A STUDY OF THE RELATIONSHIPS BETWEEN GROWTH, CARCASS AND MEAT CHARACTERISTICS OF ANGUS STEERS

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ABSTRACT

Growth, defined as change in weight, may be considered the most important single characteristic of slaughter cattle. Fast-growing cattle may have better food conversion and reach slaughter early. The end-products in a beef production business, namely, carcass and meat, have properties which determine consumer acceptability. This study focussed attention on growth, carcass and meat characteristics in cattle. Literature was reviewed on factors that influence variability in these traits and relationships reported in the literature between some of the traits were summarised.

Records on 117 Angus steers born in 1975 and 1976 (years 1 and 2) were analysed by the least squares method of fitting constants. Data included birth weight, calf milk consumption pre-weaning average daily gain (ADG), weaning weight, post-weaning ADG, yearling weight, 2-year weight, finish (30-month) weight, carcass weight, kidney and channel fat weight, eye muscle width, depth, and area, fat depth, fat trim percentage, intra-muscular fat percentage, sarcomere length, meat tenderness, muscle pH, and colour, lean percentage and bone percentage.

Fixed-effects constants fitted to growth data were: herd, age of dam and peri-natal treatment (calving on pasture or sawdust pad). Covariance analysis was adopted with 3 covariates: dam autumn liveweight, calf birth weight, and milk consumption. Factors fitted to post-slaughter data were: maturity, slaughter lot and pre-slaughter fasting, with 3 covariates, carcass weight, pre-weaning ADG, and post-weaning ADG.

Results were inconsistent between years. Therefore, few factors were conclusively judged to be important sources of variation in the traits studied. Herd influenced milk consumption ($P<0.05$) and pre-weaning ADG in year 1, and weaning and yearling weight ($P<0.01$) in year 2. Age of dam did not affect growth traits ($P>0.10$). Treatment was unimportant to pre-weaning growth in both years, but year 1 analyses suggested that it affected post-weaning ADG ($P<0.01$) and finish weight ($P<0.05$). This result may be attributed to chance.

Regression on dam weight was non-significant for all growth traits. Calf birth weight was found to be an important factor as far as various growth traits in year 2 were concerned, namely, weaning weight ($P<0.01$), and milk consumption, pre-weaning ADG and yearling weight ($P<0.05$). Regression of weaning weight on birth weight approached significance ($P<0.10$), but birth weight was otherwise unimportant in year 1. Milk consumption influenced weaning weight ($P<0.05$) in year 1; approached significance for its effect on pre-weaning ADG and yearling weight in year 1, and weaning and 2-year weight in year 2 ($P<0.10$).

Maturity did not affect post-slaughter characteristics other than eye muscle depth ($P<0.05$) in year 2. Slaughter lot was responsible for variation in eye muscle width ($P<0.001$) and dressing-out percentage ($P<0.01$) in year 1; dressing-out percentage and bone percentage ($P<0.001$) in year 2.

Four-day pre-slaughter fasting affected few carcass or meat traits adjusted for carcass weight by covariance analysis. The results were inconsistent between years. In year 1, fasting affected dressing-out

percentage ($P<0.001$) only, while in year 2 such effect was not apparent ($P>0.10$), but it was appreciable on other traits: eye muscle width and meat tenderness ($P<0.05$) and sarcomere length ($P<0.001$).

Regression of various traits on carcass weight was significant: dressing out percentage, kidney and channel fat, fat depth, intra-muscular fat percentage, fat trim percentage, eye muscle depth, eye muscle area, sarcomere length, and bone percentage in year 2; it was significant for dressing-out percentage and kidney and channel fat in year 1. Pre- and post-weaning ADG were less important covariates: the former was significant to eye muscle depth, dressing-out percentage, intra-muscular fat percentage and bone percentage in year 2, but non-significant in year 1. The latter approached significance in eye muscle area, dressing-out percentage, fat trim percentage and bone percentage in year 2 ($P<0.10$).

Residual sums of squares were used to estimate phenotypic correlations between traits studied. Correlation coefficients between growth traits were positive and medium to high except those between early growth (pre-weaning ADG, and birth, and weaning weights) and post-weaning ADG, which were negligible. Pre-weaning ADG and weaning weight had a perfect correlation coefficient ($r = 1.0$) in both years. Estimates between growth and carcass traits varied widely; notable were those for post-weaning ADG, 2-year weight, and finish weight with carcass weight, which were high in both years ($r = 0.86, 0.80$; $r = 0.80, 0.85$; and $r = 0.92, 0.92$, respectively).

Carcass traits were mostly positively correlated, with low to medium coefficients between them. Lean percentage had a strong negative correlation with fat trim percentage (r = -0.71), but bore little relationship with other traits. Correlation coefficients between carcass and meat traits were mostly positive, but low and inconsistent between years. Carcass weight was related to most fatness attributes of the carcass and meat. Most meat traits were positively correlated with each other with low and medium correlation coefficients.

