklm} = \mu + s_i + g_j + a_k + t_l + b(x_{ijklm} - \bar{x}) + e_{ijklm} \quad ...(3.13)$$

where: Y_{ijklm} = the observation on the m^{th} calf of x days of age at weaning, within the t^{th} post-calving nutritional treatment class, reared in the j^{th} mating group, by the i^{th} sire and from a dam in the k^{th} age class

μ = the population mean with equal subclass numbers and with age at weaning equal to the average

s_i = the effect of the i^{th} sire,

g_j = the effect of the j^{th} mating group,

a_k = the effect of the k^{th} age-of-dam group,

t_l = the effect of the l^{th} post-calving nutritional treatment

b = the partial regression of the Y_{ijklm} on x_{ijklm}

x_{ijklm} and e_{ijklm} = the age of weaning and random error, respectively, associated with the m^{th} calf, within the t^{th} post-calving nutritional treatment class, reared in the j^{th} mating group, by the i^{th} sire and out of a dam in the k^{th} age class

$\bar{x}$ = the mean age of weaning

(ii) Friesian-sired calves from dams aged 3 years and older.

The model chosen for the two traits was:

$$Y_{ijklmn} = \mu + s_i + g_j + a_k + t_l + c_m + b(x_{ijklmn} - \bar{x}) + e_{ijklmn} \quad \ldots(3.14)$$

where: Y_{ijklmn} = the observation on the n^{th} calf of x days of age at weaning, within the l^{th} post-calving nutritional treatment class, reared in the j^{th} mating, by the i^{th} sire and from a dam in the k^{th} age class and m^{th} dam breed

s_i, g_j, a_k, t_l and b are as specified in model (3.13)

c_m = the effect of the m^{th} dam breed

x_{ijklmn} and e_{ijklmn} are the age at weaning and the random error, respectively, associated with the n^{th} calf, within the l^{th} post-calving nutritional treatment class, reared in the j^{th} mating group, by the i^{th} sire and from a dam in the k^{th} age class and of the m^{th} dam breed

$\bar{x}$ = the mean age of weaning

(iii) Friesian-sired calves from 2-year-old dams.

The 1-way analysis of variance model was chosen as the numbers involved in these analyses were small. Justification for the model arises as treatments were randomized with respect to sire, mating group, dam breed and age of weaning.

The model employed was:

$$Y_{ij} = \mu + t_i + e_{ij} \quad \ldots(3.15)$$

where: Y_{ij} = the observation on the j^{th} calf within the i^{th} post-calving nutrition treatment class

μ = the population mean with equal subclass numbers

t_i = the effect of the i^{th} post-calving nutrition treatment

e_{ij} = the random error peculiar to the j^{th} calf within the i^{th} post-calving nutritional treatment class

Following the exclusion of the post-calving nutritional treatment effect (see Chapter Four) procedures were applied to derive suitable models for estimating population parameters. In straightbred Angus analyses, main effects were fitted before interactions. In Friesian-sired analyses, interactions were fitted simultaneously with main effects. All 2-way nested and non-nested interactions could not be tested in any one model as first, the computer language placed limitations on the sizes of matrices and secondly, confounding amongst interactions with low subclass numbers would have been unavoidable.

Interactions of sire within year and mating group within year with other factors were only tested for those other factors found to have a significant effect ($P < 0.05$) on the trait concerned. Interactions among the Friesian-sired populations were only tested for those calves from dams aged 3-years and older.

A general model describing a record for which every effect was fitted is:

$$Y_{ijklmn} = \quad + y_i + s_{ij} + g_{ik} + c_l + a_m + (yc)_{il} + (ya)_{im} + (ca)_{lm} + (sg)_{ijk} + (sc)_{ijl} + (sa)_{ijm} + (gc)_{ikl} + (ga)_{ikm} + b(x_{ijklmn} - \bar{x}) + e_{ijklmn} \quad \ldots(3.16)$$

where: Y_{ijklmn} = the observation on the n^{th} calf born on the x^{th} day (or weaned at x days of age) reared in the k^{th} mating group, by the j^{th} sire in the i^{th} year from a dam in the m^{th} age class and of the l^{th} dam breed

μ = the population mean with equal subclass numbers and day of birth (or age at weaning) equal to the average

y_i = the effect of the i^{th} year

s_{ij} = the effect of the j^{th} sire within the i^{th} year

g_{ik} = the effect of the k^{th} mating group within the i^{th} year (excluded for factors affecting birth weight)

c_l = the effect of the l^{th} dam breed (excluded for factors affecting Angus calf records)

a_m = the effect of the m^{th} age-of-dam class (excluded for analyses of calves from 2-year-old dams)

$(yc)_{il}$ = interaction effects for year and dam breed

$(ya)_{im}$ = interaction effects for year and age of dam

$(ca)_{lm}$ = interaction effects for dam breed and age of dam

$(sg)_{ijk}$ = interaction effects for sire within year and mating group within year

$(sc)_{ijl}$ = interaction effects for sire within year and dam breed

$(sa)_{ijm}$ = interaction effects for sire within year and age of dam

$(gc)_{ikl}$ = interaction effects for mating group within year and dam breed

$(ga)_{ikm}$ = interaction effects for mating group within year and age of dam

b = the partial regression of Y_{ijklmn} on x_{ijklmn}

x_{ijklmn} and e_{ijklmn} = the covariate and random error, respectively associated with the n^{th} calf reared in the k^{th} mating group, by the j^{th} sire in the i^{th} year from a dam in the m^{th} age class and of the l^{th} dam breed

$\bar{x}$ = the mean covariate

The actual models fitted are indicated in terms of the notation used in model 3.16 in the Tables presented in Chapter Four.

B. An intra-class regression model for cow - calf weight relationships

The relationships examined within sex of calf and within the straight-bred Angus and Friesian populations using the intra-class regression model of Searle (1971) were:

(i) The regression of calf birth weight on dam post-calving live weight.

(ii) The regression of calf weaning weight on dam post-calving liveweight.

(iii) The regression of calf weaning weight on dam liveweight at weaning.

Birth weights and weaning weights were adjusted to mean birth dates and ages at weaning, respectively, using the regression coefficients obtained from the models from which genetic, environmental and phenotype parameters were obtained as adjustment factors.

Hence:

Adjusted weight = Actual weight − d (Actual weight x deviation from the mean)

where in the birth weight study, d was the regression of birth weight on day of birth, and in the weaning weight study, d was the regression of weaning weight on age of weaning.

The model used for the intra-class regression of a calf weight on a dam weight can be written as:

$$Y_{ij} = \mu + a_i + b_i X_{ij} + e_{ij} \qquad \ldots(3.17)$$

where Y_{ij} = the j^{th} calf weight in the i^{th} age-of-dam-year class whose dam liveweight record was X_{ij}

μ = the mean when equal subclass numbers exist and dam liveweight is equal to the average

a_i = the effect of the i^{th} age-of-dam-year class

b_i = the partial regression of the Y_{ij} on the X_{ij} within the i^{th} age-of-dam-year class

X_{ij} = the j^{th} dam weight in the i^{th} age-of-dam-year class

The regression coefficient pooled over the a_i classes was used to calculate in each case.

The sum of squares due to fitting the pooled regression (b^*) was also calculated so that the homogeneity of the regression could be tested

i.e. H_0: b_i's are equal

with: Difference sum of squares[1] = $R(b/\mu, a) - R(b^*/\mu, a)$

and the test of homogeneity involves the calculation of the F ratio:

$$F = \frac{N - 2c}{c-1} \left[\frac{\text{Difference S.S.}}{\text{SSE}} \right]$$

where N = the total number of observations

c = the number of age-of-dam-year classes

SSE = error sum of squares

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[1] The terminology for reductions in sums of squares given by Searle (1971) will be used throughout the test. e.g. R (μ, a, b:a) is the reduction due to fitting the nested model:

$$Y_{ijk} = \mu + a_i + b_{ij} + e_{ijk}$$

and R(a/μ, b:a) is the reduction due to fitting the a_i after having already fitted μ and the b_{ij}.

CHAPTER FOUR

RESULTS AND DISCUSSION

I. Preliminary Analyses of Variance

The analyses of variance for the effects of post-calving nutritional treatments in 1972 and 1973 on pre-weaning growth rate and weaning weight indicated that in all instances the effects were non-significant (P > 0.05, see Appendix I). This finding is not surprising as the treatments were only imposed for short periods within one month of calving. Owing to the non-significance of these effects and as the nutritional treatments were randomly allocated according to the other classifications, all further analyses were conducted with this effect excluded from the models.

Analyses of variance for other main effects and interactions follow, and are presented according to sire breed and sex of calf for birth weight, pre-weaning growth rate and weaning weight. The ways in which the least squares reductions were taken are also shown, based on model 3.16.

A. Angus female calves from 2- to 10-year-old dams

Analyses of variance for main effects models and various interaction models for factors affecting birth weight are presented in Table 4.1, and for factors affecting pre-weaning growth rate and weaning weight in Table 4.2 for all Angus female calves.

Year effects significantly affected birth weight, but not pre-weaning growth rate and weaning weight. Age of dam was significant for all three traits and mating group within year was a highly significant factor affecting both pre-weaning growth rate and weaning weight. Other significant main effects were the regression of birth weight on day of birth and the regressions of pre-weaning growth rate and weaning weight on age at weaning. Differences between sires within years were non-significant. In the case of birth weight, the year x age-of-dam interaction was a significant source of variation (P < 0.05).

B. Angus male calves from 2- to 10-year-old dams

The analyses of variance shown in Table 4.3 for birth weight and Table 4.4 for pre-weaning growth rate and weaning weight indicate that the effect of age of dam was a highly significant factor affecting these traits. Year and sire within year significantly affected birth weight, but not pre-weaning growth rate and weaning weight.

