A STUDY OF ADJUSTMENT FACTORS FOR THE WEANING WEIGHTS OF HEREFORD AND ANGUS CALVES

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ABSTRACT

From the files of the Beef Cattle Weight Gain Performance Recording Scheme of the New Zealand Meat Producers Board and the New Zealand Wool Board, the weaning weights of 7771 Hereford calves born in 18 herds, and 16666 Angus calves born in 37 herds, from 1964 to 1972, were analysed. Objectives of the study involved estimation of the effects of age and sex of calf, and age of dam, in order that methods of adjustment currently used in the National Beef Recording Service for these environmental influences could be evaluated.

Each calf was classified according to herd, year of birth, age-of-dam group, and sex, with age at weaning as a covariate. The data were analysed within breeds by least squares to investigate the main effects of these five factors and the first-order interactions among herd, year, age-of-dam group, and sex effects. The importance of each interaction was examined by comparing the proportionate reduction in intra-class residual variation after all main effects had been fitted.

The results of the analyses of main effects indicated that for each breed, all effects contributed to more than a 2 percent reduction in intra-class residual variance. The results of the interaction analyses showed that only the herd x year interaction for Hereford calves, and the herd x year and herd x sex interactions for Angus calves, contributed to at least a 2 percent reduction in residual variance after all main effects had been fitted.

Within-subclass linear regression coefficients of weight on age at weaning for Hereford and Angus calves, were 0.70 ± 0.01 and 0.62 ± 0.01 kg/day, respectively. Least-squares estimates for sex indicated that the weaning weights of Hereford and Angus males were heavier than those of females by 29.8 and 25.6 kg, respectively. Estimates for age of dam indicated that the weights of Hereford calves out of dams of 2, 3, 4, 5 and, 10 years of age and older, deviated from the weights of Hereford calves out of mature dams (6 to 9 years-old) by 33.3, 17.6, 8.7, 3.8 and 2.2 kg, respectively. The corresponding deviations for Angus calves were 22.7, 15.2, 7.9, 5.4 and 1.4 kg. Estimates for age-of-dam effects were also obtained by best linear unbiased estimation procedures from the records of 7698 Hereford calves out of 2901 dams, and 14198 Angus calves out of 5086 dams. Differences in the estimates of deviations of non-mature from mature dam age groups

derived by least squares and by best linear unbiased estimation, were in general relatively small.

In relation to the procedure currently used in the National Beef Recording Service, alternative adjustment procedures derived for age at weaning involved additive and multiplicative applications of linear regression of weight on age for each breed. The current procedure, for both breeds, was the least effective in reducing the dependence of adjusted weight on age, whilst the procedure additively applying linear regression of weight on age was the least effective in reducing intra-class residual variance.

Adjustments determined for age-of-dam effects by least squares and by best linear unbiased estimation, were considered to differ only slightly from current industry adjustment factors, with the exception of factors applicable to Angus calves out of 3-year-old dams. Examination of the variances within age-of-dam groups, and of the reductions in residual variances within herd-year-sex subclasses, indicated the applicability of additive, rather than multiplicative, adjustment factors for each breed.

Comparisons of additive and multiplicative adjustment factors for sex effects were varied. Multiplicative adjustments were more appropriate in equalizing variances within sex groups, whilst additive adjustments were more appropriate in reducing residual variance within herd-year subclasses.

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CHAPTER 1

INTRODUCTION

The accurate evaluation of productive differences between animals is fundamental to the genetic improvement of economically important characters. Differences in performance are due to two major causes - genetic and environmental - the latter being defined as all that variation in the character which is non-genetic in origin. The contribution of environmental variation to total variation is important because it is not transmitted from parent to offspring and its effect is to obscure that part of the variation due to genotype. As a result of this masking action, efforts are often made to lessen the environmental variation in order to reduce discrepancies between an individual's phenotype and its estimated breeding worth, and hence to increase the accuracy of selection. Such "control" of the environment can be achieved either physically or statistically.

Physical control is an attempt to greatly reduce environmental variation by recording the performance of all animals under physically standardized feeding and management conditions. Aside from being economically prohibitive under New Zealand's pastoral conditions, this approach suffers from the difficulty that must be experienced in maintaining a constant set of environmental conditions.

Statistical control of environmental influences involves the estimation of the magnitude of such effects on the recorded trait in question, and adjustment of the records through the use of factors derived from such estimates. The use of adjustment factors aims at a more objective assessment of what each animal would have achieved under standard environmental conditions. Consequently, a larger proportion of the variance in adjusted records of performance should be genetic than was true of the variance in the original unadjusted observations.

By controlling environmental effects known to influence performance, a breeder can rank individual animals more accurately on their estimated genetic worth for specified traits. The environmental-control approach most generally favoured in the past, both overseas and in New Zealand, has been statistical rather than physical, although it may not necessarily be the more effective. Some workers have stressed the need for caution in the use of statistical adjustment factors. For instance, Koger, Reynolds, Meade, Kirk, Peacock and Kidder (1962) concluded from studies of the records of 4729 beef calves that the indiscriminate use of adjustment factors, particularly for age of dam, may introduce more serious errors than working with unadjusted data. Statistical adjustment factors, as products of the data at hand, can at best only be as accurate as the biometrical procedures used in their derivation.

Historically, performance recording programmes for beef cattle avoided statistical adjustment of records for known environmental effects by comparing animals within specified groups. For example, in reviewing performance recording in beef cattle, I.L. Mason (1951) noted that the first proposal to record the performance of beef steers in the United States (Sheets, 1932) specified that comparisons should be made between animals born within a period of 60 days, presumably to reduce the influence of age on rate of growth. With increasing sophistication of both recording procedures and the processing of recorded data, and the expansion of the number of animals recorded on performance, greater reliance has been placed on statistical control of some of the important environmental influences, rather than total control by comparisons within sub-groups according to each environmental effect.

The importance of statistical control through the application of adjustment factors appears at two levels: first, at the individual level where for objective ranking of individuals their production records must be compared on a common or standardized basis, for instance by adjusting for differences in performance due to the influence of age. Secondly, the importance of adjustment factors arises at the population level, where a major component affecting the rate of genetic gain in the population is the accuracy with which breeding value is predicted, especially in the case of sire evaluation. One of the factors determining this prediction accuracy is the magnitude of the heritability of the character in question. Statistical adjustment factors are applied to reduce the contribution of environmental variance to total phenotypic variation relative to that of genetic variation, with consequent increases in the accuracy of, and rate of response to, selection within the population.

The statistical adjustment procedures for environmental effects on recorded weights in beef cattle (such as those for age and age of dam) that are currently in use in New Zealand, originated from the beef cattle performance recording recommendations of the United States Beef Cattle Records Committee Report (1965). The applicability of these standardized American-based adjustment factors to New Zealand conditions is a question worthy of consideration.

The objectives of the present study were first to estimate the effects of age and sex of calf and age of dam on the weaning weights of performance recorded Hereford and Angus cattle in New Zealand, and secondly to evaluate current and possible alternative methods of adjustment of weight records for these environmental effects.

CHAPTER 2

REVIEW OF LITERATURE

I. THE IMPORTANCE OF WEANING WEIGHT AS A CRITERION OF SELECTION IN BEEF CATTLE

Postnatal development of the calf primarily depends on two factors: the genetic potential of the calf to grow which is contributed by both sire and dam, and the productive maternal factors of the dam such as her mothering and milk-producing abilities. In the initial stages of development the calf is dependent upon its dam's ability to support it. At subsequent periods this reliance decreases in intensity as the calf's ability to utilize grass develops to the point at which dam and offspring are in competition for feed. In terms of management an initial close dam-offspring relationship is desirable, but as this affinity diminishes into an increasingly competitive association a decision is required to separate dam and offspring, enabling the latter a greater opportunity to express its inherent growth potential. The time at which weaning occurs may vary with seasonal conditions and management levels, however in most New Zealand performance recording beef breeding enterprises, calves are weaned at an approximate average age of 200 days. The weight of the calf at weaning is frequently the first positive indication the breeder has of the probable productive ability of his surviving calf crop. Weaning weight, therefore, is a trait that often assumes considerable significance in selection programmes.

The value of weaning weight as a criterion of selection in beef cattle depends on its heritability and on its degree of genetic correlation with characters that are of direct economic value in beef cattle. Estimates of the heritability of weaning weight in beef cattle presented by Warwick (1958), Gregory (1961), Petty and Cartwright (1966), Rice, Andrews, Warwick and Legates (1967), Gregory (1969), Preston and Willis (1970) and Lasley (1972), range from 0.25 to 0.30. Some of the published estimates of the heritability of weaning weight presented in Table 2.1, vary from 0.08 to 0.81 with a raw mean of 0.27 and a modal value of 0.25.

Many of the variations in the heritability estimates, excluding

TABLE 2.1: Published estimates of the heritability of weaning weight in beef cattle
(Age at weaning ranges from 180 days to 240 days)

Location	Number of records	Breed*	Heritability estimate	Authors
New Mexico	499	H	0.08	Blackwell *et al.* (1962)
Missouri	1066	H	0.08	Sewell *et al.* (1963)
Arizona	720	H	0.10	Pahnish *et al.* (1964)
Montana	4234	H	0.11	Koch and Clark (1955b)
Arizona	414	H	0.11	Lasley *et al.* (1961)
Nebraska	1769	H	0.15	Koch *et al.* (1973)
Missouri	1066	H	0.18	Sewell *et al.* (1963)
Kansas	265	S	0.23	Gottlieb *et al.* (1962)
Hawaii	1306	H	0.24	Mahmud and Cobb (1963)
Montana		H	0.25	Koch and Clark (1955b)
New Zealand		A	0.25	Carter (1971)
Nebraska	1963	H	0.25	Koch *et al.* (1973)
Nebraska	1671	A,H,S	0.28	Swiger *et al.* (1963)
Michigan	326	H	0.30	Magee *et al.* (1961)
Kansas	265	S	0.30	Gottlieb *et al.* (1962)
New Mexico	420	H	0.31	Blackwell *et al.* (1962)
South Dakota	436	A	0.32	Minyard and Dinkel (1965b)
South Dakota	1915	H	0.33	Minyard and Dinkel (1965b)
Georgia	180	H	0.34	Chapman *et al.* (1972)
Montana	3584	H	0.43	Fitzhugh and Taylor (1971)
Kansas	1861	A	0.47	Hamann *et al.* (1963)
North Carolina	1692	H	0.50	Vesely and Robison (1971)
Hawaii	2550	A,H	0.81	Francoise *et al.* (1973)

* H = Hereford; S = Shorthorn; A = Angus.

cases where sexes were analysed separately, are presumably due to sampling error or real environmental differences. Tallis (1960) has shown that heritability estimates may be biased downward due to controllable errors. Such errors could include those arising from analysing weights unadjusted for differences due to age at weaning and age of dam, or perhaps from weighing cattle with variable amounts of gut fill. Weaning weight appears to have a medium level of heritability and is consequently associated with a similar level of direct importance in terms of selection pressure for this character.

A further consideration in evaluating the importance of weaning weight for herd improvement is its reliability in predicting economically important traits after weaning. In view of the importance of post-weaning growth performance in selection programmes in New Zealand beef herds (Rae and Barton, 1970), it is of interest to consider the genetic relationships between weaning weight and weights or gains postweaning. Despite the variability in the estimates of the relationships presented in Table 2.2, there are indications of positive genetic correlations between weaning weight and subsequent weights and gains. However, there is some evidence of a genetic (Christian, Hauser and Chapman, 1965; Mangus and Brinks, 1971) and an environmental (Barton, 1970) antagonism between high weaning performances of heifers and their subsequent productivity as cows, expressed in terms of weight of calf weaned.

Evaluation of the importance of weaning weight as a selection criterion, should also take account of the accuracy with which the lifetime productivity of the cow can be predicted by the weaning weight of her calf. It is important to distinguish between the principle of repeatability of weaning weight and, for instance, that of milk production. The weaning weight of an individual occurs once in its lifetime and is repeatable only when regarded as a characteristic of the dam. On the other hand, in traits such as milk production, repeatability refers to the expression of the same trait at different times in the life of the same individual. From some of the published estimates of the repeatability of weaning weight present in Table 2.3, cows tend to repeat their performance of weight of calf weaned from year to year, with from 32 to 43 percent of the variation in weights being accounted for by differences between cows in most herds. Repeatability estimates of this magnitude have led many authors to conclude that cows weaning calves distinctly below the herd average weaning weight (and where

TABLE 2.2: Published genetic and phenotypic correlations of weaning weight with postweaning weights and gains in beef cattle

Correlated trait	Correlation Genetic	Correlation Phenotypic	Authors
Weights:			
Yearling weight	0.16	0.65	Blackwell *et al.* (1962)
		0.68	Carter (1971)
	0.61	0.48	Francoise *et al.* (1973)
		0.76	Scarth *et al.* (1973)
16-month weight		0.78-0.81	Williams and Murphy (1958)
18-month weight	0.70-0.79	0.73	Koch *et al.* (1973)
21-month weight		0.50-0.60	Brumby *et al.* (1963)
Slaughter weight		0.55	Christian *et al.* (1965)
		0.84	Wardrop (1968)
Gains:			
Weaning to yearling		0.29	Christian *et al.* (1965)
	0.12	-0.07	Francoise *et al.* (1973)
Postweaning gains	0.26	0.20	Koch *et al.* (1973)
Weaning to slaughter		0.38	Christian *et al.* (1965)

TABLE 2.3: Published estimates of the repeatability of weaning weight in beef cattle

Number of records	Breed*	Repeatability: Intra-class correlation	Repeatability: Regression of adjacent records	Authors
19907	A	0.19		Sellers *et al.* (1970)
	H	0.26		Sellers *et al.* (1970)
4722	A	0.25		Hohenboken and Brinks (1969)
1151	-	0.32	0.34	Hoover *et al.* (1956)
1066	H	0.38		Sewell *et al.* (1963)
607	A	0.39		Kilkenny (1968)
693	H	0.42		Kilkenny (1968)
2351	A,H	0.42		Minyard and Dinkel (1960)
603	H	0.43	0.49	Botkin and Whatley (1953)
326	A,H	0.50		Magee *et al.* (1961)
745	H	0.52		Koch (1951)
338	H	0.55	0.47	Rovira (1968)

* A = Angus; H = Hereford.

accident or illness is known not to have influenced calf weights) can be culled with little chance of culling a cow that would subsequently wean heavier calves.

The weight of a calf at weaning is an important, if complex, trait. It reflects not only the calf's genetic potential for growth and its maternal environment, but also other non-genetic influences such as age at weaning, sex, age of dam, herd of origin and year of birth. After weaning these factors may change in their relative importance, but some at least will remain influential. For weaning weight to be a useful selection criterion in beef cattle improvement, particularly for the early screening of calves before their first winter in situations where yearling matings are practiced, it follows that major known environmental influences affecting this trait should be accounted for in order that the accuracy of selection may be increased.

II. SOME FACTORS AFFECTING WEANING WEIGHT IN BEEF CATTLE

A. Age at Weaning

Once the decision has been made to separate calves from dams it is convenient for the breeder to wean all calves in one operation. Since dates of birth will have differed within the herd, the ages of calves at weaning will vary. A positive relationship between weaning weight and the age at which weaning occurs should be apparent. However, the nature of this relationship and the relative contribution of age at weaning to the total variation in weaning weight, may not be so evident.

Most studies have shown that the growth of beef calves tends to be linear in the period of 5 to 8 months of age, the time at which weaning generally occurs. Johnson and Dinkel (1951) found that the rate of growth of 297 Hereford calves was essentially linear from birth to 155 days of age and thereafter increased at a decreasing rate. These authors described the growth of the calves studied as being composed of two straight lines with a reduction in slope at 155 days of age. Botkin and Whatley (1953) observed the growth pattern of 745 Hereford calves to be linear over a range in ages of 120 to 260 days, although they cautioned that this pattern may not be typical under environmental conditions less favourable than those experienced. J.B. Burgess, Landblom and Stonaker (1954), and Pahnish (1958) found the rate of growth of suckled calves to be approximately linear. The latter study showed that within sexes, calves had linear growth rates between the ages of 121 and 323 days. Swiger, Koch, Gregory, Arthaud, Rowden and Ingalls (1962) reported that the liveweight gains of 2739 beef calves were linear up to 130 days of age, but curvilinear from 130 to 220 days of age. Creek (1964) observed, in 1280 mixed-breed calves in Jamaica, marked effects of adverse nutritional conditions on preweaning growth patterns such that growth tended to be curvilinear. It was implied that with improving standards of preweaning management, the likelihood of a linear growth curve being maintained to weaning would be enhanced. Marlowe, Mast and Schalles (1965) believed that seasonal and age effects were confounded in the study of Swiger et al. (1962), and they maintained that after removal of seasonal influences, growth of the calves was generally linear from 120 days to weaning. Baker, Carter, Cox and Templer (1974), with 4893 beef calves in New Zealand, failed to establish any departure from linearity in the regressions of weaning weight on age at weaning over several years.

The relative contribution of age at weaning to the total variation in weaning weight has generally been regarded to be of importance. Lawson and Peters (1964) noted the significance ($P < 0.01$) of age on weaning weight in 219 Highlander and Hereford cattle and their reciprocal crosses. The influence of age on the variability of weight at weaning was half of that accounted for by age of dam, but approximately three times that due to sex of calf. Carter (1971) observed age differences amounting to between 15 and 30 percent of the variation in liveweights at weaning in an investigation of selection on performance in beef cattle in New Zealand. Vesely and Robison (1971) noted the importance of age at weaning in 1692 Hereford weaning records, although sex of calf was found to be a more important source of variation in weaning weight based on the proportions of total sum of squares. Bovard and Weinland (1973) found that within six-breed-mating system subclasses for 1646 Angus, Hereford and Shorthorn calves, age at weaning was the largest determinant of variation in weaning weight. In partitioning the total sum of squares among several factors affecting the weaning weights of beef calves, Baker et al. (1974) concluded that the most important single source of variation was that due to regression on age.

It is apparent that the positive relationship between weaning weight and the age at which weaning occurs is of considerable importance, and that weaning age has a marked influence on the total variation in liveweight at weaning. On the other hand, the nature of this weight-age relationship is not as clearly defined. A linear association between weight and age up to weaning has been the generally accepted form of this relationship in many studies, although there are some indications of significant curvilinear growth patterns to weaning (e.g. Warren, Thrift and Carmon, 1965; Sullivan, 1967). Where linear growth curves to weaning have been defined, the studies concerned have often been performed under developed pastoral and animal management systems. Indications of a departure from linearity in the preweaning growth of beef calves may then be attributable to environmental conditions, such as the qualitative and quantitative aspects of herbage available under suckled cow-calf enterprises. With progressive stages of development after birth and with a decline in the nutritional value of available pasture, an earlier linear weight-age relationship may transform into an increasingly curvilinear one. At the time of weaning therefore, early-born calves will have an increased reliance on, but as yet an inefficient utilization of the available herbage, while late-born calves may be at a disadvantage in this regard. If environmental conditions are severe, it is likely that the spread of calving dates is wider than under more favourable conditions. Consequently any curvilinear association between weight and age at weaning will be intensified because of the greater numbers of calves in the extreme age groups. Conversely, under environmental conditions favourable to developed pastoral and animal management systems, prolonged production of feed of nutritional value and concentrated calving periods which reduce the number of calves in the extreme age groups, lowers the likely rate of decline in the growth of calves as weaning approaches.

B. Sex of Calf

The magnitude of sex differences for weight at weaning in the extensive literature has varied from herd to herd, but in all cases the weaning weights of males have exceeded those for females when ages at weaning have been at least 180 days (Table 2.4).

Evans, Craig, Cmarik and Webb (1955) observed that the weaning weights of bulls averaged 6.1 percent above that of heifers in a purebred Hereford herd, whilst in a grade herd of the same breed, steers averaged 4.1 percent heavier than heifers. In a study of 4729 beef calves, Koger et al. (1962) reported a difference in weaning weights of from

TABLE 2.4: Published estimates of the superiority of males over females in the weaning weights of beef calves

Location	Breed*	Weaning age (days)	Superiority over females (kg)		Authors
			Bull	Steer	
Montana	H	180		7	Brinks *et al.* (1961)
Michigan	A,H	180		7	Magee *et al.* (1961)
Louisiana	V	180	20		Vernon *et al.* (1964)
Alabama	A,H	180	23		McGuire (1969)
Colorada	H	200	10		Harwin *et al.* (1966)
Nebraska	H	200	15		Koch *et al.* (1973)
United Kingdom	H	200	40		Taylor (1967)
United Kingdom	A	200	42	5	Thomson (1968)
North Carolina	H	205	18	9	Vesely and Robison (1971)
Pennsylvania	AX	205		12	Bair *et al.* (1972)
Oklahoma	A,H	205	25	5	Cundiff *et al.* (1966a)
Arizona	H	210	12		Lasley *et al.* (1961)
Jamaica	V	210	12		Creek and Nestel (1964)
South Africa	V	210	12		Bosman and Harwin (1966)
Virginia	A,H,S	210	21	14	Marlowe and Gaines (1958)
Hawaii	H	240	13		Mahmud and Cobb (1963)

* H = Hereford; A = Angus; V = Various breeds; AX = Angus- or Hereford-sired calves out of Angus-Holstein dams; S = Shorthorn.

9 to 18 kg in favour of steers over heifers. Minyard and Dinkel (1965a) observed that bulls averaged 15 kg heavier than heifers when weaning weights were adjusted to a standard age of 203 days.