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Any inadequacies, or inaccuracies in this thesis are the sole responsibility of the author and should not be viewed as shared responsibility with any of the organizations or persons who offered help or views as stated or implied in the foregoing paragraphs.

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CHAPTER ONE

INTRODUCTION

1.1 Beef and the Meat Consumer

Meat is an important source of high quality protein in the diet of the average household. Beef appears to be the most popular kind of meat in many countries. It has also been claimed to be the most important of the red meats (Goodwin, 1977). It provides more energy and protein than other meats, on a weight for weight basis, besides being in greater demand than mutton, pork, poultry, and fish. This greater demand is not necessarily because of the nutritional superiority or food value, but mainly because of particular attributes of visual appeal and eating quality (Berg and Butterfield, 1976). The acceptable carcass and meat attributes, notably those related to visual appraisal and eating quality, vary considerably with the target market, cooking methods, and traditional or cultural biases.

While the primary effort in beef production will continue to be geared towards an overall increase in output to cope with the ever-growing and ever-demanding world population, the importance of carcass and meat acceptability aspects cannot be overlooked. Growth and development of a meat animal should, therefore, be given its due emphasis in the effort to increase meat production. At the same time the attributes of the carcass and the acceptability of the raw meat and its cooking characteristics should be kept in mind. The study of beef cattle production entails a close examination of these aspects and their interelations.

Economic considerations of beef cattle production as a business are an additional intricacy in the already complex subject requiring an appreciation of physiological processes (of both the live animal and at tissue and cell levels) as well as other chemical processes (such as those influencing muscle colour and meat quality) and physical properties of meat. Beef cattle production is thus a vast subject. It is only possible to give a brief account here to throw some light on the parts of the subject considered vital in defining prerequisites of increased production and acceptability of the product. An understanding of cattle growth is a vital tool in attempting to manipulate management procedures to achieve increased beef output and, by careful choice of slaughter point, this may be achieved along with optimum efficiency and production of high quality beef.

1.2 Growth and Development in Cattle

Growth in animals generally refers to an increase in size, usually weight or mass. This is often considered in relation to time and is referred to as growth rate. A term usually associated with growth, but which requires particular mention is development. As a distinct concept, development refers to changes in form and shape (MacDonald, 1958) associated with morphological and anatomical changes in the animal. It may be considered to be an aspect of growth (Fowler, 1968) because it results from differential increase in the sizes of various parts of the animal's body.

Growth and development are important aspects of an animal's life which enable it to survive in its environment and to reproduce to sustain the species. But a meat producer views these aspects as a way of achieving the end result, meat. It is important to see both these points of view because as the producer tries to manipulate the growth of the animal to achieve increased meat production care should be exercised to avoid antagonism with the animal's survival capabilities and its ability to reproduce, if such antagonism may exist.

The natural phenomenon of growth proceeds in a definite pattern. Development closely follows this pattern. It is important to appreciate that this pattern is a resultant balance in a process that involves gain and loss in the animal's total mass (Russel, 1969). It is not a continuous point-by-point increase in mass. Definite stages may be conveniently defined in the growth pattern of an animal. Growth starts at conception and continues through to birth, weaning and puberty before maturity is reached. At maturity weight remains relatively constant as a result of the balancing out of the gains and losses in mass.

An animal's growth may be viewed as having two distinct phases, pre-natal and post-natal. The latter can further be subdivided into a pre-weaning and a post-weaning phase in view of the importance of weaning when the young animal becomes separated from the mother and has to adapt to more independent living. Most studies on beef cattle production have dealt with the last two phases of growth, probably due to the ease with which direct measurements can be made in those phases. The measurement of growth has invariably been based on weighing at particular convenient stages. Weight changes over known periods (growth rate) have, therefore, been studied and related to influences of various factors.

Under optimal conditions of nutrition and management cattle growth proceeds in a curvilinear pattern with advancing age. Viewed as a process starting from conception to maturity it forms the classical sigmoid curve common to most other biological growth data (see Fig. 1.1).