Of the partial regressions, that of birth weight on day of birth was

Table 4.1 Analyses of variance for factors affecting birth weight (kg) in Angus female calves from 2- to 10-year-old dams

Source of variation	D F	Mean Square	Method of obtaining sum of squares
		Main effects model	
Year	4	36.61*	$\hat{\beta}' Z^{-1} \hat{\beta}$
Sire:year	14	14.99	$\hat{\beta}' Z^{-1} \hat{\beta}$
Age of dam	3	38.4[illegible]*	$\hat{\beta}' Z^{-1} \hat{\beta}$
Regression on birth date	1	97.43**	$\hat{\beta}' Z^{-1} \hat{\beta}$
Error	132	13.40	$Y'Y-R(\mu,y,s:y,a,b)$
		Interaction model	
Year x age of dam	10	27.[illegible]	$R(ya/\mu,y,s:y,a,b)$
Error	120	12.[illegible]	$Y'Y-R(\mu,y,s:y,a,ya,b)$
Sire x age of dam: year	17	[illegible]	$R(sa:y/\mu,y,s:y,a,ya,b)$
Error	95	14.[illegible]	$Y'Y-R(\mu,y,s:y,a,ya,sa:y,b)$

* significant at the 5% level

** significant at the 1% level

Table 4.2 Analyses of variance for factors affecting pre-weaning growth rate (kg/day) and weaning weight (kg) in Angus female calves from 2- to 10-year-old dams

Source	D F	Mean squares: Pre-weaning growth rate	Mean squares: Weaning weight	Method of obtaining sum of squares
		Main effects model		
Year	4	0.00[illegible]	159.37	$\hat{\beta}' Z^{-1} \hat{\beta}$
Sire : year	14	0.0079	310.74	$\hat{\beta}' Z^{-1} \hat{\beta}$
Mating group : year	15	0.0150**	459.26**	$\hat{\beta}' Z^{-1} \hat{\beta}$
Age of dam	3	0.0832**	29[illegible].74**	$\hat{\beta}' Z^{-1} \hat{\beta}$
Regression on age at weaning	1	0.0655**	28831.19**	$\hat{\beta}' Z^{-1} \hat{\beta}$
Error	117	0.0057	185.36	Y'Y-R(μ,y,s:y,g:y,a,b)
		Interaction models		
Year x age	10	0.0086	303.89	R(ya/μ,y,s:y,g:y,a,b)
Error	105	0.0054	173.81	Y'Y-R(μ,y,s:y,g:y,a,ya,b)
Sire x mating group: year	31	0.0039	146.82	R(sg:y/μ,y,s:y,g:y,a,b)
Error	64	0.0085	267.74	Y'Y-R(μ.y,s:y,g:y,a,sg:y,b)
Sire x age of dam:year	17	0.0045	131.44	R(sa:y/μ,y,s:y,g:y,a,ya,b)
Error	70	0.0072	233.76	Y'Y-R(μ,y,s:y,g:y,a,ya,b)
Mating group x age of dam:year	17	0.0034	117.29	R(ga:y/μ,y.s:y,g:y,a,ya,b)
Error	68	0.0080	244.18	Y'Y-R(μ,y,s:y.g:y,a,ya,ga:y,b)

**significant at the 1% level

Table 4.3 Analyses of variance for factors affecting birth weight (kg) in Angus male calves from 2- to 10-year-old dams

Source of variation	D F	Mean square	Method of obtaining sum of squares
		Main effects model	
Year	4	39.14*	$\hat{\beta}' Z^{-1} \hat{\beta}$
Sire : year	14	32.72**	$\hat{\beta}' Z^{-1} \hat{\beta}$
Age of dam	3	82.05**	$\hat{\beta}' Z^{-1} \hat{\beta}$
Regression on birth date	1	140.13**	$\hat{\beta}' Z^{-1} \hat{\beta}$
Error	144	14.75	$Y'Y-R(\mu,y,s:y,a,b)$
		Interaction models	
Year x age of dam	10	28.31*	$R(ya/\mu,y,s:y,a,b)$
Error	134	13.74	$Y'Y-R(\mu,y,s:y,a,ya,b)$
Sire x age of dam : year	19	14.75	$R(sa:y/\mu,y,s:y,a,ya,b)$
Error	95	16.43	$Y'Y-R(\mu,y,s:y,a,ya,sa:y,b)$

* significant at the 5% level
** significant at the 1% level

Table 4.4 Analyses of variance for factors affecting pre-weaning growth rate (kg/day) and weaning weight (kg) in Angus male calves from 2- to 1[illegible]-year old dams

Source of variation	DF	Mean squares: Pre-weaning growth rate	Mean squares: Weaning weight	Method of obtaining sum of squares
		Main effects model		
Year	4	[illegible]	[illegible]	$\hat{\beta}'Z^{-1}\hat{\beta}$
Sire : year	14	0.0174	[illegible]	$\hat{\beta}'Z^{-1}\hat{\beta}$
Mating group : year	14	0.0108	421.13	$\hat{\beta}'Z^{-1}\hat{\beta}$
Age of dam	3	0.1585**	4788.49**	$\hat{\beta}'Z^{-1}\hat{\beta}$
Regression on age at weaning	1	0.0156	50424.33**	$\hat{\beta}'Z^{-1}\hat{\beta}$
Error	130	0.0115	452.95	$Y'Y-R(\mu,y,s:y,g:y,a,b)$
		Interaction models		
Year x age of dam	10	0.0203*	979.83**	$R(ya/\mu,y,s:y,a,b)$
Error	134	0.0108	410.29	$Y'Y-R(\mu,y,s:y,a,ya,b)$
Sire x age of dam : year	19	0.0[illegible]*	619.05	$R(sa:y/\mu,y,s:y,a,ya,b)$
Error	95	0.0111	440.51	$Y'Y-R(\mu,y,s:y,a,ya,sa:y,b)$

* significant at the 5% level
** significant at the 1% level

highly significant. While the regression on age at weaning was highly significant in the case of weaning weight, this factor was non-significant for pre-weaning growth rate.

Mating group within year was not a significant factor affecting pre-weaning growth rate and weaning weight. No satisfactory explanation can be given to indicate why this effect was highly significant in female calves and non-significant in males. While it could be suggested that female calves were more sensitive to the environmental differences between mating groups, the finding of significant year x age-of-dam effects for all three traits (shown in Table 4.3) for male calves, but only for birth weight in female calves indicates that the suggested explanation is not consistent for both kinds of effects. The sire x age-of-dam within-year interaction was also found to be a significant source of variation in pre-weaning growth rate of the male Angus calves ($P < 0.05$). This interaction was not found to be significant in any of the other samples studied, and should therefore be regarded as an exceptional case that could possibly have been attributable to unintentional managerial bias, rather than the non-additivity of the genetic and environmental factors.

C. <u>Angus calves from 3- to 10-year-old dams</u>

An examination of sub-class means suggested that the significant interactions in the Angus analyses ((A) and (B) above) may not arise if the calves from 2-year-old dams were excluded. Owing to the presence of the sire x age-of-dam within-year interaction affecting pre-weaning growth rate in the male calves, and as separate analyses for 2-year-old dams were to be conducted for the samples in which Friesian bulls were used, it was considered appropriate to determine if the interactions were no longer significant on the exclusion of the calves from the 2-year-old Angus dams. On the exclusion of calves from younger dams, the analyses of variance showed the year x age-of-dam and sire x age-of-dam within-year interactions were no longer significant. Thus, it could be postulated that the year x age-of-dam interaction may have arisen because the extent to which the younger dams, which were run as a separate group prior to calving, were preferentially treated from year-to-year tended to differ.

Another possible source of this interaction, would be if year-to-year climatic differences gave rise to greater fluctuations in the weights of calves from 2-year-old dams than in the weights of calves from older dams. In less favourable years the growing foetus would be in more competition for nutrients with the younger, growing dams than would be the case for older dams. The differences could be expected to be less in years more favourable for calf development. Similarly, differences between the levels of milk production from young and mature dams may be greater under unfavourable conditions giving rise to an interaction effect on pre-weaning growth rate. The year x age-of-dam interaction effects on pre-weaning growth rate and weaning weight of calves from 2- to 10-year-old dams were however, only significant in male calves. Thus, it could also be postulated that milk production in the Angus breed tended to be limiting calf growth to a greater extent in the faster-growing male calf.

Since the sire x age-of-dam within-year interaction could be eliminated if calves from 2-year-old dams were excluded in the Angus male calf group, analyses were conducted where only those calves from 3- to 10-year-old dams were included. Conducting analyses in this way allowed comparisons of results between the Angus- and Friesian-sired populations, for calves from dams of the same age category. When the records of Angus calves from 2-year-old dams were considered within sex of calf, there were too few records to facilitate the completion of satisfactory analyses. Thus, Angus calves from 2-year-old dams were considered no further.

D. Friesian-sired female calves from 3- to 9-year-old dams

Included in Table 4.5 are the analyses of variance for interactions affecting birth weight of Friesian-sired female calves from 3- to 9-year-old dams. The results of the analyses of variance for interactions affecting pre-weaning growth rate and weaning weight within these populations are given in Table 4.6. Calves from 2-year-old dams were excluded in these analyses (and for the male calves) as the data were disconnected, as noted in Chapter Three.

The only significant interaction following the calculation of mean squares for the three traits was the highly significant age-of-dam x dam breed effect on weaning weight. Such an interaction would occur if the magnitude of the differences between the age-of-dam categories were not consistent across dams of the dairy, dairy x beef and beef types. An examination of the subclass means given in Appendix III for weaning weight show that for the Friesian and Friesian x Jersey dams there was no indication that 4-year-old and older dams wean heavier calves than 3-year-old dams, while within the 3- to 10-year age-of-dam category, the older Friesian x (Friesian x Jersey), Angus and Friesian x Angus dams tended to wean heavier calves than 3-year-old dams.

Table 4.5 Analyses of variance for interactions affecting birth weight (kg) in Friesian-sired female calves from 3- to 9- year-old dams

Source of variation	D F	Mean square[1]	Method of obtaining sum of squares
Year x age of dam	8	5.36	$\hat{\beta}' Z^{-1} \hat{\beta}$
Year x dam breed	11	25.29	$\hat{\beta}' Z^{-1} \hat{\beta}$
Age of dam x dam breed	6	25.11	$\hat{\beta}' Z^{-1} \hat{\beta}$
Error	314	17.23	$Y'Y - R(\mu, y, s{:}y, a, c, ya, yc, ac, b)$
Sire x dam breed : year	46	17.64	$R(sc{:}y / \mu, y, s{:}y, a, c, yc, b)$
Error	231	17.13	$Y'Y - R(\mu, y, s{:}y, a, c, yc, sc{:}y, b)$

[1] All non-significant at the 5 % level

Table 4.6 Analyses of variance for interactions affecting pre-weaning growth rate (kg/day) and weaning weight (kg) in Friesian-sired female calves from 3- to 9-year-old dams