The influence of sex of calf on liveweight at weaning is clearly of importance, as indicated by the volume of literature reporting the significance of this factor (Neville, 1962; Seebeck and Campion, 1964; Alexander and Beattie, 1968; Chapman, Clyburn and McCormick, 1972; Barlow, Dettman and Williams, 1974; Seifert, Rudder and Lapworth, 1974; among others). The dissenting reports include observations by Gregory, Blunn and Baker (1950), who found at two stations in Nebraska that the difference between the average weaning weights of the two sexes was not significant. This was attributed to the fact that large variations in weights and gains had occurred at both stations. Nelms and Bogart (1956) considered that any difference in the suckling gains of 103 Hereford and Angus calves due to sex, was largely attributable to sex differences in birthweight only. These authors concluded that adjusting preweaning gains for sex differences in birthweight resulted in sex being an unimportant influence on rate of growth to weaning. On the other hand Martin, Jacobson, McGilliard and Homeyer (1962) reported that although the variation due to sex on weight gains was reduced when adjustments were made on birthweight, sex still remained an important influencing factor on the growth of 659 dairy cattle of various breeds to 12 months of age. This was later substantiated by Bosman and Harwin (1966), who concluded that adjustments for differences in birthweight due to sex did not appear to be of sufficient magnitude to nullify sex differences in the rates of growth from birth to weaning (210 days of age) of 1169 beef calves. The influence of sex on preweaning liveweight gains is dependent in part on differences in birthweight due to sex. However it is unlikely that sex differences in birthweight can completely account for differences between the sexes in rate of growth from birth to weaning.

Brown (1960) analysed the weights of one herd of 287 Hereford calves and two herds of 334 and 271 Angus calves at 180 and 240 days of age. Differences between the sexes accounted for 4.5 to 8.0 percent, and 5.5 to 21.7 percent of the variation in weights at the two respective ages. With 13937 Hereford and Angus calves in Oklahoma, Cundiff, Willham and Pratt (1966a) reported sex to be the most important factor influencing liveweights, accounting for 17 percent of the total variation in weight adjusted to 205 days of age. From the weaning records of 892 Shorthorn calves, Fahmy and Lalande (1973) found males to be significantly ($P < 0.01$) heavier than females, although this difference was the least important source of variation on weaning weight at 210 days, accounting for 8.9 percent of the total variation.

It is possible that the influence of sex may be exaggerated in terms of the differences in superiority of bulls over steers and heifers, and that of steers over heifers. For instance the bull-steer and bull-heifer differences in weaning weights in the sutdy of Cundiff et al. (1966a), were considered by them to be larger than those reported for calves weaned at 205 to 210 days of age, whilst the steer-heifer difference was smaller than most other reports (see Table 2.4). Cundiff et al. postulated that these discrepancies arose from the effects of castrating males and of selection for size, that is, from a tendency of beef producers to retain faster-growing males as bulls and to castrate the slower-growing male calves. The inability to separate the physiological effects of castration from the effect that selection for size may have had in deciding which bulls to retain and which to castrate, has also been encountered in earlier studies (Koch, 1951; Koch and Clark, 1955a; Marlow et al., 1965). This confounding results in an upward bias in the bull-steer and bull-heifer differences, and a downward bias in the steer-heifer differences. Exaggerated bull-heifer differences in weaning weights may also be indicative of differential preweaning management policies, where beef producers are primarily engaged in the sale of breeding bulls.

(1) Interactions involving sex of calf. There is some suggestion that environmental factors can affect the preweaning performance of the sexes differentially. Most studies have used least squares procedures to estimate the effects of various environmental factors on weaning weight. The models used can become complex unless interactions between the main effects are omitted. If not explicitly stated, the omission of these interactions at least implies the assumption that they are unimportant, if not absent. Where sexes are not analysed separately then such models fail to determine whether males and females react differently to the various environmental factors studied. Therefore the estimation of the effects due to sex, and subsequent computation of sex adjustment factors for weaning weight, assumes similarity in the genetic potential for calves of the two sexes to respond to different environments.

Of the genotype-environment interactions originally classified by Dunlop (1962), the "microenvironmental-intrapopulation" classification is applicable to studies of weaning weight data according to Creek and Nestel (1964). The latter authors regard this class of interaction to include that between sex of calf and age of dam, an interaction which has been considered important in some studies (Rollins and Guilbert. 1954; Pahnish, Stanley, Bogart and Roubicek, 1961; W.E. Mason, Beilharz and Carraill, 1970; Baker et al., 1974), but not in others (Lehmann. Legates, Robison, Gregory and Dillard, 1962; Cunningham and Henderson, 1965a; Bailey, Koh, Hunter and Torell, 1972; Bair, Wilson and Ziegler, 1972). Creek and Nestel (1964) and Harwin, Brinks and Stonaker (1966) interpreted a greater response in the weaning weights of male calves to different ages of dam, as being an indication of the superior capability of the male genotype in realizing its potential in the presence of a favourable nutritional environment provided by the dam. Similar interpretations have been reported by Marlowe et al. (1965), Cundiff et al. (1966a) and Schaeffer and Wilton (1974a) for interactions between sex of calf and type of management (creep and non-creep) to weaning. Schaeffer and Wilton (1974a) also observed that sex of calf interacted with level of herd performance with 25571 Angus and 69058 Hereford calves in Canada. Differences between the mean preweaning average daily gains of bulls and heifers were greater in herds of high performance levels than in herds of low performance levels.

Important sex x herd or sex x year, or both sex x herd and sex x year interactions have been reported by Pahnish (1958), Cooper, Sutherland, Pattengale and Williams (1965) and Barlow et al. (1974), and have led to the conclusion that the use of a mean sex difference in weaning weights as a sex adjustment factor in various herds, or over a period of years in the same herd, appears to be inadequate. However, the effects of one or both of these interactions relative to those of the main factors studied in the analysis, have often been regarded as unimportant (Swiger, 1961; Hohenboken and Brinks, 1969; Cardellino and Frahm, 1971).

The importance of interactions for weaning weight involving sex of calf varies largely from one instance to another. As Pani and Lasley (1972) note, such interactions do not appear to be important sources of variation.

C. Age of Dam

Although age-of-dam information is usually readily available at calving, age *per se* is not the factor being adjusted for. Age of dam merely provides an easily recognizable, albeit closely related parameter of those aspects of maturity such as development of the mammary gland, milk yield, and maternal ability.

Alternatives to age as an indicator of the degree of maturity of milk production in dairy cattle, have included calving sequence or lactation number, age within lactation number, or some combination of body weight or body size and lactation number (Wickham, 1972). As far as beef cattle are concerned, age at calving appears to be acceptable as an indicator of the degree of maturity of maternal and milk-producing abilities.

Numerous investigations have drawn attention to the importance of age-of-dam influences on the weight of calf at weaning. Such studies have shown that the maximum production in terms of calf weaning weight appears to be attained when the dams are approximately 6 to 9 or more years of age (Table 2.5). The magnitude of age-of-dam differences may depend to a large extent on management and other environmental conditions, although the possibility of genetic differences in the rate of maturity in cows cannot be disregarded (Fitzhugh and Taylor, 1971; Freeman, 1973). Cundiff *et al.* (1966a) observed that the weaning weights of 13937 Hereford and Angus calves increased by 22 kg as age of dam increased from 2 to 4 years. The magnitude of this increase led these authors to recommend that cows between 2 and 4 years of age should be classified into 3- to 5-month increments in order to more accurately adjust calf weaning weights. Cundiff *et al.* further noted that in the Midwest and other high rainfall areas of the United States, there was not the pronounced decline in calf weaning weights from cows over 8 to 9 years of age (Botkin and Whatley, 1953; Marlowe and Gaines, 1958; Swiger 1961; Koger *et al.*, 1962; Marlowe *et al.*, 1965; Hohenboken and Brinks, 1969; Sellers, Willham and DeBaca, 1970) as observed in more arid regions (Knapp, Baker, Quesenberry and Clark, 1942; J.B. Burgess *et al.*, 1954; Koch and Clark, 1955a; Minyard and Dinkel, 1965a; Sullivan, 1967; Bair *et al.*, 1972). The continued high level of performance of older cows in favourable environmental situations may be due in part to the enhanced opportunity for more intense selection, where most of the poorer-producing cows may have been culled before reaching older ages (T.D. Burgess and Bowman, 1965).

The influence that age-of-dam effects have on calf liveweights at

TABLE 2.5: Published estimates of the effect of age of dam on the weaning weights of beef calves[a]

Location	Weaning age (days)	Overall mean (kg)	Breed of dam[b]	Age of dam (years) 2	3	4	5	6	7	8	9	10	11	12	13	Authors
Jamaica	210	166	V		-10	-3	-1	3	4	5	-3	6	3			Creek and Nestel (1964)
Canada	210	183	S	-24	-15	-1	-1	6	10	13	1	4	6			Fahmy and Lalande (1973)
Montana	180	186	H	-21	-16	-13	-5	7	14	16	10	12	6	-11	1	Sewell et al. (1963)
United Kingdom	200	186	A	-14	-14	-3	3	4	6	14	14	14	14	14	14	Thomson (1968)
South Dakota	190	189	H,A	-25	-9	-2	2	10	10	12	8	5	1	-6	-7	Minyard and Dinkel (1965a)
Oklahoma	205	189	H,A			0	3	6	7	8	8	7	7	5	6	Cundiff et al. (1966a)[c]
Oklahoma	205	191	H.A	-24	-2	12	14	14	14	14	14					Cardellino and Frahm(1971)
Ohio	230	196	H	-26	-8	-6	16	16	16	20	20	20	20	20	12	Swiger (1961)
United Kingdom	200	212	H	-15	-15	-5	2	4	8	6	6	6	6	6	6	Taylor (1967)
Pennsylvania	205	213	AX	-6	-3	-1	5	9	7	4	8	-8	-16			Bair et al. (1972)
Queensland	200	235	BX	-21	-14	2	6	6	6	10	10	10	16	16	16	Seifert et al. (1974)

a Values show differences from the overall mean to the nearest kilogram.

b V = Various; S = Shorthorn; H = Hereford; A = Angus; AX = Angus x Holstein; BX = Brahman crossbreds.

c See text (p.16).

weaning has been reported for instance, by Lasley, Day and Comfort (1961), Eftekhari-Shahroudi (1972), Francoise, Vogt and Nolan (1973) and Barlow et al. (1974). Lawson and Peters (1964) noted that the effect of dam age on the variability of weaning weight was twice that accounted for by calf breed, age, or year of birth, and about seven times that due to calf sex. Under New Zealand conditions, Baker et al. (1974) indicated that age of dam was the second most important factor influencing the weaning weights of beef calves, based on the proportionate contribution to total sum of squares. In contrast to the above, Neville (1962) reported that age of dam was not an important source of variation in calf weights up to weaning. In this study however, differences due to age of dam were adjusted for variations in liveweight and in milk production of dams. Rutledge, Robison, Ahlschwede and Legates (1971) confirmed the results of Neville (1962), finding that on a within herd-year-sex basis, age of dam did not contribute to the variation in weaning weight beyond its influence through such correlated variables as dam liveweight and milk yield, and calf birthweight in 193 Hereford cows.

(1) Milk production and maternal ability in relation to age of dam. From the existence of a positive relationship between age and milk yield in dairy cattle, it may seem that a similar association should exist in beef cattle. Such evidence that is available would suggest this (e.g., Neville, Warren and Griffey, 1974), bearing in mind the technical limitations associated with the collection of milk yield data from beef cows (Barton, 1970).

Gifford (1953) considered that maximum milk production in 28 Hereford cows was reached at 6 years of age. Drewry, Brown and Honea (1959) found with 48 Angus cows and calves that calf suckling gains were more rapid if their dams were older or scored as being more protective, in both cases independent of milk production. Heyns (1960), Melton, Riggs, Nelson and Cartwright (1967), and Jeffery, Berg and Hardin (1971a, b) all reported that older cows produce more milk, a relationship to which some investigators have attributed a lower lactational persistency in younger cows (e.g., Todd, Fitzhugh and Riggs, 1969), while others have noted the converse (e.g., Christian et al., 1965) despite total milk production favouring older cows.

The dam's milk production has an important influence on her calf's weight at weaning, in fact Barton (1970) considered this influence to be the most important determining factor than any other single effect investigated. Reported phenotypic correlations between dam's milk production and liveweight of the calf at weaning have generally fallen within the range of 0.40 to 0.80 (Table 2.6), depending on the age of the calf (reflected by the dam's month of lactation), or on the duration of measurement. In studying factors influencing rate of gain during the suckling period in 58 Shorthorn and 180 Hereford calves, Knapp and Black (1941) found that milk consumption accounted for approximately 38 percent of the variation in rate of gain. Neville (1962) reported that 66 percent of the variation in the 240-day weights of 135 Hereford calves was due to differences in milk consumption. In New Zealand, Brumby, Walker and Gallagher (1962) observed a positive relationship between calf liveweight gain and milk consumption, although this relationship declined in importance after the calves had reached 140 to 190 days of age. In the following year, these authors reported that some 50 percent of the variation in weaning weight was attributable to differences in milk consumption (Brumby et al., 1963).

Although the relative magnitudes of the degree of relationship between dam's milk production and liveweight at weaning of the offspring may differ, there is at least no negative association between these two variables. That milk production is also related to age of dam further supports the conclusion that age-of-dam effects have an important influence on weight of calf weaned.

(2) Interactions involving age of dam. Where analyses of calf weaning weights estimate major environmental influences with the objective of using such estimates as standardized adjustment factors applicable to beef cattle performance recording programmes, the presence of interactions among main effects can limit the applicability of the computed adjustment factors. For instance, if the weaning weights of calves out of young cows are more affected in years of poor environmental conditions than the weights of calves out of more mature cows, then an age-of-dam by year interaction may exist. Consequently the widespread use of the resulting age-of-dam estimates to adjust calf weaning weights over a number of years would be of limited value. The existence of an interaction between age of dam and year has been reported by Koger et al. (1962), Linton, Brinks, Stonaker, Sutherland and Faulkner (1968), Barlow et al. (1974) and Baker et al. (1974).

Aside from any real variation between years and dam ages, management

TABLE 2.6: Published estimates of phenotypic correlations between dam milk production and calf weaning weight in beef cattle

Month of lactation								Total	Authors
1	2	3	4	5	6	7	8		
0.12*		0.43*			0.46				Drewry *et al.* (1959)
	0.46*						0.48*		Christian *et al.* (1965)
								0.33	Hohenboken *et al.* (1971)
0.58	0.38	0.01	0.19	0.27	0.03			0.40	Melton *et al.* (1967)
								0.67-0.81	Klett *et al.* (1965)
								0.69-0.81	Neville (1962)
								0.70	Brumby *et al.* (1963)
								0.83	T.R. Mason (1964)

* Correlation between dam milk production and calf weight to this month of lactation.

policies may also contribute to the existence of an interaction between age of dam and year. Part of the variation between years may be attributable to differential management conditions for dam age groups to weaning, as for example in the preferential feeding of pregnant first- or second-calving dams relative to older dams. Schaeffer and Wilton (1974a) reported a significant ($P < 0.01$) interaction between age of dam and level of herd performance. With increasing dam age, increases in the preweaning average daily gains of 25571 Angus and 69058 Hereford calves were larger in herds of low performance levels than in herds of high performance levels. The importance of interactions between dam age groups and sex of calf have already been considered (p.15).

D. Year of Birth

In any variation among weights at weaning attributed to years of birth, not only are environmental effects *per se* contributing, but also any change in genetic merit of the herd for weaning weight caused by culling. Using the average weaning weights of all calves born within a year as a basis for adjustment, as has been the case in the past, would not differentiate between genetic and yearly influences.

There have been few attempts to eliminate the confounding of genetic change with year effects on weaning weight in beef cattle. Sewell, Comfort, Day and Lasley (1963) endeavoured to remove genetic change from estimated year adjustments by using the average weaning weights of calves from 19 cows that were producing in all but the first (1951) and last (1961) years considered in the study. The weights of calves from these cows were averaged by years and used as adjustment factors to adjust weaning weights to a base year (1953). More commonly, year effects on beef cattle weaning weights have been regarded in the literature as a reflection of the variation in environmental conditions from year to year, either within- or between-herds. Botkin and Whatley (1953) regarded year effects to be largely due to grazing conditions which, in turn, were attributable to the amount of rainfall in July and August (northern hemisphere). On finding a small but inconsistent association between day of birth and weaning weight adjusted for age of calf (205 days) and age of dam (4- to 10-years) in some years for 914 Hereford and 459 Angus calves in Oklahoma, Pherigo, Whiteman, Willham and Stephens (1969) regarded rainfall to be the major source of environmental variation to cause this relationship. Whenever the rainfall in August was less than the "...normal average..." an important day-of-birth effect on weaning weight was present.

The year in which calves are born can be expected to have an important influence on their liveweights at weaning, as reported by Gottlieb, Wheat, Smith and Wearden (1962), Tovar, Riggs and Cooper (1966), Singh, Schalles, Smith and Kessler (1970), Sacker, Trail and Fisher (1971), and others. Clark, Shelby, Quesenberry, Woodward and Willson (1958) attributed some 16 to 31 percent of total variation in birthweight, weaning weight, preweaning gain and weaning score to differences among years in 7436 Hereford cattle, while Brown (1960) attributed 6 to 8 percent of the variation in 892 Hereford and Angus calf weights at 240 days of age to the same factor. Brown also suggested that weight differences among years were greater after weaning (300- to 420-days of age) than before. Eftekhari-Shahroudi (1972) observed a more pronounced effect of year of birth on calf weights in the early suckling period than in the late period, although this influence was still important at weaning. Helms and Bogart (1956) found no difference between years in the preweaning gains of 103 Hereford and Angus calves, however this investigation was over a period of only two consecutive years.

The inability inherent in least squares analyses to completely separate the confounding effects of genetic and environmental trends in yearly variation must limit the advisability of computing year-of-birth adjustment factors for weaning weights. Furthermore, unlike other non-genetic influences affecting weaning weight such as sex of calf and age of dam, where adjustments can be based on the male sex and the mature dam age group for example, it would be difficult to determine the most suitable year on which to base adjustments for year of birth. Consequently the computation of adjustment factors for year of birth is not usually practiced. Recommendations normally rely on the comparison of weaning weights adjusted for age and age of dam within years. This is to be expected, since any selection on individual weaning weight performance would be meaningful only on a within-year basis.

(1) Interactions involving year of birth. In the studies of Pahnish et al. (1961), Chapman et al. (1972) and Baker et al. (1974), the influence of year of birth on weight at weaning differed between herds. Barlow et al. (1974) reported this interaction to be the largest source of variation in weaning weight or preweaning average daily gain of 2761 Angus calves in one analytical model employed. The possibility of a

large between-year variation among herds suggests the limited applicability of standardized adjustment factors in some years. The existence of such an interaction would indicate that weight comparisons, to be accurate, should be made on a within-herd-year basis in selection for the improvement of calf weaning weights. Other interactions involving year of birth with sex of calf and age of dam have been considered on pp.15 and 19, respectively.

E. Herd

Where investigations into factors affecting the weaning weights of beef calves have been carried out over a number of herds, differences in weights at weaning among the herds would be expected; reflecting differences in genetic potential for postpartum maternal traits in the dams and for growth capability in the calves, and differences in management and feeding levels.

In as few as two herds, important differences in beef calf weaning weights have been reported by Pahnish et al. (1961) and Mahmud and Cobb (1963). From the weaning weight records of 6364 calves in 7 herds in South Africa, Bosman and Harwin (1967) particularly noted that the nature and magnitude of between-herd variations in the sex-of-calf and age-of-dam effects indicated the need for appropriate adjustment factors to be developed within a herd. This supported the contention of Gregory, Koch, Hazel and Chambers (1961) that the most accurate adjustments of weaning weight for sex of calf and age of dam were those developed in the herd in which they were to be applied. However for the estimates of these effects to act as reliable adjustment factors, particularly within years (Baker et al., 1974), the herd size should be relatively large, a situation that is not common in New Zealand beef breeding herds (Cairney and Magnusson, 1970).

Under New Zealand conditions then, it would appear that the computation of suitable adjustment factors for beef cattle weaning weights should be from herds with similar preweaning management regimes. Where the mating policies of individual breeders differ, age-of-dam effects would tend to vary between herds. For example, the mating of "small" sires to yearling heifers would tend to bias the performance of younger dams relative to that of mature dams (Barlow et al., 1974). Apart from differential mating practices contributing to herd effects on weaning weights, the influence of preweaning feeding and management systems of calves, such as creep feeding or the use of nurse cows, may affect the accuracy of measurement of genetic differences between calves for growth. Cundiff et al. (1966a) observed that creep-fed calves tended to average 13 kg heavier at weaning (205-days) than calves not on creep feed. These authors also concluded that despite significant ($P < 0.01$) differences in the type of pasture available up to weaning, this factor was of little practical importance, accounting for approximately 1 percent of the total variation in weaning weight. Taylor (1967) and Thomson (1968) discussed the favourable influences of creep feeding and nurse cow facilities in the United Kingdom on the 200-day weights of Hereford and Angus calves, respectively. As Cundiff and Gregory (1968) have suggested, the accuracy of measuring differences in maternal ability may well be reduced under supplementary feeding regimes, since calves will compensate for differences in dam milk production by consuming additional feed in relation to their genetic potential for growth and development.