Source of variation	D F	Mean square: Pre-weaning growth rate	Mean square: Weaning weight	Method of obtaining sum of squares
Year x age of dam	8	0.0156	13[illegible].81	$\hat{\beta}' Z^{-1} \hat{\beta}$
Year x dam breed	11	0.0118	461.65	$\hat{\beta}' Z^{-1} \hat{\beta}$
Age of dam x dam breed	6	0.0172	950.14**	$\hat{\beta}' Z^{-1} \hat{\beta}$
Error	291	0.0112	325.74	$Y'Y - R(\mu, y, s{:}y, g{:}y, c, a, ya, yc, ac, b)$
Mating group x dam breed: year	56	0.0092	272.05	$R(gc{:}y / \mu, y, s{:}y, g{:}y, c, a, yc, ac, b)$
Error	242	0.0119	331.87	$Y'Y - R(\mu, y, s{:}y, g{:}y, c, a, yc, ac, gc{:}y, b)$
Sire x mating group:year	67	0.0109	269.14	$R(sg{:}y / \mu, y, s{:}y, g{:}y, c, a, yc, ac, b)$
Error	232	0.0114	335.64	$Y'Y - R(\mu, y, s{:}y, g{:}y, c, a, yc, ac, sg{:}y, b)$
Sire x age of dam:year	33	0.0095	352.81	$R(sa{:}y / \mu, y, s{:}y, g{:}y, c, a, ya, yc, ac, b)$
Error	257	0.0114	322.26	$Y'Y - R(\mu, y, s{:}y, g{:}y, c, a, ya, yc, ac, sa{:}y, b)$
Sire x dam breed:year	46	0.0115	317.93	$R(sc{:}y / \mu, y, s{:}y, g{:}y, c, a, yc, ac, b)$
Error	251	0.0113	[illegible]	$Y'Y - R(\mu, y, s{:}y, g{:}y, c, a, yc, ac, sc{:}y, b)$

** significant at the 1% level

Table 4.7 Analyses of variance for interactions affecting birthweight (kg) in Friesian-sired male calves from 3- to 9-year-old dams

Source of variation	D.F.	Mean square[1]	Method of obtaining sum of squares
Year x age of dam	8	12.61	$\hat{\beta}' Z^{-1} \hat{\beta}$
Year x dam breed	11	17.22	$\hat{\beta}' Z^{-1} \hat{\beta}$
Age of dam x dam breed	7	13.29	$\hat{\beta}' Z^{-1} \hat{\beta}$
Error		20.11	$Y'Y - R(\mu, y, s{:}y, c, a, ya, yc, ac, b)$
Sire x dam breed:year	50	19.06	$R(sc{:}y / \mu, y, s{:}y, c, a, yc, b)$
Error	250	20.95	$Y'Y - R(\mu, y, s{:}y, c,$ [illegible] $sc{:}y, b)$

[1] All non-significant at the 5% level

Table 4.8 Analyses of variance for interactions affecting pre-weaning growth rate (kg/day) and weaning weight (kg) in Friesian-sired calves from 3- to 9-year-old dams

Source of variation	D F	Mean square[1]		Method of obtaining sum of squares
		Pre-weaning growth rate	Weaning weight	
Year x age of dam	8	0.0073	248.89	$\hat{\beta}' Z^{-1} \hat{\beta}$
Year x dam breed	11	0.0146	386.11	$\hat{\beta}' Z^{-1} \hat{\beta}$
Age of dam x dam breed	7	0.0051	188.14	$\hat{\beta}' Z^{-1} \hat{\beta}$
Error	275	0.0094	360.59	Y'Y-R(μ,y,s:y,g:y,c,a, ya,yc,ac,b)
Sire x mating group:year	65	0.0108	398.12	(sg:y/μ,y,s:y,g:y,c,a yc,b)
Error	219	0.0090	347.12	Y'Y-R(μ,y,s:y.g:y,c,a,yc, sg:y,b)
Mating group x dam breed	55	0.0098	376.91	(gc:y/μ,y,s:y,g:y,c,a yc,b)
Error	99	0.0216	319.87	Y'Y-R(μ,y,s:y,g:y,c,a,yc, gc:y,gc:y,b)
Sire x dam breed:year	50	0.01132	404.22	R(sc:y/μ,y,s:y,g:y, c,a,yc,b)
Error	227	0.0093	359.85	Y'Y-R(μ,y.s:y,g:y,c,a, yc,b)

[1] All non-significant at the 5% level

The absence of other interactions is in agreement with the Angus studies within the same age-of-dam category. As age of dam did not significantly affect birth weight, this factor was excluded from subsequent analyses of that trait.

E. Friesian-sired male calves from 3- to 9-year-old dams

Results from the analyses of variance for interactions affecting birth weight in Table 4.7 and pre-weaning growth rate and weaning weight in Table 4.8 show there to be no significant interactions. As age of dam was non-significant for all three traits, this factor, like the interactions, was excluded from the models for these animals from which estimates of genetic parameters were determined. The finding that age of dam was not important suggests that in terms of maternal ability, the 3-year-old dams were mostly equal to older dams.

Unlike the case for pre-weaning growth rate and weaning weight in Friesian-sired female calves, the males were not influenced by the age-of-dam x dam breed interaction. Therefore, for the Friesian-sired calves, the effect of dam breed was essentially additive over the 3-year, 4-year and 5-year-and-over age-of-dam classes in males, but non-additive in females. The non-significant age-of-dam x dam breed interaction in males was probably largely due to there being a smaller proportion of Angus dams present, as in this breed, the age of dam effect was greatest.

II. Partitioning the Variation in Calf Growth Traits

In the models chosen for the estimation of genetic, environmental and phenotype parameters total variation was partitioned by computing variance components when temporarily regarding all factors, except the regressions (i.e., of birth weight on birth date and of pre-weaning growth rate and weaning weight on age of weaning), as random variables. The percentage of the variation attributable to each factor was then calculated using the formula:

Percentage variance due to the i^{th} factor

$$= PV_i$$

$$= \frac{VC_i}{VC_1 + VC_2 + \dots VC_P + \sigma^2_e} \times \frac{100}{1}$$

where: VC_i = the i^{th} variance component,

P = the number of classified factors fitted in the model i.e. excluding the covariate,

and σ^2_e = error mean square

Coefficients of determination (R^2 values) were calculated independently for the regressions.

The analyses of variance for the models from which genetic, environmental and phenotypic parameters were obtained are shown in Appendix II. The partitioning of the discrete variables, the coefficients of determination for the regressions and the significance levels from the analyses of variance are presented in Table 4.9 for birth weight, Table 4.10 for pre-weaning growth rate and Table 4.11 for weaning weight.

A. Birth weight

Year effects accounted for 2.3% to 8.8% of the variation in birth weight. The Angus- and Friesian-sired calves appeared to be similarly affected by year-to-year fluctuations. For both sire breeds, year effects and total variation were greater for male calves.

In Angus calves, the sire-within-year variance accounted for 9.9% of the variance in males, but was negative in females. In the Friesian breed, sire effects appeared to be mostly small, although irregular when considered over the four Friesian-sired calf populations.

Dam breed was an important factor affecting birth weight in Friesian-sired calves. This factor accounted for 10.8% to 32.9% of the variance, and is probably related to both differences in the genetic ability of the foetus to grow and in the maternal abilities of the dam breeds. Of minor importance were the influences of age of dam and regression on day of birth. Most of the variation in birth weight was unaccounted for.

B. Pre-weaning growth rate

Table 4.10 shows that pre-weaning growth rate of Angus male calves was more variable than that of Angus female calves. The variability of pre-weaning growth rate in Friesian calves was similar for males and females.

Year and sire variances were mostly non-significant and these two factors combined could account for no more than 11% of the variance in any one population.

Age of dam was an important factor affecting the pre-weaning growth of both male and female Angus calves. This factor accounted for 13.3% of the variation in gains of female calves and 17.7% of the variation for male calves and was most probably a reflection of the superior milking ability of the older dams.

Table 4.9 Percentages of the total variances, coefficients of determination and significance levels for factors affecting birth weight (kg)

Sire Breed	Age of dam (years)	No. animals	Year	Sire:year	Dam breed	Age of dam	Error	Total variance (kg)	Coefficient of determination for regression on birth date (R^2 %)
			Independent variables: Percentage of the variance attributable to each factor, $\%\ \text{variance} = \frac{\text{variance component}}{\text{total variance}} \times \frac{100}{1}$						
				Female calves					
Angus	3+	143	3.6	-3.2		5.7	93.91	14.0	3.7*
Friesian	2	114	2.3	-1.9	21.7**		77.98	19.5	5.3**
Friesian	3+	383	2.4*	3.2*	23.8**		70.58	26.0	0.5
				Male calves					
Angus	3+	159	7.2**	9.9**		3.9	79.03	16.5	1.3
Friesian	2	83	8.8	11.2*	10.8*		69.2	32.1	3.9*
Friesian	3+	377	5.7**	0.4	23.9		70.0	29.6	5.3**

* = significant at the 5% level

** = significant at the 1% level

Table 4.10 Percentages of the total variances, coefficients of determination and significance levels for factors affecting pre-weaning growth rate (kg/day)

Sire Breed	Age of dam (years)	No. animals	Year	Sire :year	Mating group :year	Dam Breed	Age of dam	Age of dam x dam breed	Error	Total variance (kg/day)	Coefficient of determination for regression on age at weaning (R^2 %)
			Independent variables								
			Percentage of the variance attributable to each factor: $\% \text{ variance} = \frac{\text{variance component}}{\text{total variance}} \times \frac{100}{1}$								
					Female calves						
Angus	3+	138	1.4	3.4	13.6*		13.3*		68.3	0.0086	5.4*
Friesian	2	102	6.9	-1.4		11.6*			83.1	0.0078	0.1
Friesian	3+	367	2.6*	-2.7	5.0*			9.7**	85.5	0.0131	0.8
					Male calves						
Angus	3+	149	5.1*	5.6			17.7**		71.6	0.0147	2.2
Friesian	2	61	-0.8	11.0	25.5*	7.0			57.0	0.0136	4.0
Friesian	3+	353	5.7**	-0.2	3.6*	19.1**			71.8	0.0134	3.0**

* = significant at the 5% level

** = significant at the 1% level

Table 4.11 Percentages of the total variances, coefficients of determination and significance levels for factors affecting weaning weight (kg)

Sire Breed	Age of dam (years)	No. animals	Year	Sire :year	Mating group :year	Dam breed	Age of dam	Age of dam x dam breed	Error	Total variance (kg)	Coefficient of determination for regression on age at weaning (R^2 %)
			Independent variables								
			Percentage of the variance attributable to each factor $\% \text{ variance} = \frac{\text{variance component}}{\text{total variance}} \times \frac{100}{1}$								
						Female calves					
Angus	3+	138	0.3	4.1	13.0**		21.4**		61.2	305.6	42.9**
Friesian	2	102	10.2*	-0.8		15.6*			75.0	346.7	43.6**
Friesian	3+	367	5.5**	-1.5	3.8*			17.8**	74.4	487.7	39.5**
						Male calves					
Angus	3+	149	3.9	8.1*			14.5**		75.5	537.9	34.[illegible]**
Friesian	2	61	0.4	9.8	26.4*	10.1			54.0	622.2	26.6**
Friesian	3+	353	5.7**	-0.9	2.3	22.4**			70.5	516.5	49.4**

* = significant at the 5% level

** = significant at the 1% level

The most important factors affecting the pre-weaning gains of Friesian-sired calves from 3- to 10-year-old dams were the effect of dam breed in the case of male calves (19.1% of the variance) and the age-of-dam x dam breed effect on female calves (9.7% of the variance). Year effects accounted for 2.6% to 5.7% of the variance in pre-weaning growth rate for Friesian-sired calves from 3- to 10-year-old dams while sire components of variance were negative.

The only significant factors affecting the pre-weaning growth rate of Friesian-sired calves from 2-year-old dams were the effects of dam breed in heifers and mating group within year in steers, which accounted for 11.6% and 25.9% of the associated total variances, respectively.

A large portion of the variation due to dam breed would have arisen from the slower gains of the Friesian-sired calves reared by Angus dams (see least squares means in Appendix III) and was most likely associated with both genetic and maternal effects.

The influence of mating group within year tended to be irregular, but was probably a direct consequence of variations in feed availability from one mating group to another. In the Angus cattle this factor was more important in male rather than in female calves.

Of the total variation in pre-weaning growth rate in the Angus animals, approximately 70% of the variation was unaccounted for. A higher proportion of the variance in the Friesian-sired heifer calves (approximately 84% for all ages of dam) remained unexplained than in steer calves (57% for calves from 2-year-old dams and 71.8% for calves from older dams).

C. Weaning weight

The results from partitioning the variance in weaning weight were largely similar to those from partitioning the variance in pre-weaning growth rate. Coefficients of determination for the regression of weaning weight on age at weaning were high (26.6% to 49.4%) showing the important effect age of calf has on weaning weight. Total variation was greater in male calves than in female calves. This difference was most noticeable in the Angus breed.

III. Heritability Estimates

Heritability estimates were calculated from the sire-within-year and residual variance components presented in Table 4.12. The sire-within-year variance components have large sampling errors while the sampling errors for the residual variance components are relatively small. In the Angus breed sire-within-year variance components are all positive except for the component for birth weight in female calves.

Positive sire-within-year variance components were obtained for birth weight in the Friesian-sired groups with the exception of the negative estimate for the female calves from 2-year-old dams. Negative values for the sire-within-year variances were predominent for pre-weaning growth rate and weaning weight in the Friesian-sired populations, with the only positive values being obtained for these two traits in analyses of male calves from 2-year-old dams.

Error variances in birth weight were greatest for the Friesian-sired calves, and in comparisons between the sire breeds, the bounds specified by the sampling errors tended not to overlap. No distinct breed differences were apparent in the error variances for the other two traits other than that the values obtained for the Friesian-sired calves tended to be more consistent than those for Angus calves.

Table 4.13 contains the heritability estimates and their standard errors, presented for each of the six groups studied. Pooling of estimates was carried out by using the reciprocals of the sampling variances as weighting factors. Estimates pooled across the ages of dam for the Friesian-sired animals and estimates obtained from pooling the sexes within each sire breed, both within the 3- to 10-year age of dam category and for all ages of dam for the Friesian bulls, are shown in Table 4.14.

A. Birth weight

The estimate of 0.44 for the heritability of birth weight using Angus male calf records is identical to the weighted average estimate for this trait given by Petty and Cartwright (1966), but higher than the summary value from Preston and Willis (1974) of 0.38 and the estimate of 0.28 based on New Zealand data for beef-bred calves (Baker et al., 1975).

The negative estimate (-0.14 ± 0.26) obtained for Angus female calves was the only negative estimate from Angus data for the three traits studied. The associated standard error for the latter estimate is large, as are the

Table 4.12 Estimates of sire-within-year ($\hat{\sigma}^2_{s:y}$) and residual ($\hat{\sigma}^2_e$) variance components and sampling errors (SE) of the estimates

Population		Trait											
		Birth weight (kg)				Pre-weaning growth rate (kg/day)				Weaning weight (kg)			
Sire Breed	Age of dam (years)	$\hat{\sigma}^2_{s:y}$	SE	$\hat{\sigma}^2_e$	SE	$\hat{\sigma}^2_{s:y}$	SE	$\hat{\sigma}^2_e$	SE	$\hat{\sigma}^2_{s:y}$	SE	$\hat{\sigma}^2_e$	SE
						Female calves							
Angus	3+	-0.44	0.77	13.11	2.23	0.00030	0.00045	0.00588	0.00087	12.6	15.3	187.1	27.8
Friesian	2	-0.38	0.71	15.19	3.10	-0.00004	0.00032	0.00693	0.00106	-6.0	11.5	285.9	43.7
Friesian	3+	0.82	0.66	18.43	1.61	-0.00036	0.00012	0.01117	0.00088	-7.4	4.3	362.9	25.7
						Male calves							
Angus	3+	1.62	1.33	13.00	2.00	0.00082	0.00084	0.01052	0.00150	43.4	35.4	395.5	56.2
Friesian	2	3.60	4.55	22.21	6.27	0.00150	0.00142	0.00774	0.00178	61.2	59.9	336.3	77.4
Friesian	3+	0.12	0.49	20.69	1.84	-0.00002	0.00019	0.00964	0.00078	-4.6	6.3	363.9	29.5

Table 4.13 Estimates of heritability (h^2) and standard errors (SE) of the estimates obtained within sex of calf, within sire breed and within the 2-year and 3- to 10-year age-of-dam categories

Population		Trait					
Sire Breed	Age of dam (years)	Birth weight		Pre-weaning growth rate		Weaning weight	
		h^2	SE	h^2	SE	h^2	SE
				Female calves			
Angus	3+	-0.14	0.26	0.19	0.30	0.25	0.32
Friesian	2	-0.10	0.23	-0.03	0.20	-0.09	0.17
Friesian	3+	0.17	0.14	-0.13	0.04	-0.09	0.06
				Male calves			
Angus	3+	0.44	0.37	0.29	0.30	0.40	0.32
Friesian	2	0.55	0.77	0.65	0.62	0.62	0.61
Friesian	3+	0.02	0.10	-0.01	0.08	-0.05	0.07

Table 4.14 Pooled estimates of heritability (h^2) and standard errors (SE) of the estimates

Population		Trait					
Sire Breed	Age of dam (years)	Birth weight h^2	Birth weight SE	Pre-weaning growth rate h^2	Pre-weaning growth rate SE	Weaning weight h^2	Weaning weight SE
(1) Pooled within sex of calf for Friesian-sired populations							
Female calves							
Friesian	2+	0.09	0.16	-0.13	0.05	-0.[illegible]	[illegible]
Male calves							
Friesian	2+	0.03	0.11	0.00	0.09	0.04	[illegible]
(2) Pooled within sire breed							
Angus	3+	[illegible]	0.30	0.24	0.30	[illegible]	0.32
Friesian	3+	0.07	0.11	-0.11	0.05	-0.07	0.06
Friesian	2+	0.05	0.13	-0.10	0.05	-0.07	0.07

other standard errors for all heritability estimates in Angus populations. The two estimates for the Angus breed for birth weight combined to give a pooled estimate close to zero.

Birth weight heritabilities for Friesian bulls were variable. The more reliable estimates for the Friesian sire breed are those calculated for the older dams as the standard errors were smaller. Even in the larger calf populations, where a greater number of sires were represented, the standard errors indicated that the estimates were not useful point estimates. Since the comparisons between the estimates for the two sexes of calf show opposite trends for the Friesian sires in the two age-of-dam categories, more useful information comes from the pooled estimates, which show both across age of dam within sex and across sex of calf that the estimates are close to zero.

Vial (1962) reported an estimate of 0.01 for the heritability of birth weight in a small sample of British Friesian cattle which agrees with the estimates obtained in the present work for the Friesian sires. The estimate of Afifi and Soliman (1971) of 0.23 suggests that genetic differences between individuals within the Friesian breed are of similar importance to those genetic differences found in British beef breeds.

B. Pre-weaning growth rate

In the Angus breed the heritability of pre-weaning growth rate was estimated as 0.29 ± 0.30 and 0.19 ± 0.30 for the male and female calves, respectively. These estimates combined to give a pooled estimate of 0.24 which compares favourably with the estimates given by Petty and Cartwright for the paternal half-sib method (0.34), Preston and Willis (1974) (0.27) and the large-scale analyses of Koch et al. (1973) (0.17) and Kennedy and Henderson (1975a)(0.32).

Negative heritability estimates, resulting from the negative sire variance components mentioned earlier, were obtained for the Friesian-sired male calves and the Friesian-sired female calves from 2-year-old dams. A high estimate of 0.65 ± 0.62 for the male progeny of Friesian bulls that were mated to heifers arose from a non-significant sire effect which accounted for 11% of the total variation. The pooled estimates for the Friesian breed approximated zero and were associated with standard errors of less than 0.1.

Literature values for the heritability of pre-weaning growth rate in Friesians are low. Hodges et al. (1961) and Mason et al. (1972) reported respective estimates of 0.12 and 0.20 in quite large samples of this breed and Vial (1962) reported a negative estimate from the records of 148 calves by 16 sires for daily gain from 7- to 84-days of age. Thus, the literature values for the heritability of pre-weaning growth rate in straightbred Friesian cattle are higher (with the exception of that given by Vial) than those obtained in the present study. All estimates for this trait for Friesians, however, do suggest that genetic improvement may be slow.

C. Weaning weight

In the Angus cattle heritability estimates of weaning weight were higher than those for pre-weaning growth, but again, it was higher for male calves (0.40) than for female calves (0.25). The standard errors were of similar size to the heritabilities. The pooled estimate for the Angus breed of 0.33 $\pm$ 0.32 is in very good agreement with the weighted average estimate of 0.32 given by Petty and Cartwright (1966) for the Angus, Hereford and Shorthorn breeds, using the paternal half-sib method, and slightly higher than the New Zealand estimates given by Carter (1971) and Baker et al. (1975) of 0.25 and 0.20, respectively.

For the Friesian bulls, the heritability estimates calculated were almost identical to those for pre-weaning growth rate within each sample as near zero estimates were found apart from the high estimate (0.62 $\pm$ 0.61) for the Friesian-sired male calves from 2-year-old dams. The pooled estimates for Friesian sires are of the range -0.09 to 0.04 with standard errors less than 0.1. The near-zero estimates computed here for the Friesian bulls are lower than all literature values cited in Chapter Two for straightbred Friesian cattle. Vial (1962) and Afifi and Soliman (1971) reported values of 0.18 and 0.55, respectively. Quite large deviations in weaning weight between calves grouped according to sire were noted by Hight et al. (1973) in a reciprocal crossbreeding experiment using data from the same location as those used in this study.