Unless the various preweaning feeding and management regimes can be identified and analysed accordingly, their contributions to the total variation in weaning weights will be confounded with that of herd effects.

(1) Interactions involving herd. Interactions involving herd effects with sex of calf, age of dam, and year of birth have previously been considered (pp. 15, 21, and 22, respectively).

III. THE ADJUSTMENT OF WEANING WEIGHT RECORDS FOR ENVIRONMENTAL EFFECTS

From the foregoing it is clear that various non-genetic sources of variation have an important influence upon calf liveweights at weaning. Among the numerous investigations reported in the literature, factors such as age and sex of calf, age of dam, year of birth, and herd, may differ in their relative contributions to total variation in weaning weight. However, their absolute contribution to the total variation warrants further consideration if the accuracy of selection is to be increased. Attention has already been drawn (p.1) to the fact that reduction in non-genetic sources of variation affecting an economically important trait can be achieved by means of the statistical adjustment of records. The adjustment of records for any given environmental effect requires a base to which all other classes of that effect are expressed. Unfortunately problems can arise with year of birth or herd, since an arbitrary decision is necessary to determine the most suitable year or herd on which to base adjustments. The computation of adjustment factors for such sources of environmental variation could be questioned, particularly where selection on individual performance is operating on a within herd-year basis, a procedure that is likely to be more meaningful under the pastoral conditions prevailing in New Zealand. On the other hand with environmental effects such as age and sex of calf, and age of dam, computed adjustment factors can be based on criteria which serve to increase both the validity of comparisons within selection groups, and the accuracy with which genetic merit for the trait in question can be estimated.

A. Adjustment for Age of Calf at Weaning

Because of the unavoidable variation in calf ages at the time of weaning and the existence of a positive relationship between weight and age, accurate comparisons within selection groups require weight records to be adjusted to a standard age at weaning. As a consequence of the commonly assumed linear preweaning growth pattern of beef calves, two methods of adjusting weaning weight records to a standard age at weaning have received most attention in the literature. (For purposes of discussion the two adjustment procedures will subsequently be referred to as Method I and Method II). In formulating a weight at a standard age, both Method I and Method II employ the following approach:

$$W_a = W_t + \frac{dW}{dt}(t_a - t) \qquad \ldots(2.1)$$

where: W_a = weaning weight adjusted to a standard age (t_a).

W_t = actual weight of the animal weaned at age t, and

$\frac{dW}{dt}$ = a measure of the rate of change in weight.

The two methods differ in their evaluation of this last variable, viz. the rate of change in weight.

Method I is the more universally employed of these two age adjustment procedures, and is the approach currently used in the New Zealand National Beef Recording Service (Anon., 1973a). Its widespread use undoubtedly stems from the beef cattle performance recording recommendations of the United States Beef Cattle Records Committee Report (1965), and more recently from those of the Beef Improvement Federation (1972). This procedure defines the rate of change in weight in equation (2.1) as the average daily gain of the individual from birth to the time it is weaned. That is, using the notation in equation (2.1):

$$\frac{dW}{dt} = \frac{W_t - W_o}{t} \qquad \ldots(2.2)$$

where: W_o = the weight of the individual at birth.

Although Method I has been shown by Swiger et al. (1962) and confirmed by Sellers et al. (1970) "...to rank calves in nearly the same order as more refined procedures...", it still has been subject to some criticism.

The main arguments stem from two disadvantages inherent in this method. First the practical difficulties associated with recording birthweights has often necessitated the use of birthweights that are assumed constant either within breed and sex (e.g., United States Beef Cattle Records Committee Report, 1965), or within breed only (e.g., Anon., 1973a).

An assumption of constant birthweights within defined classes inevitably raises the question of its suitability under widely differing conditions. Reviewing the principles involved in the performance recording of beef cattle in New Zealand, Magnusson (1973) expressed concern over the lack of information available in New Zealand to evaluate this problem. Rice et al. (1967) maintained that the calculation of average daily gains using an assumed birthweight would introduce only a small error into the computations. This may be true provided that the birthweight is assumed constant within breed and sex. If no allowance is made for weight at birth then weight per day of age is calculated, a character that was found by Munro (1962) with 5373 weaning records, to have a spurious negative correlation with age.

The second disadvantage of Method I stems from the assumption that each calf has grown at a constant rate up to the time of weighing, and that this constant rate of growth can be used to predict liveweight at a given (standard) age. Minyard and Dinkel (1965a) with 2351 Hereford and Angus calves, and Sullivan (1967) with 16622 calves, observed that the adjustment of weaning weights for age of calf using Method I over-adjusted the weights of calves in the extreme age groups. The adjusted weights of younger calves were greater, whilst those of older calves were smaller than expected, had they been weighed at the standard age.

The existence of such a bias implies that the actual rate of growth at the time the standard age is reached is less than that formulated by Method I. Consequently late-born calves would receive an adjustment which biases their records upwards, whilst the converse applies to early-born calves. If the actual rate of growth at the standard age is less than that formulated, then either Method I is inappropriate since preweaning growth patterns are not linear, or alternatively Method I remains appropriate within specified ranges in the age at weaning. With 1280 mixed-breed calves in Jamaica, Creek (1964) recommended that comparisons should be made within an age range of 60 days, that is, within a tolerance limit of ± 30 days. On the other hand tolerance limits of ± 45 days and ± 50 days have been recommended in the United States (Beef Improvement Federation, 1972) and in New Zealand (Anon., 1973a), respectively. With weekly weighings of 33 Hereford bulls on performance test in the United Kingdom, Lewis (1967) concluded that although the tolerance limits of ± 45 or ± 50 days were too wide when the exact magnitude of an animal's adjusted weight was desired, in the context of within-herd comparisons under performance recording conditions, these limits were sufficiently accurate to determine the relative magnitude of an animal's adjusted weight.

It is possible that the magnitude of errors introduced through the use of Method I depends on environmental conditions, particularly when such conditions are severe enough to favour non-linear patterns of growth to weaning. The likelihood of errors occurring in adjustment for age by this method may increase when calves at extreme ages are exposed to different climatic conditions during their development to weaning, as Pleasants (1974) has noted. The extent to which climatic factors differ during the preweaning period and the numbers of calves in the extreme age groups, would be expected, on the average, to be greater under severe environmental conditions such as those experienced in the tropics. It is not surprising therefore, that the age range that was acceptable to Creek (1964) for accurate comparisons within selection groups, is less than the ranges commonly recommended in more temperate and developed regions.

It has been suggested (e.g., Lewis, 1967; Rice et al., 1967) that by applying the principle of Method I, a more accurate adjustment for age of calf can be made when two or more weights exist. Since a reduced portion of the growth curve is being evaluated, the calculated average daily gains between the weights will more effectively reflect weight changes in the vicinity of the standard age at weaning. Creek (1964) concluded that for individual comparisons, adjustments based on two weights which did not bracket the standard age (210 days), exhibited the same bias towards younger calves as did the single-weight adjustments, implying a curvilinear growth pattern under the conditions of his study. His adjustments based on two weights bracketing 210 days and within the age range of 90 to 270 days, tended to have the same order of accuracy as those derived from a single weighing within a tolerance limit of $\pm$ 30 days. It may be possible therefore, to apply the Method I adjustment procedure, without major restrictions in age tolerance limits, under conditions in which the preweaning growth rates of calves are known to vary as they approach weaning age, provided that at least two weights are recorded at ages on either side of the standard age.

The second method of adjusting calf weights for age at weaning (Method II), interprets the rate of change in weight defined in equation (2.1) as the linear regression coefficient of weight on age. In estimating the regression coefficient, the weight-age relationship is in fact being evaluated within a range of ages about the standard age that is determined by the data at hand. It could be argued that in comparison with single-weight records adjusted for age by Method I, Method II may derive some advantage since the estimated regression coefficient is indicative of the weight-age relationship of the population over a smaller portion of the growth curve. This argument assumes that growth is linear over the portion of the growth curve to which the adjustments are to be applied may be more justified than the assumption of Method I, where growth is considered to be linear from birth to weaning. On the other hand, if the population is small, or if correlations between weight and age are low (Creek, 1964), the use of Method II in adjusting weights for age at weaning may be of limited value.

Magnusson (1973) considered that by defining the regression coefficient as the rate of gain at weighing for all animals, when "... it is obvious that there is wide variation in rate of gain...", there is a loss in the efficiency of selection since the variation between individuals is ignored. Baker et al.(1974) have argued that "...on statistical grounds..." (details not given), the adjustment of weights for age by procedures involving regression of weight on age such as Method II, is more accurate than adjustment for age by Method I.

Table 2.7 presents some of the published estimates of the regression coefficients of weight on age in beef cattle. The majority of estimates appear to fall within the range of 0.40 to 0.85, with a modal value of 0.68 and a raw mean of 0.67. Formalizing Method II as in expression (2.1), illustrates the use of linear regression of weight on age as an additive adjustment procedure, where the estimated regression coefficient is added or subtracted for each day of age under or over the standard age, respectively. Such a procedure was used by Williams and Murphy (1958) and Magee _et al._ (1961) to adjust the weaning weights of 1957 and 326 beef calves to a standard age of 210 and 180 days, respectively.

An alternative procedure to Method II (which will subsequently be referred to as Method III), involves a mutiplicative computation of age-adjusted weaning weights based on the linear regression coefficient of weight on age. This method may be formalized (after Johnson and Dinkel, 1951) using the notation defined in equation (2.1) as follows:

$$W_a = W_t \left(\frac{t_a - t_i}{t - t_i}\right) \qquad \ldots(2.3)$$

where: t_i = the intercept of the linear regression of weight on age on the age axis.

That is:

$$t_i = \frac{\bar{W} - \frac{dW}{dt}(\bar{t})}{\frac{dW}{dt}} \qquad \ldots(2.4)$$

where: $\bar{W}$ = the mean weight at weaning.

$\bar{t}$ = the mean age at weaning, and

$\frac{dW}{dt}$ = the rate of change in weight, which is defined as the estimated linear regression coefficient of weight on age.

Botkin and Whatley (1953) adjusted 701 weaning weight records to a standard age of 210 days by this procedure. Minyard and Dinkel (1965a) compared the non-adjusted weaning weights of 2351 Hereford and Angus calves with those adjusted for age by Method I and by Method III. In order to evaluate the effectiveness of the two methods of adjustment, the intra-class regressions of weaning weight on age were compared for the three groups of data, as illustrated in Table 2.8. This criterion of evaluation was justified on the grounds that age-adjusted weaning

TABLE 2.7: Published estimates of linear regression coefficients of weaning weight (kg) on age at weaning (days) in beef cattle

Number of records	Breed*	Regression coefficient	Authors
1306	H	0.32	Mahmud and Cobb (1963)
	H	0.41[a]	Evans et al. (1955)
793	H	0.42	Alexander et al. (1964)
1692	H	0.44	Vesely and Robison (1971)
	H	0.49[a]	Evans et al. (1955)
2351	H,A	0.54	Minyard and Dinkel (1965a)
	S	0.55[a]	Gottlieb et al. (1962)
219	Hi,H,RX	0.63	Lawson and Peters (1964)
1861	A	0.64	Hamann et al. (1963)
	H	0.65[a]	Bailey et al. (1972)
701	H	0.66	Botkin and Whatley (1953)
326	H,A	0.68	Magee et al. (1961)
619	H	0.68	Singh et al. (1970)
	H	0.70[a]	Bailey et al. (1972)
	A,H,RX	0.72[a,c]	Baker et al. (1974)
546	H	0.76	J.B. Burgess et al. (1954)
	S	0.81[a]	Gottlieb et al. (1962)
	A	0.82[a,c]	Baker et al. (1974)
	A,H,RX	0.83[a,b]	Baker et al. (1974)
1621	H	0.95	Harwin et al. (1966)
	A	0.97[a b]	Baker et al. (1974)
734	H	1.03	Koch (1951)

* H = Hereford; A = Angus; S = Shorthorn; Hi = Highlander;
RX = Reciprocal crosses amongst the breeds specified.

[a] Estimates obtained within herd or line.

[b] Estimates obtained for males.

[c] Estimates obtained for females.

TABLE 2.8: Regression of weaning weight (y) on age at weaning (x) within farm, year, and month of birth

(Adapted from Minyard and Dinkel, 1965a)

Source	Degrees of freedom	No age adjustment b_{yx} (kg)	Method I age adjustment[a] b_{yx} (kg)	Method III age adjustment[b] b_{yx} (kg)
Total	2350	0.58	-0.20	0.13
Within subclasses	2162	0.54	0.10	0.07

a See equations (2.1) (p.25) and (2.2) (p.26) for details of this procedure, Birth weights (W_o) of 31.8 kg and 29.5 kg for bulls and heifers respectively, and a standard age at weaning (t_a) of 190 days, were assumed.

b See equations (2.3) and (2.4) (p.29) for details of this procedure. A standard age at weaning (t_a) of 190 days was assumed.

weights, for any adjustment procedure, should be independent of calf age. Both methods of age adjustment showed a reduction in the total and intra-class regression coefficients. Method III showed a slightly greater independence of calf age than Method I, leading Minyard and Dinkel (1965a) to support this procedure in adjusting weaning weights for age, although the differences between the two methods in this regard were small (Table 2.8).

An analysis of four methods of age-of-calf adjustment with 16622 weaning weight records, indicated to Sullivan (1967) that a multiplicative linear method of adjustment was the "...most efficient...". It can only be assumed from this author's abstract that the multiplicative linear method of adjustment for age of calf that was employed, applied the principles outlined for Method III on p.29. Furthermore, the criterion of efficiency used by Sullivan (1967) to evaluate the various age-of-calf adjustment procedures was not discussed, and as Searle and Henderson (1960) have pointed out in relation to the adjustment for age effects on production in dairy cattle, no satisfactory criterion appears to evaluate adequately the effectiveness of age adjustment procedures.

One problem that arises with any evaluation of age adjustment procedures is the question of whether the adjustments should be applied additively or multiplicatively. Both approaches appear to equalize means between adjusted groups, but they differ in their effect on variances within adjusted groups. Adding a constant positive or negative value will not alter the variance within adjusted groups, while multiplicative factors raise or lower the variation depending on whether the adjustment factors are larger or smaller than unity (Cundiff, Willham and Pratt, 1966b). Cundiff <u>et al.</u> (1966b) therefore, considered that adjustment factors "...should equalize means between subclasses and variances within subclasses...". The equalization of within-subclass variances is reflected by constant coefficients of variation. Brinks, Clark, Rice and Kieffer (1961) and Creek and Nestel (1964) followed the deductions of Koch, Gregory, Ingalls and Arthaud (1959) that additive adjustments were appropriate when standard deviations were equal, and that multiplicative adjustments were appropriate when the coefficients of variation were equal. However, Searle and Henderson (1960) have noted that aside from being "...a useful adjunct for any set of age-correction factors...", the use of a constant coefficient of variation as a criterion of effective age adjustment is questionable, particularly when it is applied to other types of adjustments such as those for environmental trends.

B. Adjustment for Sex of Calf

Where selection is practiced on individual performance per se, it is unnecessary to adjust the weaning weights of calves for sex since potential male and female replacements will invariably be compared within their respective sex groups. However, the need for an adjustment for sex of calf arises when evaluation of sire progeny groups or of dam summary information is desired.

The adjustment of weaning weight records to a base sex class attempts to reduce the contribution of sex to total variation in weaning weight by estimating the weight of an animal had it been of the base sex under the same environmental conditions. Weights adjusted for age at weaning and age of dam, are commonly adjusted to a male basis, with recommendations for bull-breeding herds to adjust to a bull basis and for commercial beef units to adjust to a steer basis (e.g., Beef Improvement Federation, 1972). Both additive and multiplicative adjustment factors have been advocated to adjust weaning weights for differences between calves due to sex. Additive factors are computed from the average differences between the respective least-squares sex means whilst multiplicative factors are obtained from the ratios of the respective least-squares sex means.

Among others, Koch et al. (1959), Brinks et al. (1961), Koger et al. (1962), Vernon, Harvey and Warwick (1964) and Minyard and Dinkel (1965a) have recommended the use of multiplicative adjustment factors for sex, primarily for the resulting greater equality of means among subclasses and variances within subclasses associated with this procedure. Further to this criterion, Bosman and Harwin (1966) preferred multiplicative adjustment factors with liveweight data since they regarded liveweight growth to be basically a multiplicative process, while Linton et al. (1968) considered that multiplicative adjustment factors for sex would also reduce the size "...of some interactions...". This last point was in agreement with Cundiff et al. (1966b), who found with 13937 Hereford and Angus calves that in addition to more nearly equalizing variances within sexes, multiplicative adjustment factors appeared to account for an observed interaction between sex of calf and type of management (creep- versus non-creep feeding) whereas additive adjustment factors did not. With 25309 Angus and 68850 Hereford calves recorded over a period of 8 years, Schaeffer and Wilton (1974b) regarded that within type of management, the absence of an important interaction of sex with time implied relatively constant differences over time, which suggested the suitability of additive rather than multiplicative sex-of-calf adjustment factors.

Table 2.9 presents some of the multiplicative and additive adjustment factors that have been calculated to adjust the weaning weights of calves for differences due to sex. Estimates of adjustment factors for sex of calf were published by Petty and Cartwright (1966) in which additive differences were 0.0 kg, 5.4 kg and 17.2 kg and multiplicative factors were 1.00, 1.02 and 1.08 for bulls, steers and heifers, respectively. Factors recommended in the United States by the Beef Improvement Federation (1972) involve multiplicative adjustment factors of 1.10 for heifer weights and 1.05 for steer weights where adjustments to a bull basis are desired, and factors of 0.95 for bull weights and 1.05 for heifer weights where weights are to be adjusted to a steer basis. In New Zealand, the National Beef Recording Scheme (Anon., 1973a) additively adjusts the 200-day weights of heifer calves to those of bulls by adding the difference between the raw mean weights for each sex, provided that there are at least 20 animals of each sex. Where there are fewer than 20 animals of each sex, an assumed difference of 11 kg is added to the age-adjusted weights of heifers.

C. <u>Adjustment for Age of Dam</u>

In view of the reported important associations in beef cattle between age of dam and milk production and between milk production and weight of calf weaned (pp.18 and 19), weaning weight records should be adjusted for differences due to age of dam for accurate comparisons within selection groups. The base age to which weaning weight records are adjusted for age of dam has been by tradition the age of maximum (calf weaning weight) production.

Within the North American dairy industry the advantages and disadvantages of adjusting production records to base ages other than the (mature) age of maximum production have received attention recently (McDaniel, 1973). P.D. Miller (1973) deduced that the base age to which dairy records are adjusted by multiplicative procedures has little

TABLE 2.9: Published multiplicative and additive adjustment factors for sex of calf on the weaning weights of beef calves

	Breed*	Bull	Steer	Heifer	Authors
Multiplicative:					
Bull basis	V	1.00		1.07	Bosman and Harwin (1967)
	H	1.00		1.08	Lasley et al. (1961)
	H,A	1.00		1.08	Minyard and Dinkel (1965a)
	H	1.00		1.08	Koch et al. (1973)
	A	1.00	1.03	1.10	Sellers et al. (1970)
	V	1.00	1.06	1.11	Warren et al. (1965)
	H,A	1.00	1.12	1.15	Cundiff et al. (1966b)
	A	1.00		1.16	Seebeck and Campion (1964)
	H	1.00	1.08	1.16	Sellers et al. (1970)
	A	1.00	1.11	1.16	Barlow et al. (1974)
	H	1.00		1.18	Seebeck and Campion (1964)
Steer basis	H		1.00	1.05	Brinks et al. (1961)
	AX		1.00	1.06	Bair et al. (1972)
Additive (kg):					
Bull basis	H	0.0		11.3	Lasley et al. (1961)
	H,A	0.0		15.5	Minyard and Dinkel (1965a)
	A	0.0	6.8	18.2	O'Mary and Ament (1961)
	H,A	0.0	20.6	23.6	Cundiff et al. (1966b)
Steer basis	H,A		0.0	6.8	Magee et al. (1961)
	H		0.0	9.5	Brinks et al. (1961)
	A		0.0	12.7	Williams and Murphy (1958)
	H		0.0	13.2	Williams and Murphy (1958)
	A		0.0	18.1	Hamann et al. (1963)

* V = Various breeds; H = Hereford; A = Angus; AX = Angus- or Hereford-sired calves out of Angus-Holstein dams.

influence on the accuracy of the ranking of individuals. Where adjustment factors are applied additively the base age similarly does not affect the ranking of individuals.

Following the terminology of P.D. Miller (1973) where possible, and applying the proof to beef cattle:

If A_o = the mean weaning weight production level for the base dam age.

A_i = the mean weaning weight production level for the i^{th} dam age, and

Y_i = a record for a calf adjusted to a standard age at weaning out of a cow calving at age i,

then a calf's record adjusted multiplicatively for a cow calving at age i (Y_i^m) may be defined as:

$$Y_i^m = Y_i\left(\frac{A_o}{A_i}\right) .$$

The difference between two such records is:

$$Y_i^m - Y_j^m = Y_i\left(\frac{A_o}{A_i}\right) - Y_j\left(\frac{A_o}{A_j}\right)$$

$$= A_o\left(\frac{Y_i}{A_i} - \frac{Y_j}{A_j}\right) .$$

The base means would be expected to affect not only the magnitude of comparisons between adjusted records, but also the extent of variation among adjusted records.

The ratio of any two adjusted records is:

$$\frac{Y_i^m}{Y_j^m} = \frac{Y_i\left(\frac{A_o}{A_i}\right)}{Y_j\left(\frac{A_o}{A_j}\right)}$$

$$= \frac{Y_iA_j}{Y_jA_i} ,$$

which is unaffected by the base mean. Therefore the rankings of individuals are invariant to the dam age to which adjustments are based.

A calf's record that is adjusted additively for a cow calving at age i (Y_i^a) may be defined as:

$$Y_i^a = Y_i + (A_o - A_i) \quad ,$$

and the difference between any two adjusted records is:

$$\begin{aligned} Y_i^a - Y_j^a &= (Y_i + A_o - A_i) - (Y_j + A_o - A_j) \\ &= (Y_i - A_i) - (Y_j - A_j) \quad . \end{aligned}$$

The base mean would not be expected to affect either the magnitude of any comparison or the extent of variation among adjusted records. The ratio of adjusted records however, does depend on the base age:

$$\frac{Y_i^a}{Y_j^a} = \frac{(Y_i + A_o - A_i)}{(Y_j + A_o - A_j)} \quad ,$$

but to show that the rankings of individuals change, it must be demonstrated that if:

$$\frac{(Y_i + A_o - A_i)}{(Y_j + A_o - A_j)} \gtrless 1 \qquad \ldots(2.5)$$

then:

$$\frac{(Y_i + A_o' - A_i)}{(Y_j + A_o' - A_j} \not\gtrless 1 \quad ,$$

where: A_o' = the mean weaning weight production level for an alternative base dam age, such that $A_o' \neq A_o$.

Considering ratio (2.5) , such that:

$$\frac{(Y_i + A_o - A_i)}{(Y_j + A_o - A_j)} = \frac{Y_i + a_i}{Y_j + a_j} \quad ,$$

where: $a_i = (A_o - A_i)$

and $a_j = (A_o - A_j)$,

the ratio of weights adjusted to the alternative base age can be considered as:

$$\frac{Y_i + A_o - A_i}{Y_j + A_o' - A_j} = \frac{Y_i + A_o - A_i - A_o + A_o'}{Y_j + A_o - A_j - A_o + A_o'}$$

$$= \frac{Y_i + a_i - (A_o - A_o')}{Y_j + a_j - (A_o - A_o')}$$

$$= \frac{Y_i + a_i - k}{Y_j + a_j - k} \quad ,$$

where: $k = (A_o - A_o')$.

By definition in (2.5):

$$\frac{Y_i + a_i}{Y_j + a_j} \geqslant 1 \quad ,$$

which implies that:

$$(Y_i + a_i) \geqslant (Y_j + a_j) \quad , \qquad \ldots(2.6)$$

and subtracting a constant (k) from both sides of expression (2.6) will not alter the defined inequality.

That is:

$$(Y_i + a_i - k) \geqslant (Y_j + a_j - k)$$

and:

$$\frac{Y_i + a_i - k}{Y_j + a_j - k} \geqslant 1 \quad .$$

It can be concluded therefore that when records are adjusted additively, the rankings of individuals are invariant to the dam age to which adjustments are based.

In contrast to the United States' dairy industry, the relative merits and problems involved in adjusting weaning weight records to a base dam age other than the age of maximum production have not yet been fully investigated within most beef cattle industries. It is possible that there is no reason to change the base age to one other than maturity, unless it can be demonstrated that adjustment factors based on a non-mature age are more accurate at both the individual and population levels defined earlier (p.2).

Two convential methods of calculating adjustment factors of age of dam by least squares, are first to compare the averages of all records made at each age (the Gross Comparison Method), and secondly to compare adjacent records made by the same cow (the Paired Comparison Method). The difficulty with either of these procedures is that the effects of selection can bias the estimated age effects from those of the true age effects.

The nature of this bias was first discussed in relation to dairy cattle by Lush and Shrode (1950) and subsequently applied to beef cattle by Koch and Clark (1955a). Briefly, if cows are culled at each age for low production then older age groups would contain a larger proportion of high-producing cows than the younger age groups. Therefore, age-of-dam adjustment factors computed by the Gross Comparison Method would be biased upward from the true age effect. The Paired Comparison Method attempts to avoid such effects due to selection (i.e., eliminating differences between cows) by comparing the change in production of adjacent records of the same cow. This method however, introduces a downward bias from the true age effect because of the incomplete repeatability of weaning weight records by the same cow. Lush and Shrode (1950) considered that because the biases in the Gross Comparison and Paired Comparison methods were in opposite directions, the true age change should lie between the apparent age changes computed by the two methods. They further pointed out that errors in adjustment factors amounting to less than one quarter of a standard deviation of a cow's estimated producing ability were of little practical importance.

Koch and Clark (1955a) estimated the repeatability of adjacent weaning weights (t) "...from another study..." and attempted to derive unbiased estimates for age of dam by proportioning the differences between the Gross Comparison and Paired Comparison methods as $t/(1-t)$ for each age-of-dam class. They concluded that the resulting combination of estimates from the Gross and Paired Comparison methods represented the "...best estimates...of the additive age effect...". Table 2.10 presents the estimates of Koch and Clark (1955a) of age effects relative to a 6-year-old cow obtained by the Gross Comparison, Paired Comparison and Combined methods. It can be seen that the Combined estimates are intermediate between those derived from the Gross and Paired Comparison methods.

Marlowe et al. (1965) compared the Gross Comparison and Paired Comparison methods of computing adjustment factors for age of dam for

TABLE 2.10: Additive adjustment factors for age of dam on weaning weight obtained by Gross Comparison, Paired Comparison and Combined procedures[a]

(Adapted from Koch and Clark, 1955a)

Procedure	Age of dam (years)							
	3	4	5	6	7	8	9	10
Gross Comparison (kg):	21	10	4	0	4	1	3	7
Paired Comparison (kg):	16	6	2	0	2	5	9	16
Combined[b] (kg):	19	8	3	0	1	3	5	11

[a] Estimates are presented relative to a 6-year-old cow, to the nearest kilogram.

[b] Combined estimates derived by proportioning the difference between the gross and paired comparison methods as $t/(1-t)$, where t, the repeatability of adjacent weaning weights, is defined as 0.46.

the preweaning average daily gain records of 8972 Angus calves and 5210 Hereford calves. Both methods produced similar results for each breed, leading the authors to conclude that selection for milk production in beef cows was either not practiced or was ineffective.

Since least squares estimation of age-of-dam adjustment factors is complicated by the practice of culling on the basis of performance, Henderson (1949) illustrated the suitability of "...maximum likelihood ..." procedures to estimate environmental effects under conditions of selection for performance and of incomplete repeatability of performance. (Current terminology now refers to these procedures as "best linear unbiased estimation" procedures, Henderson, 1973).

To obtain unbiased estimates of age effects using best linear unbiased estimation, the ratio of specified variance components must be known. In relation to dairy cattle, Henderson (1958) drew attention to the biases in estimates of environmental trends caused by errors in age adjustment and repeatability (a function of variance component ratios). Henderson, Kempthorne, Searle and Von Krosigk (1959) subsequently expanded the method towards the estimation of genetic and environmental trends. This theory is also applicable to the estimation of age effects.

Models involving best linear unbiased estimation procedures for the estimation of the effects of age on production have been successfully applied to dairy cattle records of production by such workers as R.H. Miller, Harvey, Tabler, McDaniel and Corley (1966), P.D. Miller and Henderson (1968), P.D. Miller, Lentz and Henderson (1970), Wunder and McGilliard (1971) and P.D. Miller (1973). Best linear unbiased estimation, arising from mixed model techniques, has the most appeal in estimating age effects since least squares estimates assume that cow effects are completely repeatable over years whereas best linear unbiased estimates do not, employing both within-cow and among-cow differences (R.H. Miller <u>et al</u>., (1966).

There have been few applications of best linear unbiased estimation techniques to beef cattle records in order to determine age-of-dam adjustment factors for weaning weights. Cunningham and Henderson (1965a,b) iteratively estimated the effects of sex of calf, age of dam and year of birth on the preweaning average daily gains and type scores of 4838 Hereford and Angus calves. The resulting estimates were then applied as adjustment factors in order to estimate the heritabilities and repeatabilities of these traits. Subsequent presentation of this technique (Cunningham and Henderson, 1968) was later modified by Thompson (1969) in order that unbiased estimates of variance components and fixed effects may be obtained.

Neville et al. (1974) analysed 398 lactation and 820 weaning weight records from two Hereford herds by least squares and best linear unbiased estimation (termed maximum likelihood in their paper) procedures in order to estimate differences due to the effects of age of dam. For daily milk production and weaning weight (adjusted to 210 days of age by Method I), the means and multiplicative adjustment factors for each age-of-dam group within herds were similar for both procedures, although the standard errors for the least squares means were generally larger. Despite the similarity in estimates, these authors did not dispute "...the increased efficiency of the ML [maximum likelihood] procedure as compared with the LS [least squares] procedure...".

Schaeffer and Wilton (1974a,b) have provided one of the first comprehensive applications of best linear unbiased estimation procedures to beef cattle. After accounting for herd and cow differences, estimates were obtained for age of dam-sex-type of management (creep versus non-creep feeding) and for age of dam-sex-level of herd performance subclasses in 25571 Angus and 69058 Hereford calves in Canada. The resulting age-of-dam by sex by "environmental" subclass means were then employed to determine the significance of all interactions, and to compare the effectiveness of developed additive and multiplicative adjustment factors.

As has been the case for computing adjustment factors for sex of calf, both additive and multiplicative adjustment factors have been recommended for the adjustment of weaning weight records for differences due to age-of-dam effects. Cundiff et al. (1966b) suggested that additive adjustment factors were more suitable since the standard deviations of weaning weights for different ages of dams were relatively constant. This was in agreement with O'Mary and Ament (1961), who found with 97 weaning records that additive adjustment of weaning weights for age of dam was more effective in reducing variation in weaning weight due to age of dam than multiplicative adjustment. Over an 8-year period, Schaeffer and Wilton (1974b) reported that in addition to equalizing variances within age-of-dam groups, additive adjustment factors for pre-weaning average daily gain were more appropriate than multiplicative adjustments in view of the differences in the means for age-of-dam groups remaining constant over time. According to Preston and Willis (1970), published reports tend to support additive adjustment factors for age of dam, although some authors dissent from this view (e.g., Linton et al., 1968) for reasons outlined previously in relation to adjustments for sex (p.33). Baker et al. (1974) provided the first set of published estimates of age-of-dam adjustment factors for beef cattle in New Zealand, but it can only be implied that additive adjustments for age of dam were preferred in terms of reducing differences between the two locations of the herds studied.

Table 2.11 presents some of the published additive and multiplicative adjustment factors employed to adjust the weaning weights of beef calves for age-of-dam influences. Where possible, estimates presented in Table 2.11 have been adapted to a base age of dam of 6 to 9 years of age. The lack of an adequate set of criteria to evaluate the efficiency of age adjustment factors (Searle and Henderson, 1960), has no doubt contributed to the fact that neither additive nor multiplicative adjustment factors for age-of-dam effects on weaning weight records appear to be entirely satisfactory under all conditions. The most appropriate set of adjustment factors are those determined in the herd to which they are to be applied, "... provided the data are not biased and the herd is sufficiently large to give reliable estimates..." (Gregory et al., 1961). Baker et al. (1974), on the basis of estimated standard deviations and an assumed normal herd-age of dam distribution, suggested that approximately 25 animals for each non-mature age group would be required to reduce the standard error of age-of-dam estimates within years to 5 kg, implying a herd size of 125 cows. In view of the small size of registered beef herds in New Zealand (Cairney and Magnusson, 1970) and of the relatively widespread performance recording but centralized processing conditions prevailing at the present time, a general set of adjustment factors for age-of-dam effects may be more practicable. Data adjusted by such a general set of factors may be useful for making basic comparisons under on-farm conditions, but by nature of its generality inherent inaccuracies within the set would limit the accuracy of close individual comparisons.

TABLE 2.11: Published additive and multiplicative adjustment factors for age of dam on the weaning weights of beef calves[a]

Breed[b]	Standard weaning age	Age of dam (years) 2	3	4	5	6-9	10	11	12	13	Authors
Additive (kg):											
	180	15.9	5.5	2.3	0.0	0.0	0.0	1.4	3.6	8.2	Clum *et al.* (1956)
A	180	34.1	20.0	8.6	3.2	0.0					O'Mary and Ament (1961)
H,A	190	34.6	18.7	11.9	7.8	0.0	5.6	9.2	15.5	16.9	Minyard and Dinkel (1965a)[c]
H,A,RX	200	23.7	9.7	4.6	0.0	0.0	0.0	0.0	0.0	0.0	Baker *et al.* (1974)[d]
AX	205	12.3	9.8	6.2	1.3	0.0	14.9	22.7			Bair *et al.* (1972)
A	205	26.7	14.8	4.0	0.0	0.0					Cardellino and Frahm (1971)
H	205	38.0	16.6	2.3	0.0	0.0					Cardellino and Frahm (1971)
H,A	205	[e]	[e]	6.8	3.9	0.0	0.0	0.0	0.0	0.0	Cundiff *et al.* (1966b)
Multiplicative:											
H,A		1.09	1.09	1.05	1.00	1.00	1.00	1.03	0.96		Meade *et al.* (1959)
H	200	1.11	1.11	1.05	1.02	1.00	1.00	1.00	1.00	1.00	Taylor (1967)[f]
A	200	1.13	1.13	1.06	1.02	1.00	1.00	1.00	1.00	1.00	Thomson (1968)[f]
	200	1.15	1.10	1.05	1.00	1.00	1.00	1.00	1.00	1.00	Anon. (1973a)
H,A,RX	200	1.16	1.06	1.03	1.00	1.00	1.00	1.00	1.00	1.00	Baker *et al.* (1974)[d]
H,A	205	1.11[g]	1.06[h]	1.02	1.02	1.00	1.00	1.00	1.00	1.04	Sellers *et al.* (1970)[f]
	205	1.15	1.10	1.05	1.00	1.00	1.00	1.05	1.05	1.05	U.S.B.C.R.C.R. (1965)[i]
H	210	•	1.10	1.05	1.02	1.00[k]	1.02	1.02	1.02	1.02	Neville *et al.* (1974)[d,j]
H	210		1.11	1.05	1.02	1.00[k]	1.02	1.02	1.02	1.02	Neville *et al.* (1974)[d]

[a] Wherever possible, estimates have been adapted to a base (mature) age of 6 to 9 years of age inclusive.

(con't)

TABLE 2.11 (cont'd)

[b] H = Hereford; A = Angus; RX = Reciprocal crosses amongst the breeds specified; AX = Angus- or Hereford-sired calves out of Angus x Holstein dams.

[c] Combined estimates of Gross and Paired Comparison methods of adjustment after Koch and Clark (1955a). (See p.39).

[d] Factors averaged over herds.

[e] Age-of-dam groups divided into 2- to 5-month intervals (estimated adjustment factors) as follows: 27 mo. (29.3 kg), 28-30 mo. (23.5 kg), 31-33 mo. (19.9 kg), 34-39 mo. (16.1 kg) and 40-45 mo. (9.1 kg).

[f] Factors averaged over sexes.

[g] Dams 34 months of age.

[h] Dams 34-45 months of age.

[i] United States Beef Cattle Records Committee Report (1965).

[j] Factors derived by applying best linear unbiased estimation procedures. (See p.41).

[k] 9 year-old dams assigned a multiplicative factor of 1.02.

CHAPTER 3

METHODS

In this study, the major factors influencing weaning weight and the first-order interactions among them, were estimated by least squares analyses. In addition, estimates of the effects of age of dam on weaning weights, unbiased by the effects of selection and incomplete repeatability, were obtained through the application of best linear unbiased estimation procedures.

I. LEAST SQUARES ANALYSES

Within the Hereford and Angus breeds each calf was classified according to herd, year of birth, age of dam and sex. The grouping of dam ages for the age-of-dam classes is given in Table 3.1.

A. Estimation of Main Effects Excluding First-Order Interactions

The model used was:

$$Y_{ijklm} = \alpha + h_i + y_j + d_k + s_l + b(X_{ijklm}) + e_{ijklm} \quad \ldots(3.1)$$

where: Y_{ijklm} = the observed weight at X days of age of the m^{th} calf of the l^{th} sex born in the i^{th} herd and the j^{th} year out of a dam belonging to the k^{th} age group.

α = the theoretical population mean with equal sub-class numbers when weaning age is zero. The population mean with equal frequencies when the age at weaning is equal to the average age is:

$$\mu = \alpha + b\,(\bar{X})$$

h_i = the effect of the i^{th} herd.

y_j = the effect of the j^{th} year.

d_k = the effect of the k^{th} age-of-dam group.

s_l = the effect of the l^{th} sex of calf.

b = the partial regression coefficient of weight on age at weaning.

TABLE 3.1: Grouping of dam ages for age-of-dam classes on calf weaning weights

Dam age (years)	Age-of-dam class
2	1
3	2
4	3
5	4
6–9	5
10+	6

X_{ijklm} = the age at weaning of the m^{th} calf of the l^{th} sex born in the i^{th} herd and j^{th} year out of a dam of the k^{th} age group, and

e_{ijklm} = the random error peculiar to the m^{th} calf.

All effects in model (3.1), with the exception of the error effects, were assumed fixed. The e_{ijklm} were assumed to be normally and independently distributed with mean zero and variance σ_e^2; the assumption of normality being required for tests of significance.

Initially, the first-order interactions among herd, year, age-of-dam group and sex effects, were considered to contribute little to the total variation in weaning weight and were therefore excluded from the model. The validity of this assumption was tested in subsequent individual applications of model (3.1), (Section B), for the following first-order interactions:

$(hy)_{ij}$ ... the interaction effect of the i^{th} herd with the j^{th} year.

$(hd)_{ik}$ ... the interaction effect of the i^{th} herd with the k^{th} age-of-dam group.

$(hs)_{il}$ ... the interaction effect of the i^{th} herd with the l^{th} sex.

$(yd)_{jk}$ ... the interaction effect of the j^{th} year with the k^{th} age-of-dam group.

$(ys)_{jl}$ ... the interaction effect of the j^{th} year with the l^{th} sex, and

$(sd)_{lk}$ ... the interaction effect of the l^{th} sex with the k^{th} age-of-dam group.

Model (3.1) may be written in matrix notation as:

$$Y = Xb + e \qquad ...(3.2)$$

where: Y = a known (N x 1) vector of weaning weight records; where N is the total number of records.

X = a known (N x p) incidence matrix of the fixed effects defined in model (3.1); where p is the total number of groups of effects.

b = an unknown (p x 1) vector of parameter values to be estimated, and

e = an unknown (N x 1) vector of random error effects in which the elements are assumed to be normally and independently distributed 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 minimizing the sum of squares of the observations from their expected values.

With $E(e) = 0,$

then:

$$E(Y) = Xb,$$

and:

$$e'e = [Y - Xb]'[Y - Xb] \quad .$$

Differentiating e'e with respect to the elements of b, and equating to zero, leads to the equations:

$$X'Xb = X'Y \qquad \text{...(3.3)}$$

from which:

$$\hat{b} = (X'X)^{-1} X'Y , \qquad \text{...(3.4)}$$

where $\hat{b}$ is the estimated value of b which minimizes e'e. When X'X is of full rank then $(X'X)^{-1}$ exists, and $\hat{b}$ defined in (3.4), is the only solution to the normal equations (3.3). Where linear dependencies exist among the equations, the X'X matrix is not of full rank and restrictions must be imposed on the normal equations to reduce the X'X matrix to a sub-matrix of full rank. The restrictions applied to the normal equations in this study were that the estimates within a given group sum to zero. That is, in terms of model (3.1):

$$\sum_i \hat{h}_i = \sum_j \hat{y}_j = \sum_k \hat{d}_k = \sum_l \hat{s}_l = 0 \quad ,$$

and of the normal equations (3.3):

$$(X'X)_r b^o = (X'Y)_r \quad , \qquad \text{...(3.5)}$$

where b^o is a vector of estimates of the remaining effects, and $(X'X)_r$ and $(X'Y)_r$ are the reduced X'X matrix and X'Y vector respectively, after the restrictions have been imposed.

Before inversion of the reduced X'X matrix, equations for the mean and herds were absorbed into the remaining equations for years, age of dam, sex and regression of weight on age. If $(X'X)_r$, $(X'Y)_r$ and b^o in equation (3.5) are partitioned as:

$$\begin{bmatrix} A_{v \times v} & B_{v \times w} \\ B'_{w \times v} & C_{w \times w} \end{bmatrix} \begin{bmatrix} a \\ c \end{bmatrix} = \begin{bmatrix} V_{v \times 1} \\ W_{w \times 1} \end{bmatrix} \quad , \qquad ...(3.6)$$

where: A = a square (v x v) matrix with corresponding (v x 1) vectors of observations (V) and parameter values (a), and where v is the number of sub-groups for the mean and herds after the restrictions have been imposed.

C = a square (w x w) matrix with corresponding (w x 1) vectors of observations (W) and parameter values (c), and where w is the number of sub-groups for years, age of dam, sex and regression of weight on age after the restrictions have been imposed, and

B = a non-diagonal (v x w) matrix.