IV. Genetic, Environmental and Phenotypic Correlations

In Table 4.15 the estimates of genetic, environmental and phenotypic correlations are given for each of the six populations studied. As several negative heritability estimates were included in the results, only one genetic correlation for the Friesian bulls and four genetic correlations for the Angus animals were calculated. Where either or both heritability estimates were negative the phenotypic correlations were similar if not identical to the environmental correlations.

Table 4.15 Estimates of genetic (G), environmental[a] (E) and phenotypic[a] (P) correlations and standard errors for the genetic correlations

Population			Correlation		
Sire Breed	Age of dam (years)		Birth weight and pre-weaning growth rate	Birth weight and weaning weight	Pre-weaning growth rate and weaning weight
			Female calves		
Angus	3+	G	b	b	1.06 ± 0.25
		E	0.10	0.49**	0.93**
		P	0.21*	0.40**	0.95**
Friesian	2	G	b	b	b
		E	0.06	0.16	0.95**
		P	0.14	0.26**	0.95**
Friesian	3+	G	b	b	b
		E	0.24**	0.51**	0.86**
		P	0.19**	0.50**	0.85**
			Male calves		
Angus	3+	G	1.06 ± 0.20	1.07 ± 0.11	0.98 ± 0.29
		E	-0.01	0.20*	0.99
		P	0.43**	0.61**	0.98
Friesian	2	G	b	b	0.88 ± 0.29
		E	0.27*	0.14	0.90**
		P	0.07	0.25*	0.89**
Friesian	3+	G	b	b	b
		E	0.18**	0.45**	0.95**
		P	0.20**	0.47**	0.94**

[a] Significance levels test the hypothesis: $r \neq 0$

[b] Genetic correlations were not calculated due to negative sire component

* = significant at the 5% level

** = significant at the 1% level

A. Birth weight and pre-weaning growth rate

The single genetic correlation calculated between birth weight and pre-weaning growth rate was for the male Angus calves. The estimate of 1.06 ± 0.20 suggests that selection for either trait would have a large response in the additive genetic value of the other trait. The correlation is far larger than the weighted average estimate of 0.38 given by Petty and Cartwright (1966) and the estimates of 0.10 for females and 0.28 for males for Herefords in Nebraska given by Koch et al. (1973).

While one small non-significant negative environmental correlation was found for the Angus male calves (-0.01) all other environmental correlations for the two sire breeds were positive and ranged from 0.06 to 0.27. Phenotypic correlations were also all positive (0.07 to 0.43). Phenotypic correlations between birth weight and pre-weaning growth rate were highest in the Angus breed, particularly for males where a high genetic correlation was present between the two moderately heritable traits.

The phenotypic correlations between birth weight and pre-weaning growth rate in this investigation are in accord with the estimates given in Chapter Two for British beef breeds.

B. Birth weight and weaning weight

The only estimate of the genetic correlation between these two traits was calculated for Angus bulls that sired male calves. The estimate was high (1.07 ± 0.11) and very close to the genetic correlation found between birth weight and pre-weaning growth rate for the same animals. The estimate obtained here is considerably larger than those of Vesley and Robison (1971), Koch et al. (1973) and the weighted average of Petty and Cartwright (1966) which all covered the range of 0.41 to 0.58. Dunn et al. (1970) reported high estimates of 0.84 for female calves and 0.91 for males.

The environmental correlations between birth weight and weaning weight ranged from 0.14 to 0.50. The lowest estimates were for the Friesian-sired calves from 2-year-old dams and were non-significant. The larger values for the Friesian-sired and Angus calves from older dams ranged from 0.20 to 0.51 and were significantly different from zero.

Estimates of phenotypic correlations between birth weight and weaning weight for both sire breeds where calves were from 3- to 10-year-old dams were of similar order ranging from 0.47 to 0.61. The highest phenotypic correlation was for Angus male calves and was associated with the high genetic correlation between these traits. Lower phenotypic correlations were found for Friesian-sired calves from 2-year-old dams of 0.26 for males and 0.25 for females.

Phenotypic correlations between birth weight and weaning weight were therefore larger than those between birth weight and pre-weaning growth rate. The weighted average phenotypic correlation between birth weight and weaning weight given by Petty and Cartwright (1966) and the estimates of Dunn et al. (1970), Vesley and Robison (1971) and Koch et al. (1973) were all within the range of 0.35 to 0.64. The estimates obtained in this present study were therefore in good agreement with the values given by these authors.

C. Pre-weaning growth rate and weaning weight

The genetic correlations between these traits were 1.06 ± 0.25 and 0.98 ± 0.29 for Angus females and males, respectively. A lower estimate was obtained from the Friesian-sired male calves from 2-year-old dams (0.88 ± 0.29). The environmental and phenotypic correlations between gain from birth to weaning and weaning weight fell between 0.85 and 0.[illegible] and were all significantly different from zero.

These genetic, environmental and phenotypic correlation estimates [illegible] in agreement with those literature values presented in Chapter Two and also indicate that selection for one of these traits would be associated with a large correlated response in the other, provided both traits are sufficiently heritable.

V. Cow - calf Weight Relationships

a. The regression of birth weight on dam post-calving liveweight

Results for the regression of birth weight on dam post-calving liveweight in straightbred Friesian and straightbred Angus cattle are shown in Table 4.16. Relationships were computed first when all calves born were included and second when only those calves that had weaning records were included. The regressions were homogeneous over the age of dam - years with the exception that in the female Friesian calf study when only those calves weaned were considered. In this exceptional case, an examination of the within-class regression coefficients revealed that when averaged over years the regressions were positive in all age of dam classes, but higher for 2-year-old dams and highest for 3-year-old dams. The regression coefficients tended to fluctuate from year to year.

The pooled regression coefficients of birth weight on dam post-calving

Table 4.16 Results from the regression of birth weight on dam post-calving liveweight

Population	Calf sex	No. cow - calf pairs	Test for homogeneity (Significance levels[1])	Pooled regression: Regression coefficient (kg/10 kg)	Pooled regression: Coefficient of determination (R^2 %)
			Angus cows and calves		
A	Male	182	NS	0.11	0.6
A	Female	158	NS	0.07	0.3
B	Male	166	NS	0.10	0.5
B	Female	153	NS	0.06	0.2
			Friesian cows and calves		
A	Male	213	NS	0.47**	13.5
A	Female	191	NS	0.36**	12.0
B	Male	170	NS	0.38**	9.5
B	Female	161	*	0.37**	14.5

1 Significance indicates the regression to be heterogeneous over the age of dam-years

* = significant at the 5% level

NS = not significant

A = all calves born

B = those calves that had both birth and weaning records liveweight were seen to change very little when those animals without weaning records were included. Marked breed differences for this relationship were present as the pooled regressions showed larger, highly significant associations in Friesians and non-significant smaller associations in the Angus breed. These findings indicate that heavier Friesian dams gave birth to heavier calves such that for every 10 kg difference in dam post-calving liveweight there was about a 0.4 kg difference in birth weight, while lighter and heavier Angus dams gave birth to calves of more similar weights. The results show that every 10 kg increase in the post-calving liveweight of Angus cows was associated with about a 0.1 kg increase in the birth weight of straightbred Angus calves.

The coefficients of determination in Table 4.16 show quite clearly that dam liveweight differences could account for less of the variation in birth weight in Angus calves ($< 1\%$) than in Friesian calves (9.50 to 14.54%).

These findings for the Friesian breed are in good agreement with O'Conner et al. (1968) who reported a 0.34 kg increase in birth weight per 10 kg increase in cow liveweight in Friesians and Afifi and Soliman (1971) who calculated a correlation between the two characters of 0.41, also in Friesians.

The results obtained here for the Angus breed indicate, that dam post-calving liveweight and birth weight were not as closely related as they were in other studies of Angus cattle. O'Mary and Hillers (1976) reported a correlation between dam liveweight and birth weight of 0.34 in a small number of Angus animals. Bellows et al. (1971) found a comparable correlation of 0.42 for first-calving 2-year-old Angus dams. The correlation and regression estimates for this relationship for the British beef breeds in Chapter Two in general indicate that dam liveweight and calf birth weight are more frequently more closely related than they were in the present study. However, it is likely that if cows are all in similar body condition then the relationships between dam liveweight and calf birth weight would be smaller than if cows were more variable in body condition. This factor may in part account for some of the variability in the associations shown in Chapter Two and the negligible portion of the variation in birth weight that could be explained by dam liveweight for the Angus breed in this present investigation.

3. The regressions of weaning weight on dam post-calving liveweight and weaning weight on dam liveweight at weaning

Included in Table 4.17 are the results from the regressions of weaning weight on dam post-calving liveweight and of weaning weight on dam liveweight at weaning. The regression coefficients were all homogeneous over the age of dam-years apart from the regression of weaning weight on dam post-calving liveweight for Angus male calves. In the exceptional case the regression was large and positive for 3-year-old dams, consistently small and positive for the older dams and variable from year-to-year in 2-year-old dams but with small negative coefficients being more frequent.

The pooled regression coefficients for each sex of calf in both the Friesian and Angus breeds show that the relationships were similar for the two dam liveweights. For the Angus animals the regressions were significant for male calves, but not for female calves. In the Angus breed dam post-calving liveweight and dam liveweight at weaning could account for 6.6% and 3.1% of the variation in weaning weight of male calves, respectively. The lower pooled regression for the Angus male calves using dam liveweight at weaning suggests there was a small negative relationship between the weight gains of the Angus cows and the gains of male calves from calving to weaning. Dam liveweights could account for less than 1% of the variation in weaning weight of Friesian calves.

The relationships between weaning weight and dam liveweight in Angus animals show that every 10 kg increase in post-calving liveweight of Angus cows would be associated with small increases in weaning weight of male calves of the order of 0.4 to 0.5 kg, depending on which dam liveweight was used. There was also an indication that the relationship for Angus male calves was closest for 3-year-old dams. The weaning weight of Angus female calves was not significantly related to dam liveweight.