Expansion of (3.6) gives:

$$\begin{aligned} Aa + Bc &= V \\ B'a + Cc &= W \end{aligned} \qquad ...(3.7)$$

Solving the first equation for a:

$$a = A^{-1}V - A^{-1}Bc \qquad ...(3.8)$$

and substituting for a in the second equation of (3.7) gives:

$$(C - B'A^{-1}B)c = W - B'A^{-1}V \quad , \qquad ...(3.9)$$

from which:

$$\hat{c} = (C - B'A^{-1}B)^{-1}(W - B'A^{-1}V) \quad , \qquad ...(3.10)$$

and $\hat{a}$ may be computed by substitution of $\hat{c}$ for c in expression (3.8).

The total reduction in sum of squares for fitting model (3.1) is estimated from:

$$R(b^o) = b^o(X'Y)_r = \begin{bmatrix} a \\ c \end{bmatrix} \begin{bmatrix} V \\ W \end{bmatrix} \quad , \qquad ...(3.11)$$

and the sum of squares for error is computed from $Y'Y - R(b^o)$, where Y'Y is the total uncorrected sum of squares of observations.

The individual sums of squares for the mean, herd, year, age-of-dam, sex and regression of weight-on-age effects can be determined by:

$$\hat{B}'_q Z_q^{-1} \hat{B}_q \quad ,$$

where: $\hat{B}'_q$ = a row vector of the estimates for the q^{th} group of effects,

Z_q^{-1} = the inverse of the square symmetrical segment of the inverse of $\left[(X'X)_r\right]^{-1}$ corresponding to the q^{th} group of effects, and

$\hat{B}_q$ = a column vector of the estimates for the q^{th} group of effects.

Harvey (1964) has shown that sums of squares computed in this manner are identical to those obtained by differences in total reductions in the sums of squares. The square symmetrical segments of the inverse of $\left[(X'X)_r\right]^{-1}$ corresponding to the mean and to the herd effects, were not obtained directly in this study because of their absorption into the remaining effects of years, age of dam, sex and regression of weight on age. It can be shown however, that the segments of $\left[(X'X)_r\right]^{-1}$ corresponding to the mean and herd effects may be computed from the results of the absorption procedure. From expression (3.6), where the reduced X'X matrix was partitioned such that:

$$(X'X)_r = \begin{bmatrix} A & B \\ B' & C \end{bmatrix} ,$$

the correspondingly partitioned inverse of $(X'X)_r$ may be defined as:

$$\left[(X'X)_r\right]^{-1} = \begin{bmatrix} M & N \\ N' & Q \end{bmatrix} .$$

Inverting $(X'X)_r$ by partitioning involves three steps:

(i) $Q = (C - B'A^{-1}B)^{-1}$,

(ii) $N = -A^{-1}BQ$,

(iii) $M = (A^{-1} - NB'A^{-1})$.

It can be seen from equation (3.10) that Q of step (i) above has been calculated. Therefore the square symmetrical segment of the inverse of $(X'X)_r$ corresponding to the mean and herd effects (M) may be computed from steps (ii) and (iii), and that Z_q^{-1} corresponding to the q^{th} group of estimates may be determined from inverting the appropriate segments of M and Q above.

The relative importance of each main effect defined in model (3.1) was determined by comparing the percentage reduction in error variance resulting from fitting a sub-model with all effects included except the main effect in question and from fitting the full model with all effects included (model (3.1)).

The estimation of sub-group means and standard erors followed the procedures outlined by Harvey (1960). In terms of model (3.1) the mean for the i^{th} estimate of the q^{th} group of effects was defined as:

$$\hat{\mu} + \hat{q}_i = \hat{\alpha} + \hat{b}(\bar{X}) + \hat{q}_i ,$$

where: $\bar{X}$ = the mean age at weaning;

with a standard error defined as:

$$\sqrt{(Z^{\mu+q_i\,\mu+q_i})\hat{\sigma}_e^2} = \sqrt{(Z^{\alpha\alpha} + 2\bar{X}Z^{\alpha b} + \bar{X}^2 Z^{bb} + Z^{q_i q_i} + 2Z^{\alpha q_i} + 2\bar{X}Z^{bq_i})\hat{\sigma}_e^2}$$

where: Z = the inverse of the reduced X'X matrix, with superscripts denoting the row and column for each element, and

$\hat{\sigma}_e^2$ = the error mean square.

If the i^{th} coefficient of the q^{th} group of effects in the normal equations was subtracted out in accordance with the imposed restriction that $\sum_i \hat{q}_i = 0$, such that:

$$\hat{q}_i = -\sum_{i-1} \hat{q}_i \qquad \text{for } i \neq i' ,$$

the diagonal element of q_i in Z was derived by:

$$Z^{q_i q_i} = Z^{q_1 q_1} + 2(Z^{q_1 q_2}) + \ldots + 2(Z^{q_1 q_{i-1}}) + \ldots + Z^{q_{i-1} q_{i-1}} + 2(Z^{q_{i-2} q_{i-1}}).$$

The non-diagonal inverse element of $\hat{q}_i$ with the mean or the regression of weight-on-age effects was determined from:

$$Z^{\alpha q_i} = -(\sum_{i-1} Z^{\alpha q_{i'}}) \quad \text{for} \quad i \neq i' \quad ,$$

and

$$Z^{bq_i} = -(\sum_{i-1} Z^{bq_{i'}}) \quad \text{for} \quad i \neq i' \quad ,$$

respectively. Differences between sub-group means for age-of-dam and for sex groups were tested by the Student-Newman-Keuls test for multiple comparisons among means based on unequal sample sizes, as illustrated by Sokal and Rohlf (1969).

Variances within each age-of-dam group and each sex group were estimated by arranging the weaning weights, adjusted for age of calf, into herd-year-age of dam-sex sub-groups. Corrected sums of squares and associated degrees of freedom were obtained for each sub-group, and the corrected sums of squares for a given age-of-dam or sex group were pooled and divided by the correspondingly pooled degrees of freedom.

B. Estimation of First-Order Interactions

For each breed, all first-order interactions among herd, year, age-of-dam group and sex effects classified in model (3.1) were considered individually in order to determine their levels of significance and relative degrees of importance. The models used for each interaction analysis, the terms of which have been defined in Section A, are presented in Table 3.2. Least squares estimation procedures followed the principles outlined in Section A.

On occasions, the size of the X'X matrix in the normal equations was such that solution of the equations was initially simplified by absorbing the mean, the two interacting main effects and the interaction terms into the remaining main effects within each interaction analysis. For example, in the herd x year analysis, equations for the mean, herd, year and herd x year terms were absorbed into the remaining equations for age-of-dam, sex and regression of weight on age. After absorption, the equations in the resulting matrix still retained linear dependencies which necessitated the imposition of restrictions on two of the

TABLE 3.2: Models employed in within-breed least squares estimation of main effects for individual first-order interactions

Interaction analysis	Model[a]
Herd x year	$Y_{ijklm} = \alpha + h_i + y_j + d_k + s_l + b(X_{ijklm}) + (hy)_{ij} + e_{ijklm}$
Herd x dam-age	$Y_{ijklm} = \alpha + h_i + y_j + d_k + s_l + b(X_{ijklm}) + (hd)_{ik} + e_{ijklm}$
Herd x sex	$Y_{ijklm} = \alpha + h_i + y_j + d_k + s_l + b(X_{ijklm}) + (hs)_{il} + e_{ijklm}$
Year x dam-age	$Y_{ijklm} = \alpha + h_i + y_j + d_k + s_l + b(X_{ijklm}) + (yd)_{jk} + e_{ijklm}$
Year x sex	$Y_{ijklm} = \alpha + h_i + y_j + d_k + s_l + b(X_{ijklm}) + (ys)_{jl} + e_{ijklm}$
Sex x dam-age	$Y_{ijklm} = \alpha + h_i + y_j + d_k + s_l + b(X_{ijklm}) + (sd)_{lk} + e_{ijklm}$

[a] See text (Section A) for definitions of terms.

remaining effects before an inverse could be obtained. Table 3.3 presents the equations that were absorbed, the remaining main effects into which the absorption was carried out, and the restrictions subsequently imposed on the remaining effects for each interaction analysis.

The calculation of the total reduction in sums of squares for fitting the models in Table 3.2 and the error sums of squares involved the same procedures as those considered in Section A. The sums of squares for the individual interaction terms were computed by differencing the total reduction in sums of squares for fitting the respective models in Table 3.2 from the reduction in sum of squares for fitting the model of main effects only (model (3.1)). The relative level of importance of each interaction was determined by comparing the percentage reduction in error variance resulting from fitting the respective models listed in Table 3.2 and from fitting the main-effects model (3.1).

II. BEST LINEAR UNBIASED ESTIMATION ANALYSIS

In this section best linear unbiased estimation arising from mixed model techniques is applied to the problem of estimating the effects of age of dam on weaning weight, free from the influences of culling of dams on performance and the incomplete repeatability of dam records.

The model used was:

$$Y_{ijk} = \mu + a_i + h_j + c_{jk} + e_{ijk} \qquad \ldots(3.12)$$

where: Y_{ijk} = the weaning weight, adjusted for age and sex, of the calf out of the k^{th} cow belonging to the i^{th} age group in the j^{th} herd-year.

μ = the population mean weaning weight adjusted for age and sex when equal subclass numbers exist.

a_i = the effect of the i^{th} age-of-dam group as defined in Table 3.1. Age group effects were considered to be fixed effects.

h_j = the effect of the j^{th} herd-year. The herd-year effects were assumed to be fixed effects.

c_{jk} = the effect of the k^{th} cow in the j^{th} herd-year.

TABLE 3.3: Equations absorbed into remaining main effects and the restrictions subsequently imposed to solve the normal equations for each interaction analysis[a]

Interaction analysis	Equations absorbed	Remaining main effects	Restrictions imposed
Herd x year	$\alpha + h_i + y_j + (hy)_{ij}$	d_k, s_l, b	$\sum_k \hat{d}_k = \sum_l \hat{s}_l = 0$
Herd x dam-age	$\alpha + h_i + d_k + (hd)_{ik}$	y_j, s_l, b	$\sum_j \hat{y}_j = \sum_l \hat{s}_l = 0$
Herd x sex	$\alpha + h_i + s_l + (hs)_{il}$	y_j, d_k, b	$\sum_j \hat{y}_j = \sum_k \hat{d}_k = 0$
Year x dam-age	$\alpha + y_j + d_k + (yd)_{jk}$	h_i, s_l, b	$\sum_i \hat{h}_i = \sum_l \hat{s}_l = 0$
Year x sex	$\alpha + y_j + s_l + (ys)_{jl}$	h_i, d_k, b	$\sum_i \hat{h}_i = \sum_k \hat{d}_k = 0$
Sex x dam-age	$\alpha + s_l + d_k + (sd)_{lk}$	h_i, y_j, b	$\sum_i \hat{h}_i = \sum_j \hat{y}_j = 0$

[a] See text (Section A) for definitions of terms.

Cow effects were assumed to be random effects distributed independently with zero mean and variance $I\sigma_c^2$, and

e_{ijk} = the random error effect of the k^{th} cow in the j^{th} herd-year belonging to the i^{th} age group. Error effects were assumed to be independently distributed with mean zero and variance $I\sigma_e^2$.

The advantage of the mixed model approach stems from the fact that both within-cow and between-cow differences are utilized.

Writing model (3.12) in matrix notation:

$$Y = Xb + Zu + e \qquad \ldots(3.13)$$

where: Y = a known (N x 1) vector of weaning weight records adjusted for age and sex-of-calf, where N is the total number of records.

X = a known (N x p) incidence matrix of the fixed effects of the model, where p is the number of mean, age-of-dam group and herd-year effects.

b = an unknown (p x 1) vector of parameter values of the mean, age-of-dam group and herd-year effects.

Z = a known (N x q) incidence matrix of the random effects of the model, where q is the number of cow effects.

u = an unknown (q x 1) vector of parameter values of the cow effects of the model. The elements of u are assumed to have a multivariate distribution with mean zero and variance-covariance matrix $D\sigma_e^2$, where D is a known non-singular (q x q) matrix, and

e = an unknown (N x 1) vector of random error effects having a multivariate distribution with zero mean and variance-covariance matrix $R\sigma_e^2$, where R is a known non-singular (N x N) matrix.

It is further assumed that the covariance between the vectors u and e is zero.

A. Development of the Mixed Model Solution

If the variance components of the random effects in the model are known, estimable functions of the fixed effects can be determined from a solution to the normal equations:

$$X'V^{-1}Xb^{o} = X'V^{-1}Y \quad , \qquad \ldots(3.14)$$

where V is the (N x N) variance-covariance matrix of Y, the elements of which are functions of the assumed known variance components:

$$\begin{aligned} V &= E[Y - E(Y)]\,[Y - E(Y)]' \\ &= E[Y - Xb]\,[Y - Xb]' \\ &= E[Zu + e]\,[Zu + e]' \\ &= E[Zuu'Z'] + E[ee'] \\ &= (ZDZ' + R)\sigma_e^2. \end{aligned}$$

More commonly, the variance components are not known and the problem becomes one of estimation of both the fixed effects and the variance components in the model.

One approach, assuming the elements of the vectors u and e to be normally distributed, relies on the simultaneous estimation of b and u by maximizing the joint density of Y and u for variations in b and u. That is:

$$\begin{aligned} f(Y,u) &= g(Y|u)h(u) \\ &= (\text{Constant})\exp\left[-\tfrac{1}{2}(Y - Xb - Zu)'R^{-1}(Y - Xb - Zu)\right]\exp\left[-\tfrac{1}{2}u'D^{-1}u\right], \end{aligned}$$

and maximizing with respect to b and u gives:

$$\begin{bmatrix} X'R^{-1}X & X'R^{-1}Z \\ Z'R^{-1}X & (Z'R^{-1}Z + D^{-1}) \end{bmatrix} \begin{bmatrix} \hat{b} \\ \hat{u} \end{bmatrix} = \begin{bmatrix} X'R^{-1}Y \\ Z'R^{-1}Y \end{bmatrix}. \qquad \ldots(3.15)$$

As demonstrated by Henderson (1973) and Anderson (1974), solution of equations (3.15) results in best linear unbiased estimation of fixed effects and best linear unbiased prediction of random effects in the mixed model (3.13).

It is worthwhile to note that when D is a diagonal matrix of one independently distributed random effect with variance σ_1^2 and zero covariance with e, and when R is equal to $I\sigma_e^2$ under the assumption that error effects are independently distributed, equations (3.15) reduce to:

$$\begin{bmatrix} X'X & X'Z \\ Z'X & (Z'Z + \frac{\sigma_e^2}{\sigma_1^2} I) \end{bmatrix} \begin{bmatrix} \hat{b} \\ \hat{u} \end{bmatrix} = \begin{bmatrix} X'Y \\ Z'Y \end{bmatrix}. \qquad \ldots(3.16)$$

B. <u>The Mixed Model Solution Applied to Model (3.12)</u>

In applying the mixed model solution equations (3.15) to model (3.12), it is pertinent to consider the assumptions made in specifying (3.12) and some of the consequences of these assumptions.

Fitting herd-year subclasses were assumed to eliminate biases from potentially large herd-by-year interactions. Another assumption implicit in model (3.12) is that there is no interaction between age-of-dam group and herd-year. The failure of this assumption to hold true may affect the applicability of estimates. According to R.H. Miller <u>et al</u>. (1966) if adjustment factors derived from age-of-dam group estimates are applied in multiplicative form, any real interactions involving age of dam will be partially offset.

With the herd-year effects assumed to be fixed, the estimates for age-of-dam groups are effectively being fitted on an intra-herd-year basis. If herd-year effects are assumed to be random effects, the precision of age-of-dam group estimates may be increased depending on the composition of ages of dams in the different herd-years. If the age composition varies little between high- and low-producing herd-years then the increased accuracy of estimation may be expected to be slight. On the other hand, if the age compositions in high-producing herd-years differ appreciably from those in low-producing herd-years, the assumption of random herd-year effects may result in biased estimates since the average level of herd-years associated with age-of-dam groups ($\sum_j h_{j.} n_{ij.}/n_{i..}$) would be expected to differ. This bias can be eliminated by computing as though the herd-year effects are fixed (Henderson, 1973).

The error effects are assumed to have zero covariance between e_{ijk} and $e_{ijk'}$, with a consequent variance-covariance matrix of $I\sigma_e^2$, where σ_e^2 is the error variance. This assumption results in computational advantages associated with the mixed model solution equations (3.15) since:

$$R = E(ee') = I\sigma_e^2 ,$$

and equations (3.15) reduce to:

$$\begin{bmatrix} X'X & X'Z \\ Z'X & (Z'Z + D^{-1}\sigma_e^2) \end{bmatrix} \begin{bmatrix} \hat{b} \\ \hat{u} \end{bmatrix} = \begin{bmatrix} X'Y \\ Z'Y \end{bmatrix} . \qquad \ldots(3.17)$$

The random cow effects are similarly assumed to be uncorrelated, such that the covariance between the variables c_{ij} and $c_{ij'}$ is zero and the variance-covariance matrix is $I\sigma_c^2$, where σ_c^2 is the cow variance. Thus:

$$D\sigma_e^2 = E(uu') = I\sigma_c^2$$

and:

$$D = \frac{\sigma_c^2}{\sigma_e^2} I .$$

Since D is a diagonal matrix:

$$D^{-1} = \frac{\sigma_e^2}{\sigma_c^2} I ,$$

and equations (3.17) further simplify to:

$$\begin{bmatrix} X'X & X'Z \\ Z'X & (Z'Z + \frac{\sigma_e^2}{\sigma_c^2} I) \end{bmatrix} \begin{bmatrix} \hat{b} \\ \hat{u} \end{bmatrix} = \begin{bmatrix} X'Y \\ Z'Y \end{bmatrix} , \qquad \ldots(3.18)$$

which can be seen to equal the solution equations (3.16) for one random factor with σ_1^2 being replaced by σ_c^2 .

The solution equations to model (3.12) employed in this study therefore, were those of (3.18).

C. Estimation of Variance Components

The solution of equations (3.18) requires the prior estimation of the components of variance for cows and error. The analysis of variance method of estimating variance components from balanced data is based on equating mean squares of the analysis of variance to their expected values. This method is well defined, since there is a unique analysis of variance for a particular model. With unbalanced data however, there may be several ways of partitioning the total sum of squares and accordingly there is no unique analysis of variance for a given model. That is, there are several quadratic forms that can be used for estimating variance components by equating observed with expected values. In relation to multi-way classifications of unbalanced data, Henderson (1953) extended previously existing variance component estimation procedures by describing three different methods (referred to as Henderson's Methods 1, 2 and 3). Searle (1968, 1971) has discussed the features and relative merits of various methods of variance component estimation, with considerable attention to the three methods of Henderson. Briefly, Method 1 is analogous to the analysis of variance procedure used with balanced data, equating calculated sums of squares with their expected values. However, where both fixed effects (other than μ) and random effects are specified in the model, this method suffers from an inability to estimate variance components free from the fixed effects.

Method 2 applies the analysis of variance principles of Method 1 to mixed models, endeavouring to remove the bias in variance component estimates derived in Method 1, by determining variance components from the data adjusted for fixed effects. Searle (1968) suggested that Henderson's Method 2 is not uniquely specified since several generalized inverses for the coefficient matrix of the fixed effects exist, and no unique set of variance component estimators can be determined. However, Henderson, Searle and Schaeffer (1974) demonstrated that for a range of models in which there are no interactions between fixed and random effects, nor any nesting of fixed and random factors within each other, Method 2 is a procedure that is well defined.

Method 3 makes use of reductions in sums of squares due to fitting different sub-models of the original model, estimating the variance components by equating individual reductions with their expected values under the full model. This method has the distinct advantage of being the most appropriate procedure for variance component estimation in the mixed model, deriving estimators that are unaffected by the fixed effects. However, Henderson's Method 3 suffers from computational difficulties in the calculations of reductions in sums of squares and the derivations of their expectations. Therefore, despite the biased estimates of variance components derived by Henderson's Method 1, the computational advantages over Method 3 determined its application to the estimation of cow and error variance components in the mixed model (3.12) of this present study.

The model used was:

$$Y_{ij} = \mu + c_i + y_j + e_{ij} \qquad \ldots(3.19)$$

where: Y_{ij} = the weaning weight, adjusted for age and sex, of the calf out of the i^{th} cow in the j^{th} year.

μ = the population mean weaning weight adjusted for age and sex when equal subclass frequencies exist.

c_i = the effect of the i^{th} cow. Cow effects were assumed to be random and distributed independently with zero mean and variance $I\sigma_c^2$.

y_j = the effect of the j^{th} year. Year effects were assumed to be random and distributed independently with zero mean and variance $I\sigma_y^2$.

e_{ij} = the error effect peculiar to the record of the i^{th} cow in the j^{th} year. Error effects were assumed to be random and distributed independently with zero mean and variance $I\sigma_e^2$.

It was further assumed that all the variables in the model were independent of each other and that the cow x herd-year interaction was zero.

In the analysis of model (3.19) cows were not permitted to have more than one weaning record in the same year. Where this occurred the first of the two records was utilized. Corrected sums of squares and their expectations were obtained for each herd and then pooled over all herds to determine the variance component estimators for cow, year and error effects.

Deriving the vector of the uncorrected analysis of variance sums of squares (T) as:

$$T = \begin{bmatrix} \text{Total} \\ \text{Cows} \\ \text{Years} \\ \text{Correction term} \end{bmatrix} = \begin{bmatrix} T_t \\ T_c \\ T_y \\ T_1 \end{bmatrix} = \begin{bmatrix} \sum_{ij} Y_{ij}^2 \\ \sum_i \left(\frac{Y_{i.}^2}{n_{i.}} \right) \\ \sum_j \left(\frac{Y_{.j}^2}{n_{.j}} \right) \\ \frac{Y_{..}^2}{N} \end{bmatrix} ,$$

where N is the total number of records, the corresponding vector of corrected analysis of variance sums of squares (T^c) is determined from:

$$T_c = \begin{bmatrix} T_c - T_1 \\ T_y - T_1 \\ T_t - T_c - T_y + T_1 \end{bmatrix} . \qquad \ldots(3.20)$$

The matrix of expectations of the uncorrected analysis of variance sums of squares (A) is given as:

$$E[T] = \begin{bmatrix} E(T_t) \\ E(T_c) \\ E(T_y) \\ E(T_1) \end{bmatrix} = A = \begin{bmatrix} N & N & N & N \\ N & N & \sum_i \left(\frac{\sum_j n_{ij}^2}{n_{i.}} \right) & n_c \\ N & \sum_j \left(\frac{\sum_i n_{ij}^2}{n_{.j}} \right) & N & n_y \\ N & \frac{\sum_i n_{i.}^2}{N} & \frac{\sum_j n_{.j}^2}{N} & 1 \end{bmatrix} , \qquad \ldots(3.21)$$

where n_c represents the number of cows and n_y represents the number of years. From A in (3.21) the matrix of expectations of the corrected sums of squares (A^c), which is the coefficient matrix of the vector of variance components (V), is determined from:

$$A^c V = \begin{bmatrix} E(T_c) - E(T_1) \\ E(T_y) - E(T_1) \\ E(T_t) - E(T_c) - E(T_y) + E(T_1) \end{bmatrix} \begin{bmatrix} \sigma_c^2 \\ \sigma_y^2 \\ \sigma_e^2 \end{bmatrix} . \qquad \ldots(3.22)$$

Equating expression (3.22) to the vector of the corrected analysis of variance sums of squares:

$$A^c V = T^c ,$$

enables the vector of estimates of the variance components for cows, years and error $(\hat{V})$ to be determined from:

$$\hat{V} = \begin{bmatrix} \hat{\sigma}_c^2 \\ \hat{\sigma}_y^2 \\ \hat{\sigma}_e^2 \end{bmatrix} = (A^c)^{-1} T^c .$$

Primarily, estimates of the variance components for cows and error were obtained for the computation of the solution equations (3.18) for model (3.12). However, these variance component estimates may also be applied to the estimation of the intra-class correlation (t) among the weaning weights of calves out of the same cow in subsequent years as:

$$t = \frac{\hat{\sigma}_c^2}{\hat{\sigma}_c^2 + \hat{\sigma}_e^2} ,$$

with a standard error of:

$$\frac{(1 - t)\left[1 + (k - 1)t\right]}{\sqrt{\tfrac{1}{2}(k)(k - 1)\ (d - 1)}} ,$$

where: d = the total number of dams, and

k = the average number of calves per dam.

Sellers <u>et al.</u> (1970) have noted (details not given) that the above formula gives only an indication of the magnitude of the standard error of the estimate of repeatability.

D. <u>Estimation of Age-of-Dam Effects</u>

With appropriate restrictions imposed on the fixed effects in equations (3.18):

$$\hat{\mu} = \hat{h}_b = 0 ,$$

where b is the number of herd-years, computation of the estimates $\hat{b}$ and $\hat{u}$ of the vector of parameter values requires that the coefficient matrix in (3.18) be inverted. Since only the estimates of age-of-dam effects are desired in order to derive the appropriate adjustment factors, inversion of the coefficient matrix may be simplified by absorbing the equations for cows and herd-years into the age-of-dam group equations. Equations (3.18) can be partitioned as:

$$\begin{bmatrix} A_{a \times a} & B_{a \times (b-1)} & D_{a \times c_j} \\ B'_{(b-1) \times a} & H_{(b-1) \times (b-1)} & F_{(b-1) \times c_j} \\ D'_{c_j \times a} & F'_{c_j \times (b-1)} & C_{c_j \times c_j} \end{bmatrix} \begin{bmatrix} d \\ h \\ g \end{bmatrix} = \begin{bmatrix} G_{a \times 1} \\ U_{(b-1) \times 1} \\ V_{c_j \times 1} \end{bmatrix} , \quad \ldots(3.23)$$

where: A = a square diagonal matrix of the age-of-dam group effects: a is the number of age-of-dam groups.

H = a square diagonal matrix of the herd-year effects: b is the number of herd-years of which the b^{th} herd-year has been deleted.

C = $(Z'Z + \frac{\sigma_e^2}{\sigma_c^2} I)$ = a diagonal matrix of cow effects nested within herd-years: c_j is the number of cows in the j^{th} herd-year.

B = a non-diagonal sub-matrix in the X'X sub-matrix.

D and F = non-diagonal sub-matrices in the X'Z sub-matrix such that:

$D + F = X'Z$ and $D' + F' = Z'X$.

G = an (a x 1) vector of observations pertaining to the age-of-dam group effects.

U = a (b-1 x 1) vector of observations pertaining to the herd-year effects.

V = Z'Y = the (c_j x 1) vector of observations pertaining to the cow-within-herd-year effects.

d = an (a x 1) vector of age-of-dam group parameter values.

h = a (b-1 x 1) vector of herd-year parameter values, and

g = a (c_j x 1) vector of cow-within-herd-year parameter values.

Expansion of expression (3.23) yields:

$$\begin{aligned} Ad + Bh + Dg &= G \\ B'd + Hh + Fg &= U \quad , \\ D'd + F'h + Cg &= V \end{aligned} \qquad \ldots(3.24)$$

from which the absorption of the equations for cows can be accomplished by solving the last equation of (3.24) for g:

$$\hat{g} = C^{-1} (V - D'd - F'h) \quad ,$$

and substituting for g into the remaining equations of (3.24) to give:

$$\begin{aligned} (A - DC^{-1}D')d + (B - DC^{-1}F')h &= T - DC^{-1}V \\ (B' - FC^{-1}D')d + (H - FC^{-1}F')h &= U - FC^{-1}V \end{aligned} \quad . \qquad \ldots(3.25)$$

Absorption of the equations for herd-years can now proceed by solving the second equation of (3.25) for h:

$$\hat{h} = (H - FC^{-1}F')^{-1} \left[(U - FC^{-1}V) - (B' - FC^{-1}D')d\right] \quad ,$$

and substituting for h into the first equation of (3.25) to give:

$$\left[(A - DC^{-1}D') - (B - DC^{-1}F')\ (H - FC^{-1}F')^{-1}\ (B' - FC^{-1}D')\right] d$$

$$= \left[(T - DC^{-1}V) - (B - DC^{-1}F')\ (H - FC^{-1}F')^{-1}(U - FC^{-1}V)\right] \quad . \qquad \ldots(3.26)$$

The estimates of age-of-dam group effects $(\hat{d})$ may be determined from (3.26) by inverting the (a x a) coefficient matrix and post-multiplying by the (a x 1) vector of observations. If desired, the estimates of herd-years effects $(\hat{h})$ may be obtained by the substitution of $\hat{d}$ for d in the second equation of (3.25) and solving for h. The estimates of cow effects $(\hat{g})$ may be similarly determined by substituting $\hat{d}$ and $\hat{h}$ for d and h respectively, in the third equation of (3.24) and solving for g.

The large numbers of herd-years and cows in this study prohibited the storage in memory of equations (3.23) in the computer (Burroughs B6700). Therefore, the above double-absorption procedure was executed indirectly as the data were read in from magnetic tape in the following manner:

(i) Data were sorted by cow within herd-year.

(ii) Equations for the effects of age-of-dam group, herd-year, and cows were collected for one herd.

(iii) Cow equations for the herd, after adding the appropriate variance ratio to the diagonal elements, were absorbed into the herd-year and age-of-dam group equations.

(iv) Herd-year equations for the herd were absorbed into the age-of-dam group equations.

(v) Steps (ii), (iii), and (iv) were repeated until the records of all cows and herd-years had been processed.

The solutions for the fixed age-of-dam effects from the resulting absorbed equations (3.26) are identical to solving the entire best linear unbiased equations (3.18), where the coefficient matrix of equations (3.18) is inverted by partitioning.

CHAPTER 4

DATA

I. SOURCE OF DATA

In 1963 the New Zealand Sheep and Beef Cattle Survey of the New Zealand Meat Producers Board and the New Zealand Wool Board initiated New Zealand's first comprehensive beef cattle performance recording service. This was known as the Beef Cattle Weight Gain Performance Recording Scheme. After approximately 10 years of operation this scheme was servicing 325 predominantly registered beef cattle herds, which represented 26 percent of all registered beef herds in New Zealand (Anon., 1973b). The particulars recorded included identification of the calf, sex, herd, and breed; birth date, birth weight, dates and weights at weaning and at eighteen-months, and the identification numbers of the calf's dam and sire and their respective years of birth.

The Sheep and Beef Cattle Survey was disbanded in 1972, at which time control and operation of the Beef Cattle Weight Gain Performance Recording Scheme was transferred to the New Zealand Dairy Board who operated it on behalf of the New Zealand Meat Producers Board. By 1973 this recording scheme had been replaced by the National Beef Recording Service (Beefplan), which is the present performance recording system for beef cattle in New Zealand.

Despite the modifications that have been incorporated into this service to date, the adjustments of weaning weights for the effects of age of calf and age of dam remain the same as those that were employed in the Beef Cattle Weight Gain Performance Recording Scheme. These adjustments followed the recommendations of the United States Beef Cattle Records Committee Report (1965).

The data used in this present study were the weaning records of Hereford and Angus calves recorded in the Beef Cattle Weight Gain Performance Recording Scheme filed in the Farm Production Division of the New Zealand Dairy Board.

II. DESCRIPTION OF DATA

For the objectives of the study to be fulfilled, it was considered necessary to extract data covering a comprehensive range of herds and environments in which beef cattle records of high performance had been maintained over several years. A high proportion of the animals recorded in the Beef Cattle Weight Gain Performance Recording Scheme was registered with the appropriate Breed Associations.

Although approximately one quarter of the registered beef cattle herds in New Zealand were recording calf weaning weights by 1972, a proportion of these herds had relatively small numbers of cows within their breeding units. Consequently the first of two criteria determining the suitability of weight records for the analysis was the number of breeding cows within each herd. A minimum herd size of 40 cows was considered a reasonable level upon which to base this criterion. The second requirement imposed on the files in the original data involved the length of time during which herds had been participating in the scheme. A minimum duration of four successive years of weight recording was regarded to be sufficient.

The original data from the Beef Cattle Weight Gain Performance Recording Scheme were screened according to the two criteria mentioned above and resulted in 55 Hereford and Angus herds with a total of 24437 weaning weights, recorded over a nine-year period from 1964 to 1972 inclusive, being withdrawn for analysis.

Table 4.1 presents some descriptive statistics associated with these data. Despite the larger numbers of calf weaning weight records and of cows that were recorded to have weaned at least one calf in the Angus breed, the average weights and ages at weaning, and the average number of records per cow weaning at least one calf were similar for both breeds.

TABLE 4.1: Numerical description of data extracted from the Beef Cattle Weight Gain Performance Recording Scheme (1964 to 1972)

Item	Breed	
	Hereford	Angus
Number of weaning records	7771	16666
Average weight at weaning (kg)	208.0	204.9
Average age at weaning (days)	218.5	220.7
Number of herds	18	37
Average number of recorded years per herd	8.0	7.6
Number of males weaned	3922	9261
Number of females weaned	3849	7405
Number of cows weaning at least one calf	2911	6106
Average number of weaning records per cow weaning at least one calf	2.7	2.7

CHAPTER 5

RESULTS AND DISCUSSION

I. MAIN EFFECTS AND INTERACTIONS

The analyses of variance of the main effects for the weaning weights of Hereford and Angus calves are presented in Table 5.1. All main effects included in model (3.1) were highly significant sources of variation for each breed.

The analyses of variance of first-order interactions fitted individually with the main effects of Table 5.1 are summarized in Table 5.2. These reveal that each first-order interaction between respective main effects was highly significant. The levels of significance in Tables 5.1 and 5.2 could be explained by the large number of degrees of freedom for the error estimates.

As discussed in Chapter 3 the relative levels of importance of the main effects were determined by comparing the reductions in error variance resulting from fitting models that respectively excluded and included the main effect in question. The relative levels of importance of the individual interaction effects were similarly obtained, comparing the reductions in residual variance from fitting models with and without inclusion of the interaction effect in question.

The percentage reduction in error variance due to fitting the main effects and individual interaction effects for each breed are given in Table 5.3. In both breeds, the most important single source of variation was that due to linear regression on age, followed by that due to sex. All main effects for each breed contributed to more than a 2 percent reduction in error variance. Of the interaction effects, only the herd x year term for the Herefords and the herd x year and herd x sex terms for the Angus contributed to at least a 2 percent reduction in error variance after all main effects had been fitted.

The percentage reductions in error variance associated with fitting regression on age, age of dam, and sex of calf, indicate that these sources of variation warrant adjustment where weaning weights are to be compared accurately. Although herd effects were an important influence on the weaning weights in this present study, it is likely that weight

TABLE 5.1: Analyses of variance of the main effects for weaning weights

Source of variation	Hereford		Angus	
	df	Mean square	df	Mean square
Total	7770		16665	
Mean	1	1656110.7***	1	5690232.2***
Herds	17	68522.8***	36	51325.1***
Years	8	22362.9***	8	33677.4***
Age of dam	5	118966.8***	5	126048.0***
Sex	1	1708783.0***	1	2533228.9***
Regression on age	1	4492672.9***	1	5668884.0***
Error	7737	803.1	16613	619.2

*** $P < 0.001$

TABLE 5.2: Mean squares of first-order interactions fitted individually with main effects for weaning weights

Source of variation	Hereford		Angus	
	df	Mean square	df	Mean square
Total	7770		16665	
Herd x year	119	10625.3***	235	9022.5***
Error	7618	649.7***	16378	498.6
Herd x age of dam	83	1914.4***	173	1261.5***
Error	7654	791.0	16440	612.5
Herd x sex	17	4783.5***	35	7803.4***
Error	7720	794.3	16578	604.0
Year x age of dam	40	2154.0***	40	1499.0***
Error	7697	796.1	16573	617.1
Year x sex	8	6479.2***	8	6191.1***
Error	7729	797.2	16605	616.5
Sex x age of dam	5	7856.1***	5	1529.5*
Error	7732	798.5	16608	618.9

* $0.05 > P > 0.01$

*** $P < 0.001$

TABLE 5.3: Percentage reductions in error variance due to the individual fitting of main effects and first-order interactions

Item	Reduction (%)	
	Hereford	Angus
Main effects:		
Herds	15.6	15.0
Years	2.7	2.5
Age of dam	8.7	5.7
Sex	21.6	19.7
Regression on age	41.9	35.5
Interaction effects:		
Herd x year	19.1	19.5
Herd x age of dam	1.5	1.1
Herd x sex	1.1	2.4
Year x age of dam	0.9	0.3
Year x sex	0.7	0.4
Sex x age of dam	0.6	0.0

comparisons would be made within herds under on-farm performance recording situations, hence obviating the need for adjustment of these effects. The existence of an important herd x year term in both breeds indicates that weight comparisons at weaning should not only be made within herds, but within years as well. The absence of other important interactions relative to the contributions of the main effects in the Hereford data implies that adjustment factors for age-of-dam and sex-of-calf effects on weaning weights may be applied over a range of herds and years. Similar conclusions may be drawn for adjustments for age of dam on the weaning weights of Angus calves. The occurrence of a relatively important interaction between herd and sex effects in the Angus data indicates that the use of a mean sex difference in weaning weight as a sex adjustment factor applicable to all herds is inadequate, although an adjustment computed by such a procedure is applicable to all years. An important herd x sex interaction suggests differential preweaning management policies favouring a greater realization of the superior growth potential in the male genotype.

A. Regression of Weight on Age

The estimated partial linear regression coefficients of weight on age at weaning within herd, year, age-of-dam and sex subclasses for Hereford and Angus calves were 0.70 ± 0.01 and 0.62 ± 0.01 kg/day, respectively. These estimates correspond closely to the arithmetic mode of published values presented in Table 2.7. The estimated coefficients, together with the mean ages at weaning for Hereford and Angus calves of 218 and 221 days respectively, were employed to determine the mean weaning weights for the two breeds (204.6 ± 0.6 kg and 202.8 ± 0.4 kg respectively) as outlined in Chapter 3.

B. Age of Dam

Least-squares estimates, means and mean differences from mature (6 to 9 year-old) dams for each age-of-dam group are shown in Table 5.4. Weaning weights of Hereford and Angus calves increased by 33.3 kg and 22.7 kg respectively, as age of dam increased from 2 to 6 to 9 years of age. It is possible for reasons outlined in Chapter 2, that the estimates of age-of-dam effects in Table 5.4 are biased slightly downward in the younger age groups and upward in the older ages if Hereford and Angus dams

TABLE 5.4: Least-squares estimates, means and mean differences from mature dams of age-of-dam groups for weaning weight

Breed	Number of records	Estimate (kg)	Mean (kg)	Mean difference (kg)
Hereford:				
General mean	7771		204.6 ± 0.6[a]	
Age of dam (years):				
2	436	-22.4 ± 1.2[a]	182.2 ± 1.5	33.3**
3	1504	-6.6 ± 0.7	197.9 ± 0.8	17.6**
4	1359	2.3 ± 0.7	206.8 ± 0.9	8.7**
5	1106	7.1 ± 0.8	211.6 ± 0.9	3.8**
6–9	2537	10.9 ± 0.6	215.5 ± 0.7	0.0
10+	829	8.7 ± 0.9	213.3 ± 1.1	2.2
Angus:				
General mean	16666		202.8 ± 0.4	
Age of dam (years):				
2	495	-13.9 ± 1.0	188.9 ± 1.2	22.7**
3	2976	-6.4 ± 0.4	196.4 ± 0.5	15.2**
4	2701	0.9 ± 0.5	203.7 ± 0.5	7.9**
5	2309	3.3 ± 0.5	206.2 ± 0.6	5.4**
6–9	5797	8.8 ± 0.4	211.6 ± 0.4	0.0
10+	2388	7.3 ± 0.5	210.2 ± 0.6	1.4*

a Standard error

* $0.05 > P > 0.01$

** $P < 0.01$

have been selected on productivity. In an endeavour to overcome these biases, age-of-dam influences on the weaning weights for each breed were determined by best linear unbiased estimation procedures.

(1) Best linear unbiased estimation of age-of-dam effects. From the discussion in Chapter 3, best linear unbiased estimation of age-of-dam effects on weaning weights necessitates the prior estimation of variance components for cow and error effects. As indicated in model (3.30) the weaning weights for each breed were adjusted for age and sex of calf. Adjustment for age of calf employed Methods I, II and III of Chaper 2, with adjustment for sex being applied multiplicatively to the records of females as the ratio of the respective sex means for each breed. Table 5.5 presents the variance component estimates derived by Henderson's Method 1, the inverted variance component ratios required for best linear unbiased estimation of age-of-dam influences, and corresponding estimates of the repeatability of weaning weight, according to the method of adjustment for age at weaning for each breed.

The estimates of repeatability of weaning weight as a character of Hereford dams agree with those reported in the literature. For example, Botkin and Whatley (1953), with 603 210-day weight records and Kilkenny (1968), with 693 200-day weight records, estimated the repeatability of weaning weight for Hereford dams to be 0.43 and 0.42, respectively.

The repeatability estimates obtained for Angus dams are slightly lower than most of the reported estimates presented in Table 2.3.

With the voluntary participation of beef cattle breeders in the Beef Cattle Weight Gain Performance Recording Scheme, weaning weights were not recorded in consecutive years in some herds. Consequently the degree of adjacency of calf records may, on the average, be less than that with single-herd data from which many of the published estimates of repeatability have been derived. As Cunningham and Henderson (1965b) have demonstrated, the magnitude of repeatability estimates tends to decline with the degree of adjacency of calf records. Lower estimates of repeatability may also occur where calves are encouraged to feed independently of their dams. Under these conditions the maternal influence of the dam is reduced and any measure of intraclass correlation is more an indication of the genetic effects that are common in calves of the same cow (Kilkenny, 1968).

With the variance component ratios presented in Table 5.5, best linear

TABLE 5.5: Estimates of variance components, their ratios and repeatabilities of weaning weight according to method of adjustment for age at weaning[a]

Breed	Method of adjustment for age at weaning	Variance component			Repeatability
		Cow (σ_c^2)	Error (σ_e^2)	Ratio (σ_e^2/σ_c^2)	($\sigma_c^2/(\sigma_c^2 + \sigma_e^2)$)
Hereford[b]:					
	I	314.97	368.67	1.17	0.46 ± 0.01[c]
	II	373.81	434.99	1.16	0.46 ± 0.01
	III	327.69	364.03	1.11	0.47 ± 0.01
Angus[d]:					
	I	164.00	328.27	2.00	0.33 ± 0.01
	II	196.55	395.25	2.01	0.33 ± 0.01
	III	180.59	340.56	1.89	0.35 ± 0.01

a Weight records adjusted for age at weaning by Methods I, II and III of Chapter 2, and for sex by multiplicative adjustment factors of 1.16 and 1.13 to Hereford and Angus heifers, respectively.

b Total number of dams = 2901.
Total number of calves = 7698.

c Standard error.

d Total number of dams = 5086.
Total number of calves = 14198.

unbiased estimates of age-of-dam effects on the weaning weights of Hereford and Angus calves were determined according to the method of adjustment for age at weaning (Methods I, II and III). Table 5.6 presents such estimates together with differences from the mature (6 to 9 year-old) dam age group. The weaning weights of Hereford and Angus calves increased by approximately 28 kg and 26 kg respectively, as age of dam increased from 2 years to the mature ages. From 398 210-day weight records in two Hereford herds, Neville et al. (1974) obtained "...maximum likelihood..." differences from mature (6 to 8 year-old) dams of 18, 12, 5 and 3 kg for 3, 4, 5 and 9 to 12 year-old dams for one herd, and 15, 5, 1 and 3 kg for the respective dam ages for the second herd. These authors concluded that in comparison with age-of-dam estimates derived by least squares procedures, there was little difference between the estimates derived by either procedure.