Tanner *et al.* (1965) found a 0.85 kg increase in weaning weight in Angus calves per 10 kg increase in dam liveweight. Other published regression estimates for this relationship in Chapter Two, most of which have been obtained for Hereford cattle, show 0.44 to 1.18 kg increases in weaning weight per 10 kg increases in dam liveweight. Therefore, while there was good agreement in the present study for Angus male calves, the low estimates for Angus female calves were different from the literature values. However, as shown in the review of literature relating to Hereford cattle, in addition to the regression relationships a number of workers have calculated near zero correlations between calf weaning weight and dam liveweight (Gregory *et al.*, 1950; Brinks *et al.*, 1962; Singh *et al.*, 1970) while

Table 4.17 Regressions of calf weaning weight on dam post-calving liveweight and on dam liveweight at weaning

Breed	Calf sex	No. cow-calf pairs	Test for homogeneity (significance levels[1])	Pooled regression: Regression coefficient (kg/10 kg)	Pooled regression: Coefficient of determination (R^2 %)
			I. The regression of calf weaning weight on dam post-calving liveweight		
Angus	Female	153	NS	-0.06	0.2
Angus	Male	166	*	0.53*	6.6
Friesian	Female	161	NS	0.10*	0.3
Friesian	Male	170	NS	-0.06	0.1
			II. The regression of calf weaning weight on dam liveweight at weaning		
Angus	Female	153	NS	-0.01	< 0.1
Angus	Male	164	NS	0.36*	8.1
Friesian	Female	159	NS	0.10	0.3
Friesian	Male	168	NS	-0.04	< 0.1

1 Significance indicates the regression to be heterogeneous over the age-of-dam-years

NS = not significant

* = significant at the 5% level

others have reported this correlation to be low to medium (O'Mary et al., 1959; Tanner et al., 1965; Jeffery et al., 1971).

The findings for the Friesians that post-calving liveweight was positively associated with calf birth weight, but not related to calf weaning weight suggests that there was a negative relationship between cow liveweight and pre-weaning growth rate. In the Angus breed the absence of a significant association of dam post-calving liveweight with birth weight, but a significant positive association with weaning weight in male calves suggests that pre-weaning growth rate in males was positively associated with cow liveweight. Despite the large liveweight changes that occur in Angus cows between calving and weaning, the relationships between weaning weight and dam post-calving liveweight, and weaning weight and dam liveweight at weaning were essentially the same.

CHAPTER FIVE

CONCLUDING DISCUSSION

Knowledge of the genetic parameters for productive traits is required for beef animals used under New Zealand conditions. While there is a small amount of information of this nature based on New Zealand data for British beef breeds, there is a need for further estimates. Consideration must also be made of the genetic parameters where other breeds of cattle are being used as straightbreds or in crossing programmes. The analyses reported here were conducted with the prime objective of calculating estimates of the heritabilities of and genetic and phenotypic correlations among birth weight, pre-weaning growth rate and weaning weight in straightbred Angus- and Friesian-sired calves using the sire and residual components of variance and covariance. The dams to which the Friesian bulls were mated were predominately high milk-producing Friesian and Friesian-cross types with a small number of straightbred Angus individuals.

Using records from the straightbred Angus male calves, the [illegible] estimates of the heritabilities of birth weight, pre-weaning growth rate and weaning weight were in very good agreement with overseas literature values (mostly American) and slightly higher than published estimates from analyses of data collected in New Zealand. The heritability of birth weight for Angus female calves was negative but low and moderate estimates were determined for pre-weaning growth rate and weaning weight, respectively. In the Angus breed large standard errors could account for the differences between the estimates for the two calf sexes. The estimates of heritability for the Angus breed reported here are not in agreement with those studies which suggest that heritabilities for calf growth traits are higher for the female sex. Pooling calf sexes, heritability estimates for the Angus individials were 0.05, 0.24 and 0.32 for birth weight, pre-weaning growth rate and weaning weight, respectively, and were associated with standard errors of the order of 0.3, thereby placing little reliability on these estimates.

Published estimates of the heritabilities of calf growth rates in Friesians are few and tend to be highly variable. The findings of some workers who studied straightbred Friesian cattle (Afifi and Soliman, 1971; Mason et al., 1972), and others working with calves from Angus-Holstein dams and sired by Hereford bulls (Stout et al., 1970; Wilson et al., 1976), leave no reason to suspect that heritabilities of calf growth traits are any different where calves are from high milk-producing dairy x beef or dairy dams than those obtained from British beef breeds. In disagreement are the findings reported by Vial (1962) and Hodges et al. (1961). The pooled estimates for the Friesian-sired calves in this study were near zero for all three traits and suggest that genetic improvement would be very slow. As the bulk of evidence suggests that maternal effects do not affect the expression of sire effects on calf performance and as large sire effects on offspring performance at various stages have frequently been observed using Friesian bulls (Afifi and Soliman, 1971; Mason et al., 1972; Hight et al., 1973; Dalton et al., 1975; Everitt et al., 1975) then the estimates calculated here for Friesians may have been biased downward because of sampling errors, and possibly from intentional selection for milking ability.

The genetic correlations between traits with positive heritabilities were all close to the theoretical upper limit of one. Those between pre-weaning growth rate and weaning weight were therefore similar to literature values for this relationship. The genetic correlations between birth weight and pre-weaning growth rate and birth weight and weaning weight were far higher than most published estimates. The standard errors for the genetic correlations were large. Nevertheless, there was no suggestion of genetic antagonisms. In so far as birth weight and pre-weaning growth rate are concerned - both partly a measure of the inherent ability of the pre- and post-natal young to respond to feeding - then it could be expected that many of the same genes would affect both characters.

The non-significance of interactions of sire within year with mating group within year and, in all but one exceptional case where bias was suspected, the absence of sire x age of dam within-year interactions indicate that genotype-environment interactions of these kinds were not occurring. Interactions of sire within year by dam breed were also non-significant, which is consistent with a majority of other reports outlined in the review of literature, which have suggested that differences of specific combining ability in birth weight, pre-weaning growth rate and weaning weight are small.

Conclusive information on genetic parameters for beef cattle in New Zealand requires that further investigations be documented, particularly for crossbreeding systems, as it is likely that these will play an important role in the future. The heritability estimates presented in this thesis should be considered in conjunction with the estimates of other workers. The genetic and environmental parameters reported here provide information on only a few of the many productive traits of beef cattle, and more specifically, the heritabilities only account for individual and not maternal effects on calf growth. Consideration of genetic and environmental parameters of all the productive traits of beef cattle is necessary before optimal selection schemes can be developed.

A second part of this thesis was concerned with the relationships between cow and calf liveweights. The results showed that birth weight was significantly related to dam post-calving liveweight in straightbred Friesian but not in straightbred Angus cattle. The regression relationships indicated that for every 10 kg increase in dam post-calving liveweight, birth weight in Friesian calves was increased by approximately 0.4 kg. In the same breed, dam liveweight was not related to weaning weight. In Angus male calves small, but significant, associations were found between weaning weight and dam liveweights. No similar relationships were found for female calves. For both breeds, where positive relationships were calculated, there was some evidence that cow - calf weight relationships were highest for 3-year-old dams. As the cows were fed alike, the effects of cow liveweight reported here should be a reasonable indication of the effect of mature cow size.

TABLE I.1 Analyses of variance to test the significance of the effect of post-calving nutritional treatments on pre-weaning growth rate (kg/day) in years 1972 and 1973

Population		1972				1973			
Sire Breed	Age of dam (years)	Treatments		Error		Treatments		Error	
		DF	Mean square[1]	DF	Mean square	DF	Mean square[1]	DF	Mean square
Female calves									
Angus	2+	3	0.0035	22	0.0027	3	0.0088	22	0.0050
Friesian	2	3	0.0052	25	0.0045				
Friesian	3+	2	0.0000	71	0.0127	3	0.0187	65	0.0191
Male calves									
Angus	2+	3	0.0035	24	0.0174	3	0.0007	28	0.0076
Friesian	2	2	0.0011	14	0.0062				
Friesian	3+	3	0.0038	71	0.0168	3	0.0111	65	0.0074

1 All non-significant at the 5% level

TABLE I.2 Analyses of variance [illegible] treatments on weaning weight (kg) in years 1972 and 1973

Population		1972				1973			
		Treatments		Error		Treatments		Error	
Sire Breed	Age of dam (years)	DF	Mean square[1]	DF	Mean square	DF	Mean square[1]	DF	Mean square
Female calves									
Angus	2+	3	117.2	22	81.4	3	272.1	22	203.4
Friesian	2	3	436.7	25	438.2				
Friesian	3+	3	306.2	71	551.3	3	293.7	65	283.0
Male calves									
Angus	2+	3	96.7	24	572.5	3	305.4	28	305.3
Friesian	2	2	789.1	14	567.3				
Friesian	3+	3	155.7	71	596.9	3	410.2	65	254.0

1 All non-significant at the 5% level

APPENDIX II

In this appendix 18 tables are presented where the analyses of variance are shown for the models used to estimate genetic and environmental parameters. The excess number of digits in the mean squares have not been suppressed.

The following significance levels appear :

NS	=	0.1	<	P		
(NS)	=	0.05	<	P	<	0.1
*	=	0.01	<	P	<	0.05
**	=	0.005	<	P	<	0.01
***	=	0.001	<	P	<	0.005
****	=			P	<	0.001

TABLE 1 : ANGUS FEMALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT(KG)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	25.742332 NS	1.96	P=0.1034
SIRES/YEAR 1	3	12.100001		
SIRES/YEAR 2	3	9.247929		
SIRES/YEAR 3	3	2.785267		
SIRES/YEAR 4	3	4.173330		
SIRES/YEAR 5	2	18.407105		
SIRE/YEAR	14	8.796109 NS	0.67	P=0.7993
DAM AGE	2	30.822537(NS)	2.35	P=0.0976
REG. DAY OF BIRTH	1	71.955782 *	5.49	P=0.0196
ERROR	121	13.112537		

NO. ANIMALS	143	COVARIATE:	
MEAN	26.36	MEAN	256.78
S.D.	3.78	S.D.	21.08

TABLE 2 :   ANGUS FEMALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PRE-WEANING GROWTH RATE(KG/DAY)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	0.008581 NS	1.46	P=0.2189
SIRES/YEAR 1	3	0.001189		
SIRES/YEAR 2	3	0.009151		
SIRES/YEAR 3	3	0.012009		
SIRES/YEAR 4	3	0.006099		
SIRES/YEAR 5	2	0.006185		
SIRE/YEAR	14	0.007677 NS	1.31	P=0.2166
MATING GP/YEAR 1	5	0.012405		
MATING GP/YEAR 2	3	0.007663		
MATING GP/YEAR 3	3	0.016637		
MATING GP/YEAR 4	2	0.011194		
MATING GP/YEAR 5	2	0.014414		
MATING GROUP/YEAR	15	0.012725 *	2.17	P=0.0123
DAM AGE	2	0.025464 *	4.33	P=0.0154
REG.AGE AT WEANING	1	0.055927 ***	9.52	P=0.0030
ERROR	101	0.005877		