In comparison with the least-squares differences from the mature age-of-dam group presented in Table 5.4, best linear unbiased differences are generally of slightly smaller magnitude for the younger age groups. From Chapter 2, estimates of non-mature age-of-dam effects by least squares Gross Comparison procedures tend to be biased from the true age effects due to the influence of selection of cows on performance. Best linear unbiased estimation procedures however, take account of this bias by utilizing both within- and between-cow differences. Comparisons of best linear unbiased estimates of deviations of non-mature dam age groups from the mature dam age group in Table 5.6, with those estimated by least squares in Table 5.4, tend to support this theory for Hereford dams, and for Angus dams with the exception of the two extreme age groups.

In evaluating adjustments for the effects of age on production in dairy cattle, Lush and Shrode (1950) noted that errors amounting to less than one quarter of a standard deviation of a cow's estimated producing ability, may be regarded to be of little practical significance. Under conditions of selection on individual performance, a similar basis of comparison was employed in order to obtain some indication of the importance of differences between age-of-dam deviations from mature ages derived by least squares and by best linear unbiased estimation procedures. With a heritability of weaning weight of 0.25 (modal value of Table 2.1), and within-subclass standard deviations of 28.3 kg and 24.9 kg for Hereford and Angus calves, respectively (Table 5.1), one quarter of a standard deviation about an individual's estimated breeding value was determined

TABLE 5.6: Best linear unbiased estimates (BLUE) and differences from mature dams of age-of-dam groups for weaning weight[a]

Breed	Method of adjustment for age at weaning	Age of dam (years)					
		2	3	4	5	6–9	10+
Hereford:							
BLUE	I	159.0	170.4	179.4	183.8	185.6	182.6
	II	156.3	169.2	178.1	183.5	185.8	182.2
	III	160.1	172.4	180.9	185.5	187.5	184.1
Differences	I	26.7	15.2	6.2	1.8	0.0	3.0
	II	29.6	16.6	7.7	2.4	0.0	3.6
	III	27.4	15.1	6.6	2.0	0.0	3.4
Angus:							
BLUE	I	180.6	193.7	200.9	202.8	205.9	205.4
	II	180.0	192.8	199.7	202.5	206.5	205.9
	III	178.6	193.3	199.6	202.5	206.3	205.6
Differences	I	25.3	12.2	5.0	3.1	0.0	0.5
	II	26.5	13.7	6.8	4.0	0.0	0.6
	III	27.7	12.9	6.6	3.8	0.0	0.7

[a] Weight records adjusted for age at weaning by Methods I, II and III of Chapter 2, and for sex by multiplicative adjustment factors of 1.16 and 1.13 to Hereford and Angus heifers, respectively.

to be 6.1 kg for Hereford calves and 5.4 kg for Angus calves. For each breed, comparison of the deviations of non-mature from mature dam age groups presented in Table 5.4 with those presented in Table 5.6, indicated no major differences between deviations estimated by least squares and by best linear unbiased estimation procedures. This suggests that selection on performance in the Hereford and Angus dams in this present study was either not effective or was not undertaken by breeders.

C. Sex of Calf

Table 5.7 presents least-squares estimates and means of sex groups for the weaning weights of Hereford and Angus calves. The weaning weights of males were significantly heavier than those of females. The magnitudes of the superiority in average weights weaned of males over that of females do not compare with those reported by Harwin et al. (1966), Taylor (1967), Thomson (1968) or Koch et al. (1973) in Table 2.4. In New Zealand, recently reported estimates of differences in the weaning weights of the two sexes have generally been of a smaller magnitude than those presented in Table 5.7. Baker et al. (1974) reported bull-heifer differences of 16.4 kg and 14.0 kg in two herds, whilst Pleasants (1974) observed male-female differences to range from 15.1 kg to 23.6 kg in one herd, and 9.0 kg to 18.6 kg in a second herd of Angus cattle over a period of three years.

It is unlikely that estimated differences between the weaning weights of males and females in the present study were due to a confounding between the effects of castrating males and of selection for size, as discussed in Chapter 2. Differential preweaning management policies affording males a greater opportunity to realize their superior growth potential is more likely to contribute to inflated bull-heifer differences, particularly where beef producers are primarily engaged in the sale of bulls. The existence of a significant interaction between herd and sex effects in the Hereford and Angus data (Table 5.2) lends support to this view.

II. EVALUATION OF ADJUSTMENT PROCEDURES

A. Age of Calf at Weaning

The adjustment of weaning weights for age of calf presently employed by the National Beef Recording Service applies the principle of Method I

TABLE 5.7: Least-squares estimates and means of sex groups for weaning weight

Breed	Number of records	Estimate (kg)	Mean (kg)
Hereford:			
General mean	7771		204.6 ± 0.6[a]
Males (M)	3922	14.9 ± 0.3[a]	219.5 ± 0.6
Females (F)	3849	-14.9 ± 0.3	189.7 ± 0.6
Difference (M-F)			29.8**
Angus:			
General mean	16666		202.8 ± 0.4
Males (M)	9261	12.8 ± 0.2	215.6 ± 0.4
Females (F)	7405	-12.8 ± 0.2	190.0 ± 0.4
Difference (M-F)			25.6**

[a] Standard error

** $P < 0.01$

discussed in Chapter 2. Birthweights of 33 kg and 28 kg are assumed for Hereford and Angus calves, respectively. Following this procedure, weaning weights were adjusted to a standard age of 200 days. Weaning weights were also adjusted separately to 200 days of age by applying Methods II and III of Chapter 2 using the estimated regression coefficients of weight on age for each breed. Evaluation of the three methods of adjustment was based on the premise that age-adjusted weights should be independent of age. Table 5.8 presents the pooled and within-subclass regression coefficients of 200-day weight on age for each breed. Where within-subclass regression coefficients did not explain a significant portion of variation in adjusted weights and did not deviate significantly from zero, the adjusted weights were regarded to be independent of age. On the basis of this criterion, Methods II and III were considered superior procedures of adjustment for age at weaning for the Hereford calves, whilst Method II only satisfied the criterion for the Angus calves. In either breed, the adjustment of weights for age at weaning by the procedure used in the National Beef Recording Service (Method I) was less efficient in reducing the dependence of weight on age. The superiority of Methods II and III evident in Table 5.8 must however, be regarded with caution. Methods II and III, in contrast to Method I, were evaluated by their application to data from which the parameters they employed had been estimated.

An alternative basis of comparison of Methods I, II and III was also employed in which the magnitudes of the residual variance within herd-year-age of dam-sex subclasses were evaluated. The percentage reductions in the error variances resulting from fitting herd, year, age-of-dam, and sex effects, and from fitting the same main effects with age at weaning accounted for by Methods I, II and III are given in Table 5.9. In both breeds, the percentage reductions in residual variance resulting from adjusting weights by Methods I and III were similar, whereas the reductions after adjusting weights for age by Method II were approximately 9 percent less than those for Methods I and III. On the basis of these results, the adjustment of weaning weights for age by an additive application of linear regression of weight on age was less efficient in reducing within-subclass residual variation than both the multiplicative linear regression procedure and the procedure currently employed in the National Beef Recording Service.

TABLE 5.8: Pooled and within herd-year-age of dam-sex regression coefficients of 200-day weight on age

Breed	Method of adjustment for age at weaning[a]			
	No adjustment	I	II	III
Hereford:				
Pooled	0.708 ± 0.009[b]	-0.091 ± 0.008	0.012 ± 0.009[c]	0.009 ± 0.008[c]
Within-sub-classes	0.696 ± 0.009	-0.088 ± 0.008	0.000 ± 0.009[c]	0.011 ± 0.009[c]
Angus:				
Pooled	0.690 ± 0.006	-0.094 ± 0.005	0.073 ± 0.006	0.079 ± 0.006
Within-sub-classes	0.617 ± 0.007	-0.161 ± 0.006	0.000 ± 0.006[c]	0.014 ± 0.006

a Weight records adjusted for age of Methods I, II and III of Chapter 2.

b Standard error

c $P > 0.05$. (Regression coefficients are not significiant, nor do they deviate significantly from zero).

TABLE 5.9: Percentage reductions in error variance according to method of adjustment of weights for age at weaning[a]

Breed	Method of adjustment for age at weaning	Error mean square	Reduction (%)
Hereford:			
	None	1383.6	-
	I	667.2	51.8
	II	803.0	42.0
	III	670.3	51.6
Angus:			
	None	960.4	-
	I	537.4	44.0
	II	619.2	35.5
	III	537.3	44.0

[a] Weight records adjusted for age at weaning by Methods I, II and III of Chapter 2. Error variance is within herd-year-age of dam-sex subclasses.

B. Age of Dam

Adjustment factors for age-of-dam effects on calf weaning weights in the National Beef Recording Service employ multiplicative factors recommended by the United States Beef Cattle Records Committee Report (1965) as shown in Table 2.11. Adjustments for age-of-dam effects on the weaning weights of Hereford and Angus calves in this study were derived from the least squares and best linear unbiased estimates of age-of-dam group means presented in Tables 5.4 and 5.6, respectively. For comparisons with the National Beef Recording Service, adjustments determined in this present study, converted to multiplicative form, are given in Table 5.10. In general, the estimated factors differed from those employed in the New Zealand beef cattle industry. The results indicate greater handicaps for Hereford calves out of 2, 5 and 10 years and older dams than those accounted for by the industry adjustment factors. The converse applied to Hereford calves out of 4-year-old dams. National Beef Recording Service factors under-adjusted the records of Angus calves out of 5-year-old dams, and over-adjusted progeny records of 3- and 4-year-old dams. In contrast to Hereford calves, the industry factors for Angus calves out of dams at the two extreme age groups were generally consistent with those estimated in the present study.

Indications of the importance of differences between estimated adjustments and those employed in the National Beef Recording Service were evaluated by expressing all adjustments as additive deviations from the mature dam age group. Adjustment factors of the National Beef Recording Service were applied to the mean weaning weight of each breed in order to approximate corresponding factors in additive form. The results of these conversions are presented in Table 5.11. With standard deviations of an individual's estimated breeding value of 24.5 kg and 21.6 kg for Hereford and Angus calves, respectively (from p.79), differences among corresponding adjustments amounting to less than one quarter of these values were considered to be unimportant.

There were few notable differences between the adjustments computed for both Hereford and Angus breeds, and those modified from the National Beef Recording Service. Differences between estimated and modified adjustments for Angus calves out of 3-year-old dams exceeded one quarter of a standard deviation whilst the corresponding differences between adjustments for Angus calves out of 2-year-old dams closely approached this level of importance. Therefore, when modified to additive forms,

TABLE 5.10: Multiplicative adjustment factors for age-of-dam effects on weaning weights

Breed	Source of adjustment factors	Age of dam (years)					
		2	3	4	5	6-9	10+
Hereford:							
	NBRS[a]	1.15	1.10	1.05	1.00	1.00	1.00
	LS[b]	1.18	1.09	1.04	1.02	1.00	1.01
	$BLUE^{c}_{I}$	1.17	1.09	1.03	1.01	1.00	1.02
	$BLUE^{c}_{II}$	1.19	1.10	1.04	1.01	1.00	1.02
	$BLUE^{c}_{III}$	1.17	1.09	1.04	1.01	1.00	1.02
Angus:							
	NBRS[a]	1.15	1.10	1.05	1.00	1.00	1.00
	LS[b]	1.12	1.08	1.04	1.03	1.00	1.01
	$BLUE^{c}_{I}$	1.14	1.06	1.02	1.01	1.00	1.00
	$BLUE^{c}_{II}$	1.15	1.07	1.03	1.02	1.00	1.00
	$BLUE^{c}_{III}$	1.15	1.07	1.03	1.02	1.00	1.00

[a] Adjustment factors presently employed in the National Beef Recording Service.

[b] Adjustment factors estimated by least squares.

[c] Adjustment factors estimated by best linear unbiased estimation. Subscripts indicate prior adjustment of weight reocrds for age at weaning by Methods I, II and III of Chapter 2.

TABLE 5.11: Additive adjustment factors for age-of-dam effects on weaning weights

Breed	Source of adjustment factors	Age of dam (years)					
		2	3	4	5	6-9	10+
Hereford:							
	NBRS[a]	30.7	20.5	10.2	0.0	0.0	0.0
	LS[b]	33.3	17.6	8.7	3.8	0.0	2.2
	$BLUE^c_I$	26.7	15.2	6.2	1.8	0.0	3.0
	$BLUE^c_{II}$	29.6	16.6	7.7	2.4	0.0	3.6
	$BLUE^c_{III}$	27.4	15.1	6.6	2.0	0.0	3.4
Angus:							
	NBRS[a]	30.4	20.3	10.1	0.0	0.0	0.0
	LS[b]	22.7	15.2	7.9	5.4	0.0	1.4
	$BLUE^c_I$	25.3	12.2	5.0	3.1	0.0	0.5
	$BLUE^c_{II}$	26.5	13.7	6.8	4.0	0.0	0.6
	$BLUE^c_{III}$	27.7	12.9	6.6	3.8	0.0	0.7

[a] Modified adjustment factors presently employed in the National Beef Recording Service.

[b] Adjustment factors estimated by least squares.

[c] Adjustment factors estimated by best linear unbiased estimation. Subscripts indicate prior adjustment of weight records for age at weaning by Methods I, II and III of Chapter 2.

age-of-dam adjustment factors presently employed in the National Beef Recording Service tended to account adequately for the handicaps incurred by Hereford calves out of dams in all age groups studied. On the other hand, they failed to account for the smaller handicaps of Angus calves out of dams in the younger age groups, particularly for calves out of 3 year-old dams.

Applying the same comparison to the data presented by Baker et al. (1974) resulted in similar conclusions. With a standard deviation of an individual's estimated breeding value of 15.8 kg for Angus and Hereford weaning weights at Waikite, adjustment factors to a base dam age of 5 years and older, differed markedly from modified National Beef Recording Service factors for adjustments applicable to calves out of 3 year-old dams. From a standard deviation of 16.9 kg for Angus weaning weights in two herds at Waikeria, differences between estimated and modified adjustments for calves out of 3 and 4 year-old dams in one herd, and 3 year-old dams in the second herd, exceeded one quarter of a standard deviation.

From Chapter 2, the mode of application of adjustment factors for age-of-dam effects on weaning weights has received some attention in the past. Additive adjustments have generally been regarded to be appropriate when standard deviations are equal, whereas multiplicative adjustments have been preferred when the coefficients of variation remain constant. The effects of least-squares estimated additive and multiplicative adjustment factors on the variances of Hereford and Angus weight data adjusted to 200 days of age by Method I are compared in Table 5.12. Corresponding comparisons for weights adjusted for age at weaning by Methods II and III are illustrated in Appendix I, Tables I.1 and I.2, respectively. Under the application of additive adjustment factors, standard deviations remain unchanged since the addition of a constant will not alter the variance. The use of multiplicative adjustment factors however, will alter the variance in proportion to the square of the adjustment factor (Cundiff et al., 1966b). The expected standard deviations resulting from the application of multiplicative adjustments in these data were estimated in Table 5.12 by multiplying the adjustment factor by the observed standard deviation.

Bartlett's test (Sokal and Rohlf, 1969) for homogeneity of variance indicated that for each breed, unadjusted and adjusted variances differed significantly among age-of-dam groups, except where weights of Hereford

TABLE 5.12: Standard deviations (SD), coefficients of variation (CV) and expected standard deviations of weaning weights after adjustment for age of dam by least-squares derived factors[a]

Breed	Age of dam (years)	d.f.[b]	SD (kg)	CV	Additive		Multiplicative	
					Factor (kg)	Adjusted SD (kg)	Factor	Adjusted SD (kg)
Hereford:	2	327	24.2	13.3	33.3	24.2*	1.18	28.6**
	3	1232	22.8	11.5	17.6	22.8*	1.09	24.8**
	4	1085	23.1	11.1	8.7	23.1*	1.04	24.0**
	5	839	22.0	10.4	3.8	22.0*	1.02	22.4**
	6-9	2253	21.7	10.1	0.0	21.7*	1.00	21.7**
	10+	584	22.9	10.7	2.2	22.9*	1.01	23.1**
Mean adjusted SD						22.8		24.1
Range						2.5		6.9
SD						0.9		2.5
Angus:	2	366	24.7	13.1	22.7	24.7**	1.12	27.7**
	3	2455	18.1	9.3	15.2	18.1**	1.08	19.5**
	4	2178	19.1	9.4	7.9	19.1**	1.04	19.9**
	5	1804	19.7	9.6	5.4	19.7**	1.03	20.3**
	6-9	5262	19.7	9.3	0.0	19.7**	1.00	19.7**
	10+	1908	20.9	9.9	1.4	20.9**	1.01	21.1**
Mean adjusted SD						20.4		21.3
Range						6.6		8.2
SD						2.3		3.2

[a] Weights adjusted to 200-days of age by Method I of Chapter 2.

[b] Degrees of freedom for estimates of variance.

* $0.05 > P > 0.01$

** $P < 0.01$

calves had been adjusted for age by Method III and for age of dam by additive procedures (Table I.2).

The unadjusted standard deviations in Table 5.12 indicated that Hereford and Angus calves out of 2-year-old dams varied more in 200-day weight than those out of older dams. There was little indication of a reduction in the variability of 200-day weights from 3-year-old dams to older age groups. In Table 5.12, the expected standard deviations after adjustment of 200-day weights for age of dam by additive procedures displayed a range of 2.5 kg and 6.6 kg with a standard deviation of 0.9 kg and 2.3 kg for Hereford and Angus weights, respectively. Adjustment for age of dam by multiplicative procedures indicated that both the ranges for Hereford and Angus weights (6.9 kg and 8.2 kg) and the standard deviations (2.5 kg and 3.2 kg) were greater than those resulting from adjustment by additive procedures. Although the application of additive adjustments for age-of-dam effects did not equalize variances, they at least caused no further divergence in the records as was the case for adjustment by multiplicative methods. Similar conclusions were drawn from the results presented in Tables I.1 and I.2.

A further comparison of additive versus multiplicative adjustment factors was employed, in which the reductions in residual variation within herd-year-sex subclasses resulting from fitting weight data unadjusted for age at weaning or age of dam, and from fitting the same data adjusted for these effects, were examined. Table 5.13 presents the percentage reductions in residual variance for each breed, where weights were adjusted for age of calf by Method I, and for age of dam by factors employed in the National Beef Recording Service and by factors obtained in this study. The corresponding reductions after adjusting weights for age by Methods II and III and for age of dam as above, are given in Appendix II, Tables II.1 and II.2, respectively. The results in Table 5.13 indicate that in both breeds, the application of additive adjustment factors for age-of-dam effects resulted in a 3 to 4 percent greater reduction in residual variance within herd-year-sex subclasses than with the application of multiplicative factors. Under the assumption that comparisons are likely to be made within herd, year and sex subgroups, present results indicate that after adjustment for age at weaning, adjustment for age-of-dam effects by additive procedures tends to be more appropriate than adjustment by multiplicative procedures. The results presented in Tables II.1 and II.2 in Appendix II lead to similar conclusions.

TABLE 5.13: Percentage reductions in error variance according to method of adjustment for age of dam[a]

Breed	Source of adjustment factors	Additive		Multiplicative	
		Error mean square	Reduction (%)	Error mean square	Reduction (%)
Hereford:					
	No adjustment	1459.5	-	1459.5	-
	NBRS[b]	764.9	47.6	820.6	43.8
	LS[c]	758.5	48.0	818.0	44.0
	$BLUE^{d}_{I}$	759.1	48.0	814.9	44.2
	$BLUE^{d}_{II}$	758.5	48.0	824.3	43.5
	$BLUE^{d}_{III}$	758.9	48.0	815.8	44.1
Angus:					
	No adjustment	998.0	-	998.0	-
	NBRS[b]	613.9	38.5	647.9	35.1
	LS[c]	601.1	39.8	637.1	36.2
	$BLUE^{d}_{I}$	601.8	39.7	631.4	36.7
	$BLUE^{d}_{II}$	601.7	39.7	635.6	36.3
	$BLUE^{d}_{III}$	602.2	39.7	635.8	36.3

a Weights adjusted to 200 days of age by Method I of Chapter 2. Error variance is within herd-year-sex subclasses.

b Adjustment factors employed in the National Beef Recording Service

c Adjustment factors estimated by least squares.

d Adjustment factors estimated by best linear unbiased estimation. Subscripts indicate prior adjustment of weight records for age at weaning by Methods I, II and III of Chapter 2.