NO. ANIMALS	138	COVARIATE:	
MEAN	0.72	MEAN	171.31
S.D.	0.09	S.D.	21.23

TABLE 3 : ANGUS FEMALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING WEANING WEIGHT(KG)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	204.106090 NS	1.09	P=0.3654
SIRES/YEAR 1	3	5.724494		
SIRES/YEAR 2	3	325.138069		
SIRES/YEAR 3	3	512.572276		
SIRES/YEAR 4	3	192.907339		
SIRES/YEAR 5	2	255.553619		
SIRE/YEAR	14	263.944899 NS	1.41	P=0.1618
MATING GP/YEAR 1	5	437.532312		
MATING GP/YEAR 2	3	238.328904		
MATING GP/YEAR 3	3	771.925495		
MATING GP/YEAR 4	2	243.024535		
MATING GP/YEAR 5	2	264.676931		
MATING GROUP/YEAR	15	419.471785 **	2.24	P=0.0094
DAM AGE	2	1304.583254 ***	6.97	P=0.0018
REG AGE AT WEANING	1	24296.307032****	129.84	P=0.0000
ERROR	101	187.113828		

NO. ANIMALS 138

MEAN 150.59

S.D. 25.25

COVARIATE:

MEAN 171.31

S.D. 21.23

TABLE 4 : ANGUS MALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT(KG)

SOURCE	DF	MEAN SQUARE		F	PROBABILITY
YEAR	4	45.170146	**	3.47	P=0.0100
SIRES/YEAR 1	3	13.655244			
SIRES/YEAR 2	3	44.278705			
SIRES/YEAR 3	3	55.553148			
SIRES/YEAR 4	3	22.160964			
SIRES/YEAR 5	2	16.972029			
SIRE/YEAR	14	30.663677	**	2.35	P=0.0061
DAM AGE	2	28.672872	NS	2.20	P=0.1124
REG. DAY OF BIRTH	1	33.363195	NS	2.56	P=0.1077
ERROR	137	13.021441			

NO. ANIMALS 159

MEAN 28.31

S.D. 3.98

COVARIATE:

MEAN 254.90

S.D. 21.52

TABLE 5 : ANGUS MALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PRE-WEANING GROWTH RATE(KG/DAY)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	0.028411 *	2.70	P=0.0330
SIRES/YEAR 1	3	0.015465		
SIRES/YEAR 2	3	0.038317		
SIRES/YEAR 3	3	0.007727		
SIRES/YEAR 4	3	0.004283		
SIRES/YEAR 5	2	0.023191		
SIRE/YEAR	14	0.016645(NS)	1.58	P=0.0926
DAM AGE	2	0.067153 ***	6.38	P=0.0027
REG AGE AT WEANING	1	0.040055(NS)	3.81	P=0.0502
ERROR	127	0.010520		

NO. ANIMALS	149	COVARIATE:	
MEAN	0.77	MEAN	174.89
S.D.	0.11	S.D.	21.35

TABLE 6 : ANGUS MALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING WEANING WEIGHT(KG)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	903.376966(NS)	2.28	P=0.0630
SIRES/YEAR 1	3	613.705713		
SIRES/YEAR 2	3	1445.177635		
SIRES/YEAR 3	3	569.257569		
SIRES/YEAR 4	3	151.518842		
SIRES/YEAR 5	2	1036.215069		
SIRE/YEAR	14	720.781177 *	1.82	P=0.0416
DAM AGE	2	2120.130905 **	5.36	P=0.0061
REG AGE AT WEANING	1	36507.067597****	92.31	P=0.0000
ERROR	127	395.485416		

NO. ANIMALS	149	COVARIATE:	
MEAN	163.47	MEAN	174.89
S.D.	29.24	S.D.	21.35

TABLE 7 : FRIESIAN-SIRED FEMALE CALVES OF 2-YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT(KG)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	22.856297 NS	1.51	P=0.2053
SIRES/YEAR 1	1	5.017942		
SIRES/YEAR 2	1	6.017557		
SIRES/YEAR 3	1	7.505023		
SIRES/YEAR 4	1	3.034861		
SIRES/YEAR 5	1	12.616079		
SIRE/YEAR	5	6.920005 NS	0.46	P=0.8098
DAM BREED	3	99.712766****	6.57	P=0.0007
REG. DAY OF BIRTH	1	109.582305 **	7.22	P=0.0084
ERROR	100	15.186249		

NO. ANIMALS 114		COVARIATE:	
MEAN	30.99	MEAN	236.11
S.D.	4.26	S.D.	24.09

TABLE 8 : FRIESIAN-SIRED FEMALE CALVES OF 2-YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PRE-WEANING GROWTH RATE(KG/DAY)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	[illegible]	0.0100[illegible] NS	1.57	P=0.1[illegible]
SIRES/YEAR 1	1	0.001[illegible]		
SIRES/YEAR 2	[illegible]	0.016[illegible]1		
SIRES/YEAR 3	[illegible]	0.007211		
SIRES/YEAR 4	1	0.001774		
SIRES/YEAR 5	[illegible]	0.005044		
SIRE/YEAR	5	0.006566 NS	0.95	P=0.5429
DAM BREED	3	0.020472 *	2.96	P=0.0376
MATING GROUP/YEAR	19	0.005061 NS	0.73	P=0.7753
MATING GP/YEAR 1	3	0.002472		
MATING GP/YEAR 2	4	0.006762		
MATING GP/YEAR 3	3	0.006048		
MATING GP/YEAR 4	4	0.008022		
MATING GP/YEAR 5	5	0.001934		
REG AGE AT WEANING	1	0.000397 NS	0.06	P=0.8067
ERROR	69	0.006926		

NO. ANIMALS 102

MEAN 0.75

S.D. 0.0[illegible]

COVARIATE:

MEAN 191.86

S.D. 23.31

TABLE 9 : FRIESIAN-SIRED FEMALE CALVES OF 2-YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING WEANING WEIGHT(KG)

SOURCE	DF	MEAN SQUARE		F	PROBABILITY
YEAR	4	722.310072	*	2.53	P=0.0477
SIRES/YEAR 1	1	30.943406			
SIRES/YEAR 2	1	446.569027			
SIRES/YEAR 3	1	428.007148			
SIRES/YEAR 4	1	9.634876			
SIRES/YEAR 5	1	276.334505			
SIRE/YEAR	5	236.194026	NS	0.83	P=0.5369
DAM BREED	3	1162.563763	*	4.07	P=0.0102
MATING GROUP/YEAR	19	193.105116	NS	0.66	P=0.8302
MATING GP/YEAR 1	3	179.319615			
MATING GP/YEAR 2	4	193.630499			
MATING GP/YEAR 3	3	115.685536			
MATING GP/YEAR 4	4	285.321422			
MATING GP/YEAR 5	5	158.472200			
REG AGE AT WEANING	1	21135.723172	****	73.92	P=0.0000
ERROR	69	285.931155			

NO. ANIMALS	102	COVARIATE:	
MEAN	180.99	MEAN	191.86
S.D.	26.24	S.D.	23.31

TABLE 10: FRIESIAN-SIRED MALE CALVES OF 2-YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT(KG)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	44.709200 NS	2.01	P=0.1017
SIRES/YEAR 1	1	49.110456		
SIRES/YEAR 2	1	75.584152		
SIRES/YEAR 3	2	99.122879		
SIRES/YEAR 4	1	0.723245		
SIRES/YEAR 5	1	9.293428		
SIRE/YEAR	6	60.745236 *	2.73	P=0.0193
DAM BREED	4	59.534352 *	2.68	P=0.0383
REG. DAY OF BIRTH	1	92.999048 *	4.19	P=0.0421
ERROR	67	22.214463		

NO. ANIMALS	83	COVARIATE:	
MEAN	33.90	MEAN	238.55
S.D.	5.16	S.D.	26.83

TABLE 11 : FRIESIAN-SIRED MALE CALVES OF 2-YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PRE-WEANING GROWTH RATE(KG/DAY)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	0.007033 NS	0.91	P=0.5272
SIRES/YEAR 1	1	0.0012[illegible]		
SIRES/YEAR 2	1	0.048500		
SIRES/YEAR 3	1	0.000161		
SIRES/YEAR 4	1	0.009571		
SIRES/YEAR 5	1	0.010522		
SIRE/YEAR	5	0.013269 NS	1.72	P=0.1596
MATING GP/YEAR 1	2	0.004450		
MATING GP/YEAR 2	4	0.031546		
MATING GP/YEAR 3	3	0.005236		
MATING GP/YEAR 4	4	0.014423		
MATING GP/YEAR 5	3	0.011011		
MATING GROUP/YEAR	16	0.015763 *	2.04	P=0.0433
DAM BREED	3	0.015164 NS	1.96	P=0.1392
REG AGE AT WEANING	1	0.016871 NS	2.18	P=0.1465
ERROR	31	0.007742		

NO. ANIMALS	61	COVARIATE:	
MEAN	0.83	MEAN	191.31
S.D.	0.12	S.D.	25.46

TABLE 12: FRIESIAN-SIRED MALE CALVES OF 2-YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING WEANING WEIGHT(KG)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	319.402173 NS	0.95	P=0.5499
SIRES/YEAR 1	1	97.982670		
SIRES/YEAR 2	1	1052.518058		
SIRES/YEAR 3	1	378.680862		
SIRES/YEAR 4	1	265.052129		
SIRES/YEAR 5	1	152.922968		
SIRE/YEAR	5	563.018562 NS	1.67	P=0.1697
MATING GP/YEAR 1	2	289.916840		
MATING GP/YEAR 2	4	1466.585293		
MATING GP/YEAR 3	3	163.774944		
MATING GP/YEAR 4	4	639.714798		
MATING GP/YEAR 5	3	473.652973		
MATING GROUP/YEAR	16	712.744827 *	2.12	P=0.0354
DAM BREED	3	631.898810(NS)	2.47	P=0.0790
REG AGE AT WEANING	1	10280.534455****	30.57	P=0.0000
ERROR	31	336.275516		

NO. ANIMALS	61	COVARIATE:	
MEAN	192.34	MEAN	191.31
S.D.	34.71	S.D.	25.46

TABLE 13 : FRIESIAN-SIRED FEMALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT(KG)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	59.160060 *	3.21	P=0.0131
SIRES/YEAR 1	3	8.166296		
SIRES/YEAR 2	3	52.925666		
SIRES/YEAR 3	4	56.304661		
SIRES/YEAR 4	3	61.184115		
SIRES/YEAR 5	4	6.238062		
SIRE/YEAR	17	36.376033 *	1.97	P=0.0122
DAM BREED	4	391.506102****	21.24	P=0.0000
DAM AGE	2	13.994173 NS	0.76	P=0.5270
REG. DAY OF BIRTH	1	48.731498 NS	2.64	P=0.1007
ERROR	354	18.430405		