C. Sex of Calf

The National Beef Recording Service does not directly employ standardized adjustment factors for sex of calf, provided that at least 20 animals of each sex have been recorded. When this is the case, the difference between the average 200-day weight of each sex is added to the 200-day weight of each heifer. In cases where fewer than 20 animals of each sex are recorded, an assumed difference of 11 kg is added to the 200-day weight of each heifer. In contrast to the recommendations of Koch et al. (1959), Brinks et al. (1961), the United States Beef Cattle Records Committee Report (1965) and the Beef Improvement Federation (1972) for multiplicative adjustment factors for sex of calf, the National Beef Recording Service applies adjustments for sex additively.

The effects of least-squares estimated additive and multiplicative sex adjustment factors on the variances of Hereford and Angus weight data, adjusted for age at weaning by Method I, are compared in Table 5.14. The results for weights adjusted for age at weaning by Methods II and III are given in Appendix III, Tables III.1 and III.2, respectively. It is noted that the existence of an important interaction between herd and sex effects limits generalization of the following results for the Angus data over all herds.

Bartlett's test (Sokal and Rohlf, 1969) for homogeneity of variances revealed that in both breeds, males were significantly more variable in 200-day weight than females. Multiplicative adjustment for sex significantly reduced the differences in the variances of the two sexes for Herefords, where weaning weights had been adjusted for age by Methods I and III. Reduced differences in the variances of males and females remained significant however, for Herefords where weights had been adjusted for age by Method II, and for Angus where weights had been adjusted for age by Methods I, II and III. Despite the failure of multiplicative sex adjustment factors to fully equalize the variances in most cases, the results present in Table 5.14 and Tables III.1 and III.2 suggest that variances were more nearly equalized under multiplicative, rather than under additive adjustment methods. Examination of the substantially similar coefficients of variation in each of the above-mentioned three tables also suggests that the adjustment of weights to a male basis is more appropriate with multiplicative factors.

TABLE 5.14: Standard deviations (SD), coefficients of variation (CV) and expected standard deviations of weaning weights after adjustment for sex of calf by least-squares derived factors[a]

Breed	Sex	d.f.[b]	SD (kg)	CV	Additive		Multiplicative	
					Factor (kg)	Adjusted SD (kg)	Factor	Adjusted SD (kg)
Hereford:								
	Male	3183	24.2	11.0	0.0	24.2**	1.00	24.2
	Female	3137	20.5	10.8	29.8	20.5**	1.16	23.7
Angus:								
	Male	7860	21.0	9.8	0.0	21.0**	1.00	21.0**
	Female	6113	17.8	9.4	25.6	17.8**	1.13	20.2**

a Weights adjusted to 200 days of age by Method I of Chapter 2.

b Degrees of freedom for estimates of variance.

** $P < 0.01$.

Further evaluation of the least-squares estimated additive and multiplicative adjustment factors for sex with the adjustment procedures employed by the National Beef Recording Service, was based on comparisons of the reductions in residual variances within herd and year subclasses after adjusting weights for age, age of dam and sex of calf.

Table 5.15 presents the percentage reductions in residual variance for each breed, in which weights have been adjusted for age of calf by Method I, for age of dam by factors employed in the National Beef Recording Service and by additive factors estimated in this study, and for sex of calf by National Beef Recording Service procedures and by estimated additive and multiplicative factors. The corresponding reductions after standardizing weights for age by Method III only, are given in Appendix IV, Table IV.1. The results in Table 5.15 indicate that multiplicative adjustment of 200-day weights out of mature dams for sex of calf was less efficient in reducing residual variance within herds and years than additive adjustments, by approximately 5 to 6 percent. Additive adjustment of records by factors determined in this present study contributed to a 2 to 3.5 percent greater reduction in residual variance than that resulting from additive adjustment by the procedures employed in the National Beef Recording Service. Similar conclusions may be drawn from the reductions presented in Table IV.1 of Appendix IV.

Selection based on weaning records within herds requires accurate adjustments for age at weighing, age of dam and sex of calf in combination, such that the amount of unexplained variation within years is minimized. Despite the tendency of variances within sex groups to equilibrate under multiplicative sex adjustment procedures, when combined with adjustments for age and age of dam, a larger proportion of residual variation within herd-year subclasses remained unaccounted for compared with additive sex adjustment procedures.

TABLE 5.15: Percentage reductions in error variance according to method of adjustment for sex of calf[a]

Breed	Source of dam adjustment factors	NBRS[b]		Additive[c]		Multiplicative[c]	
		Error mean square	Reduction (%)	Error mean square	Reduction (%)	Error mean square	Reduction (%)
Hereford:	No adjustment	1680.0	-	1680.0	-	1680.0	-
	NBRS[b]	794.1	52.7	724.3	56.9	827.0	50.8
	LS[c]	729.7	56.6	669.5	60.1	765.2	54.4
	BLUE$_{I}^{d}$	730.1	56.5	669.5	60.1	763.7	54.5
	BLUE$_{III}^{d}$	730.1	56.5	669.5	60.1	763.8	54.5
Angus:	No adjustment	1150.4	-	1150.4	-	1150.4	-
	NBRS[b]	611.0	46.9	582.5	49.4	641.1	44.3
	LS[c]	563.7	51.0	539.7	53.1	593.0	48.4
	BLUE$_{I}^{d}$	564.0	51.0	540.0	53.1	593.3	48.4
	BLUE$_{III}^{d}$	564.6	50.9	540.6	53.0	594.0	48.4

[a] Weights adjusted to 200 days of age by Method I of Chapter 2. Error variance is within herd-year subclasses.

[b] Adjustment factors presently employed in the National Beef Recording Service.

[c] Adjustment factors estimated by least squares.

[d] Adjustment factors estimated by best linear unbiased estimation. Subscripts indicate prior adjustment of weight records for age at weaning by Methods I and III of Chapter 2.

CHAPTER 6

CONCLUDING DISCUSSION

For a given economically important trait in beef cattle, the measured performance of each animal is the result of its heredity and the total environment in which it is raised. Knowing the important environmental influences, and adjusting records of performance for these effects, breeders may rank individual animals more accurately on their estimated additive genetic value for a specified trait. The preceding analyses have involved the estimation of the effects of age, age of dam, and sex on the weaning weights of Hereford and Angus calves. Appropriate adjustment factors for these effects were also determined, and compared with those presently employed in the National Beef Recording Service.

Initial analyses indicated that age, age-of-dam, and sex influences contributed markedly to the variation in weaning weights. Examination of the first-order interactions among herd, year, age-of-dam, and sex effects further indicated that on the basis of their individual levels of significance, generalization of the results would be limited. On the other hand, the proportionate contributions of individual interactions to total variation in weaning weights, relative to the contributions of the main environmental effects, were negligible in most cases, although results did illustrate the importance of the herd x year interaction in the Hereford data, and of the herd x year and herd x sex interactions in the Angus data. The existence of an interaction between herd and year effects served to indicate that weight comparisons should be made within herds and years. Attention has been drawn (Chapter 5) to the limited application of a generalized sex adjustment factor to the weaning weights of Angus calves over the herds in these data. The level of management in beef enterprises primarily engaged in the sale of bulls, could be expected to be such that the fullest opportunity is afforded male calves so that they may express their superior growth potential. The degree with which this management policy was carried out before weaning in these data, appeared to be more variable among Angus herds than among Hereford herds.

Results of the evaluation of age-of-calf adjustment procedures, involving additive (Method II) and multiplicative (Method III) application of linear regression of weight on age, with the procedure employed in the National Beef Recording Service (Method I), were variable. Adjustment for age by Method I was relatively less efficient than adjustment by Methods II and III in reducing the dependence of weight on age in the data studied. On the other hand, Methods I and III were more efficient than Method II in reducing the amount of residual variation within herd, year, age-of-dam, and sex subclasses. In terms of the potential application to weaning weights recorded under the National Beef Recording Service, present results have indicated the suitability of adjusting for age of calf by multiplicative procedures employing linear regression of weight on age. If the superiority of Method III over Method I in reducing the dependence of weight on age is treated with some reserve, for reasons outlined in Chapter 5, it could be concluded that the present adjustment procedure in the National Beef Recording Service may, at least, be as efficient as the multiplicative linear adjustment method in accounting for the effects of age on weight at weaning.

Consideration has been given (Chapter 2) to the biases inherent in the estimation of age-of-dam effects on weaning weights by least squares procedures, where selection of dams on performance is operating. Discussion too, has outlined the suitability of best linear unbiased estimation procedures to the estimation of age-of-dam influences free from any effects due to selection. As R.H. Miller et al. (1966) have noted, even if dams were not selected on performance, best linear unbiased estimates of age effects were more efficient than least squares estimated because they were based on differences between cows as well as within cows.

The results have indicated in general that adjustment factors for age-of-dam effects estimated by least squares procedures, tended to differ from those estimated by best linear unbiased estimation procedures, and that the adjustments derived by both procedures differed from those used in the National Beef Recording Service. However, following the criterion of comparison of Lush and Shrode (1950), from Chapter 5, the differences between adjustments derived by least squares and by best linear unbiased estimation tended to be relatively unimportant, implying either ineffective or non-existent selection of dams on performance. On the same basis of comparison, age-of-dam adjustment factors determined in the present study generally did not differ markedly from those employed in the National Beef Recording Service, with the exception of factors applicable to Angus calves out of 3-year-old dams.

Examination of the variances within age-of-dam groups, and of the reductions in residual variances within herd, year, and sex subclasses, has suggested the application of additive age-of-dam adjustment factors in these data, rather than multiplicative application. In contrast, age-of-dam adjustments in the National Beef Recording Service employ multiplicative application. The recommendation for additive adjustments from the present results is in agreement with the conclusions of most published reports (Preston and Willis, 1970). For reasons outlined previously, additive adjustment factors for age-of-dam effects determined by best linear unbiased estimation procedures, would be the most appropriate sets to apply according to breed.

In considering whether additive or multiplicative adjustment factors for sex were suitable, present results varied. Multiplicative adjustments equalized within sex-group variances to a greater degree than additive adjustments, although multiplicative factors were less effective in reducing the amount of residual variance within herd-year subclasses. It has been noted in Chapter 5 that in within-herd selection situations, the most suitable adjustment for sex is that which, in combination with adjustments for age and age of dam, minimizes the amount of unexplained variation within herds and years. On the basis of this criterion, present results indicated that additive sex adjustment factors were more appropriate than multiplicative factors. This conclusion does not agree with most of the published reports considered in Chapter 2, where multiplicative factors have generally been preferred on the basis of equalization of means between sex groups, and of variances within sex groups (e.g., Koch _et al_., 1959; Brinks _et al_., 1961; Cundiff _et al_., 1966b). Schaeffer and Wilton (1974b) however, concluded that the preweaning average daily gain records of Angus and Hereford calves should be additively adjusted for sex of calf, simultaneously with additive adjustments for age of dam and, if necessary, for preweaning management (creep- versus non-creep feeding).

In the present study, the estimated additive adjustments for sex tended to reduce the amount of within herd-year residual variance to a slightly greater extent, than the additive procedures employed in the National Beef Recording Service. This would indicate the need to reappraise the current sex adjustment procedures, at least for the weaning weights of Hereford calves, if a generalized adjustment for sex is desired. The existence of an important herd x sex interaction in the weaning weights of Angus calves in these data limits the applicability of a generalized adjustment for sex. On this basis therefore, the additive adjustment procedure for sex currently employed in the National Beef Recording Service may be concluded to be adequate for Angus calves.

Baker et al. (1974) provided the first set of estimated adjustments for age and age of dam, applicable to the weaning and postweaning records of beef cattle in New Zealand. These authors concluded that the present adjustment procedures in the National Beef Recording Service warranted "...further study and perhaps some reappraisal.".

With data on Hereford and Angus calves drawn from a range of herds and environments in New Zealand, the present study has endeavoured to fulfil this requirement in relation to weaning weights, assessing the validity of present adjustment procedures and determining the relative merits of additive and multiplicative applications of such adjustments. Consideration of the suitability of present adjustment procedures in relation to postweaning weights is also acknowledged to be necessary. Such an investigation is currently in progress for 18-month weights of Hereford and Angus cattle recorded in this thesis.

APPENDIX I

TABLE I.1: Standard deviations (SD), coefficients of variation (CV) and expected standard deviations of weaning weights after adjustment for age of dam by least-squares derived factors[a]

Breed	Age of dam (years)	d.f.[b]	SD (kg)	CV	Additive		Multiplicative	
					Factor (kg)	Adjusted SD (kg)	Factor	Adjusted SD (kg)
Hereford:	2	327	26.5	14.5	33.3	26.5*	1.18	31.3**
	3	1232	24.8	12.5	17.6	24.8*	1.09	27.0**
	4	1085	24.1	11.7	8.7	24.1*	1.04	25.2**
	5	839	23.8	11.2	3.8	23.8*	1.02	24.2**
	6-9	2253	23.7	11.0	0.0	23.7*	1.00	23.7**
	10+	584	23.4	10.9	2.2	23.4*	1.01	23.6**
Mean adjusted SD						24.4		25.8
Range						3.1		7.7
SD						1.1		3.0
Angus:	2	366	22.4	11.9	22.7	22.4**	1.12	25.1**
	3	2455	19.5	9.9	15.2	19.5**	1.08	21.0**
	4	2178	20.3	9.9	7.9	20.3**	1.04	21.1**
	5	1804	21.1	10.2	5.4	21.1**	1.03	21.7**
	6-9	5262	21.5	10.2	0.0	21.5**	1.00	21.5**
	10+	1908	23.4	11.1	1.4	23.4**	1.01	23.6**
Mean adjusted SD						21.4		22.3
Range						3.9		4.1
SD						1.4		1.6

[a] Weights adjusted to 200 days by age of Method II of Chapter 2.

[b] Degrees of freedom for estimates of variance.

* $0.05 > P > 0.01$

** $P < 0.01$

TABLE I.2: Standard deviations (SD), coefficients of variation (CV) and expected standard deviations of weaning weights after adjustment for age of dam by least-squares derived factors[a]

Breed	Age of dam (years)	d.f.[b]	SD (kg)	CV	Additive		Multiplicative	
					Factor (kg)	Adjusted SD (kg)	Factor	Adjusted SD (kg)
Hereford:	2	327	24.3	13.4	33.3	24.3	1.18	28.8**
	3	1232	22.9	11.6	17.6	22.9	1.09	25.0**
	4	1085	22.8	11.0	8.7	22.8	1.04	23.8**
	5	839	22.0	10.4	3.8	22.0	1.02	22.4**
	6-9	2253	22.1	10.2	0.0	22.1	1.00	22.1**
	10+	584	23.1	10.8	2.2	23.1	1.01	23.3**
Mean adjusted SD						22.9		24.2
Range						2.3		6.7
SD						0.8		2.5
Angus:	2	366	23.9	12.7	22.7	23.9**	1.12	26.8**
	3	2455	18.5	9.4	15.2	18.5**	1.08	19.9**
	4	2178	19.3	9.5	7.9	19.3**	1.04	20.1**
	5	1804	19.8	9.6	5.4	19.8**	1.03	20.3**
	6-9	5262	20.1	9.5	0.0	20.1**	1.00	20.1**
	10+	1908	21.5	10.2	1.4	21.5**	1.01	21.7**
Mean adjusted SD						20.5		21.5
Range						5.4		6.9
SD						1.9		2.7

a Weights adjusted to 200 days of age by Method III of Chapter 2.

b Degrees of freedom for estimates of variance.

** $P < 0.01$.

APPENDIX II

TABLE II.1: Percentage reductions in error variance according to method of adjustment for age of dam[a]

Breed	Source of adjustment factors	Additive		Multiplicative	
		Error mean square	Reduction (%)	Error mean square	Reduction (%)
Hereford:					
	No adjustment	1459.5	-	1459.5	-
	NBRS[b]	918.9	37.0	987.9	32.3
	LS[c]	913.4	37.4	985.5	32.5
	$BLUE^{d}_{I}$	916.8	37.2	982.8	32.7
	$BLUE^{d}_{II}$	914.9	37.3	992.2	32.0
	$BLUE^{d}_{III}$	916.4	37.2	983.8	32.6
Angus:					
	No adjustment	998.0	-	998.0	-
	NBRS[b]	708.2	29.0	747.4	25.1
	LS[c]	698.0	30.1	738.4	26.0
	$BLUE^{d}_{I}$	700.4	30.0	732.6	26.6
	$BLUE^{d}_{II}$	699.1	30.0	736.3	26.2
	$BLUE^{d}_{III}$	699.9	29.9	736.4	26.2

[a] Weights adjusted to 200 days of age by Method II of Chapter 2. Error variance is within herd-year-sex subclasses.

[b] Adjustment factors employed in the National Beef Recording Service.

[c] Adjustment factors estimated by least squares.

[d] Adjustment factors estimated by best linear unbiased estimation. Subscripts indicate prior adjustment of weight records for age at weaning by Methods I, II and III of Chapter 2.

TABLE II.2: Percentage reductions in error variance according to method of adjustment for age of dam[a]

Breed	Source of adjustment factors	Additive		Multiplicative	
		Error mean square	Reduction (%)	Error mean square	Reduction (%)
Hereford:					
	No adjustment	1459.5	-	1459.5	-
	NBRS[b]	769.6	47.3	825.3	43.4
	LS[c]	762.9	47.7	822.0	43.7
	$BLUE_{I}^{d}$	764.1	47.6	819.4	43.9
	$BLUE_{II}^{d}$	763.3	47.7	828.4	43.2
	$BLUE_{III}^{d}$	763.9	47.7	820.3	43.8
Angus:					
	No adjustment	998.0	-	998.0	-
	NBRS[b]	615.4	38.3	650.7	34.8
	LS[c]	604.5	39.4	641.1	35.8
	$BLUE_{I}^{d}$	605.9	39.3	635.6	36.3
	$BLUE_{II}^{d}$	604.9	39.4	639.0	36.0
	$BLUE_{III}^{d}$	605.4	39.3	639.1	36.0

a Weights adjusted to 200 days of age by Method III of Chapter 2. Error variance is within herd-year-sex subclasses.

b Adjustment factors employed in the National Beef Recording Service.

c Adjustment factors estimated by least squares.

d Adjustment factors estimated by best linear unbiased estimation. Subscripts indicate prior adjustment of weight records for age at weaning by Methods I, II and III of Chapter 2.

APPENDIX III

TABLE III.1: Standard deviations (SD), coefficients of variation (CV) and expected standard deviations of weaning weights after adjustment for sex of calf by least-squares derived factors[a]

Breed	Sex	d.f.[b]	SD (kg)	CV	Additive: Factor (kg)	Additive: Adjusted SD (kg)	Multiplicative: Factor	Multiplicative: Adjusted SD (kg)
Hereford:								
	Male	3183	26.3	12.0	0.0	26.3**	1.00	26.3*
	Female	3137	21.7	11.5	29.8	21.7**	1.16	25.2*
Angus:								
	Male	7860	23.0	10.7	0.0	23.0**	1.00	23.0**
	Female	6113	18.7	9.9	25.6	18.7**	1.13	21.3**

a Weights adjusted to 200 days of age by Method II of Chapter 2.

b Degrees of freedom for estimates of variance.

* $0.05 > P > 0.01$

** $P < 0.01$

TABLE III.2: Standard deviations (SD), coefficients of variation (CV) and expected standard deviations of weaning weights after adjustment for sex of calf by least-squares derived factors[a]

Breed	Sex	d.f.[b]	SD (kg)	CV	Additive Factor (kg)	Additive Adjusted SD (kg)	Multiplicative Factor	Multiplicative Adjusted SD (kg)
Hereford:								
	Male	3183	24.5	11.1	0.0	24.5**	1.00	24.5
	Female	3137	20.5	10.8	29.8	20.5**	1.16	23.7
Angus:	Male	7860	21.5	9.9	0.0	21.5**	1.00	21.5**
	Female	6113	17.9	9.4	25.6	17.9**	1.13	20.3**

[a] Weights adjusted to 200 days of age by Method III of Chapter 2.

[b] Degrees of freedom for estimates of variance.

** $P < 0.01$

TABLE IV.1: Percentage reductions in error variance according to method of adjustment for sex of calf[a]

Breed	Source of dam adjustment factors	NBRS[b] Error mean square	NBRS[b] Reduction (%)	Additive[c] Error mean square	Additive[c] Reduction (%)	Multiplicative[c] Error mean square	Multiplicative[c] Reduction (%)
Hereford:	No adjustment	1680.0	-	1680.0	-	1680.0	-
	NBRS[b]	797.0	52.6	727.0	56.7	827.6	50.7
	LS[c]	732.6	56.4	671.9	60.0	765.5	54.4
	$BLUE^d_I$	733.6	56.3	672.6	60.0	764.8	54.5
	$BLUE^d_{III}$	733.5	56.3	672.4	60.0	764.7	54.5
Angus:	No adjustment	1150.4	-	1150.4	-	1150.4	-
	NBRS[b]	610.7	46.9	580.4	49.5	637.4	44.6
	LS[c]	564.7	50.9	538.3	53.2	590.2	48.7
	$BLUE^d_I$	565.7	50.8	539.3	53.1	591.3	48.6
	$BLUE^d_{III}$	565.3	50.9	538.9	53.1	590.9	48.6

[a] Weights adjusted to 200 days of age by Method III of Chapter 2. Error variance is within herd-year subclasses.

[b] Adjustment factors presently employed in the National Beef Recording Service.

[c] Adjustment factors estimated by least squares.

[d] Adjustment factors estimated by best linear unbiased estimation. Subscripts indicate prior adjustment of weight records for age at weaning by Methods I and III of Chapter 2.

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