NO. ANIMALS	383	COVARIATE:	
MEAN	31.73	MEAN	254.70
S.D.	4.99	S.D.	21.98

TABLE 14 : FRIESIAN-SIRED FEMALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PRE-WEANING GROWTH RATE(KG/DAY)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	0.029049 *	2.60	P=0.0356
SIRES/YEAR 1	3	0.008665		
SIRES/YEAR 2	3	0.005400		
SIRES/YEAR 3	4	0.004861		
SIRES/YEAR 4	3	0.011359		
SIRES/YEAR 5	4	0.000901		
SIRE/YEAR	17	0.005838 NS	0.52	P=0.9414
DAM AGE/DAM BREED	12	0.040214****	3.60	P=0.0001
MATING GP/YEAR 1	6	0.010450		
MATING GP/YEAR 2	4	0.041639		
MATING GP/YEAR 3	3	0.007671		
MATING GP/YEAR 4	4	0.043579		
MATING GP/YEAR 5	6	0.001689		
MATING GROUP/YEAR	23	0.019012 *	1.70	P=0.0248
REG AGE AT WEANING	1	0.037470(NS)	3.35	P=0.0645
ERROR	309	0.011174		

NO. ANIMALS	367	COVARIATE:	
MEAN	0.83	MEAN	172.69
S.D.	0.11	S.D.	22.10

TABLE 15 : FRIESIAN-SIRED FEMALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING WEANING WEIGHT(KG)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	1765.032774****	5.[illegible]0	P=0.000[illegible]
SIRES/YEAR 1	3	167.951352		
SIRES/YEAR 2	3	360.952792		
SIRES/YEAR 3	4	302.004304		
SIRES/YEAR 4	3	249.067964		
SIRES/YEAR 5	4	36.127839		
SIRE/YEAR	17	216.170653 NS	0.66	P=0.8403
DAM AGE/DAM BREED	12	2311.211287****	7.07	P=0.0000
MATING GP/YEAR 1	6	400.140860		
MATING GP/YEAR 2	4	1252.215516		
MATING GP/YEAR 3	3	282.356401		
MATING GP/YEAR 4	4	959.542699		
MATING GP/YEAR 5	6	94.130994		
MATING GROUP/YEAR	23	546.161541 *	1.67	P=0.0290
REG AGE AT WEANING	1	99161.184546****	303.37	P=0.0000
ERROR	309	326.865825		

NO. ANIMALS 367

MEAN 175.42

S.D. 28.46

COVARIATE:

MEAN 172.69

S.D. 22.10

TABLE 16: FRIESIAN-SIRED MALE CALVES OF 3-10 YEAR OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT(KG)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	132.922633****	6.42	P=0.0002
SIRES/YEAR 1	3	20.825680		
SIRES/YEAR 2	3	35.659946		
SIRES/YEAR 3	4	25.145450		
SIRES/YEAR 4	3	26.913419		
SIRES/YEAR 5	4	10.430313		
SIRE/YEAR	17	23.199452 NS	1.12	P=0.3309
DAM BREED	4	467.035053****	22.57	P=0.0000
REG. DAY OF BIRTH	1	113.638669 *	5.49	P=0.0186
ERROR	350	20.694579		

NO. ANIMALS	377	COVARIATE:	
MEAN	34.94	MEAN	257.58
S.D.	5.27	S.D.	23.66

TABLE 17 : FRIESIAN-SIRED MALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PRE-WEANING GROWTH RATE(KG/DAY)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	0.050568****	5.25	P=0.0007
SIRES/YEAR 1	3	0.017387		
SIRES/YEAR 2	3	0.002605		
SIRES/YEAR 3	4	0.011118		
SIRES/YEAR 4	3	0.003674		
SIRES/YEAR 5	4	0.010387		
SIRE/YEAR	17	0.009331 NS	0.97	P=0.5053
MATING GP/YEAR 1	6	0.016064		
MATING GP/YEAR 2	4	0.015895		
MATING GP/YEAR 3	3	0.037238		
MATING GP/YEAR 4	4	0.014466		
MATING GP/YEAR 5	6	0.003763		
MATING GROUP/YEAR	23	0.015221 *	1.58	P=0.0464
DAM BREED	4	0.147375****	15.29	P=0.0000
REG AGE AT WEANING	1	0.130739****	13.56	P=0.0005
ERROR	303	0.009640		

NO. ANIMALS	353	COVARIATE:	
MEAN	0.89	MEAN	169.31
S.D.	0.11	S.D.	24.07

TABLE 18: FRIESIAN-SIRED MALE CALVES OF 3-10 YEAR-OLD DAMS

ANALYSIS OF VARIANCE FOR FACTORS AFFECTING WEANING WEIGHT(KG)

SOURCE	DF	MEAN SQUARE	F	PROBABILITY
YEAR	4	1943.057326****	5.34	P=0.0006
SIRES/YEAR 1	3	343.144988		
SIRES/YEAR 2	3	154.996032		
SIRES/YEAR 3	4	577.042961		
SIRES/YEAR 4	3	5.572767		
SIRES/YEAR 5	4	294.517052		
SIRE/YEAR	17	296.908528 NS	0.82	P=0.6755
MATING GP/YEAR 1	6	439.087512		
MATING GP/YEAR 2	4	476.155378		
MATING GP/YEAR 3	3	1259.058584		
MATING GP/YEAR 4	4	439.092867		
MATING GP/YEAR 5	6	249.138436		
MATING GROUP/YEAR	23	500.117365 NS	1.37	P=0.1205
DAM BREED	4	6584.021532****	18.09	P=0.0000
REG AGE AT WEANING	1	156940.107007****	431.24	P=0.0000
ERROR	303	363.930833		

NO. ANIMALS	353	COVARIATE:	
MEAN	186.73	MEAN	169.31
S.D.	33.76	S.D.	24.07

APPENDIX III

TABLE III.1 Least squares means[1] for birth weight (kg) according to sire breed, dam breed, calf sex and age of dam

Sire breed	Dam[2] breed	Age of dam (years) 2	3	4	≥ 5	≥ 3
		Female calves				
A	A		24.8 ± 0.9	24.9 ± 1.0	26.6 ± 0.4	
F	F	32.3 ± 0.6				33.8 ± 0.4
F	FxJ					33.1 ± 0.5
F	Fx(FxJ)	31.6 ± 0.8				33.3 ± 0.9
F	A	24.5 ± 1.8				29.0 ± 0.5
F	FxA	29.2 ± 0.9				29.8 ± 0.9
		Male calves				
A	A		26.2 ± 1.2	29.2 ± 0.8	28.3 ± 0.4	
F	F	36.5 ± 1.0				36.9 ± 0.4
F	FxJ	24.2 ± 4.5				35.7 ± 0.5
F	Fx(FxJ)	29.3 ± 1.5				35.5 ± 0.9
F	A	31.9 ± 3.3				31.2 ± 0.5
F	FxA	33.5 ± 1.4				32.5 ± 1.1

[1] Regarding the model as a fixed effects model

[2] F = Friesian; J = Jersey; A = Angus

TABLE III.2 Least squares means[1] for pre-weaning growth rate (kg/day) according to sire breed, dam breed, calf sex and age of dam

Sire breed	Dam[2] breed	Age of dam[3] (years) 2	3	4	≥ 5	≥ 3
		Female calves				
A	A		0.67 ± 0.02	0.67 ± 0.03	0.73 ± 0.01	
F	F	0.78 ± 0.01	0.85 ± 0.02	0.84 ± 0.02	0.86 ± 0.01	
F	FxJ		0.85 ± 0.03	0.86 ± 0.02	0.85 ± 0.02	
F	Fx(FxJ)	0.81 ± 0.02	0.85 ± 0.03	0.92 ± 0.04		
F	A	0.70 ± 0.04	0.72 ± 0.03	0.75 ± 0.03	0.79 ± 0.01	
F	FxA	0.77 ± 0.02	0.82 ± 0.03	0.87 ± 0.04		
		Male calves				
A	A		0.65 ± 0.04	0.75 ± 0.02	0.78 ± 0.01	
F	F	0.[illegible]0 ± 0.02				0.93 + 0.01
F	FxJ	0.85 ± 0.12				0.93 + 0.[illegible]
F	Fx(FxJ)	0.88 ± 0.04				0.89 + 0.02
F	A					0.82 + 0.01
F	FxA	0.80 + 0.03				0.88 [illegible]

[1] Regarding the model as a fixed effects model

[2] F = Friesian; J = Jersey; A = Angus

[3] Average age at weaning of calves from 2-year-old dams was approximately 190 days
Average age at weaning of calves from 3- to 10-year-old dams was approximately 170 days

TABLE III.3 Least squares means[1] for weaning weight (kg) according to sire breed, dam breed, calf sex and age of dam

Sire breed	Dam breed[2]	Age of dam[3] (years)				
		2	3	4	≥ 5	≥ 3
				Female calves		
A	A		139.3 ± 3.8	141.5 ± 4.6	153.0 ± 1.7	
F	F	183.3 ± 2.9	181.9 ± 4.1	179.1 ± 4.1	183.2 ± 2.2	
F	FxJ		187.6 ± 4.8	187.0 ± 3.9	179.2 ± 3.4	
F	Fx(FxJ)	185.2 ± 3.8	175.8 ± 4.6	189.6 ± 6.9		
F	A	161.0 ± 8.6	152.4 ± 5.4	157.9 ± 4.7	167.0 ± 2.1	
F	FxA	178.3 ± 4.3	169.5 ± 4.3	180.5 ± 6.9		
				Male calves		
A	A		141.5 ± 6.9	160.9 ± 4.6	164.0 ± 2.1	
F	F	189.3 ± 3.7				194.4 ± 1.9
F	FxJ	154.6 ± 24.5				192.2 ± 2.3
F	Fx(FxJ)	206.3 ± 8.3				185.8 ± 3.9
F	A					170.0 ± 2.3
F	FxA	183.1 ± 6.6				181.5 ± 4.7

1 Regarding the model as a fixed effects model

2 F = Friesian; J = Jersey; A = Angus

3 Average age at weaning of calves from 2-year-old dams was approximately 190 days.
Average age at weaning of calves from 3- to 10-year-old dams was approximately 170 days.

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