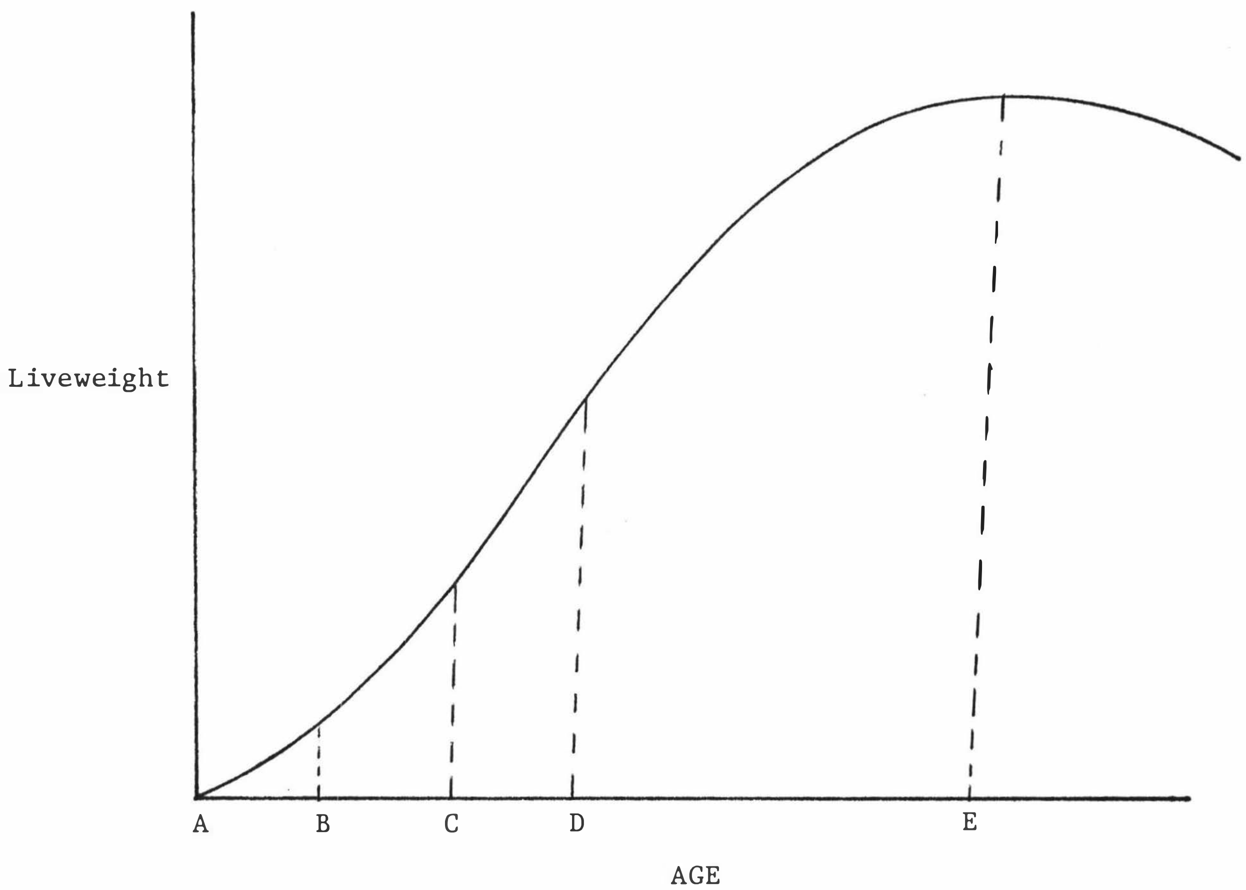

Fig. 1.1: Curve of liveweight growth in cattle - adapted from Goodwin (1977) with minor alterations.

Note: (1) The curve is not drawn to scale;

(2) A, B, C, D and E indicate some important stages in the animal's life (conception, birth, weaning, puberty and maturity, respectively).

The general shape of the growth curve represents a well-established concept in farm animals (McMeekan, 1943), but it should be pointed out that the exact location of the curve in the axes varies tremendously. First, it is known that biological material is very variable and, secondly, growth is known to be influenced by a variety of factors. For example, species and breed of the animal, its sex, climatic conditions and other environmental factors and interactions between these factors are known to influence growth and would therefore determine the exact location and shape of the growth curve, even if nutrition and management were ideal.

The close relationship of development with growth and their change with age makes it possible for an experienced stockman to estimate an animal's age from its outward appearance. The external form and appearance of the animal changes following internal changes. These changes reflect growth of the major component tissues in beef cattle, bone, lean, and fat. Differential growth in these tissues follows a definite pattern as the animal's age advances (Barton, 1958; MacDonald, 1958; Yeates and Schmidt, 1974; Berg and Butterfield, 1976; de Boer and Martin, 1978). Bone tissue is known to develop and grow fastest in the earlier stages of the animal's life. Lean (muscle tissue) growth tends to follow that of bone closely, but it is initially at a slower rate. As bone growth reaches a peak and slows down muscle growth takes the lead. Fat tissue develops later than the other tissues and initially grows at a slower rate. When muscle tissue growth has reached a peak and slows down fat tissue growth becomes the fastest of the three. Fat growth is fastest when the animal approaches maturity. By this time most increase in weight of the animal is due to fat deposition. Fig. 1.2 illustrates the differential growth of these tissues in beef cattle.

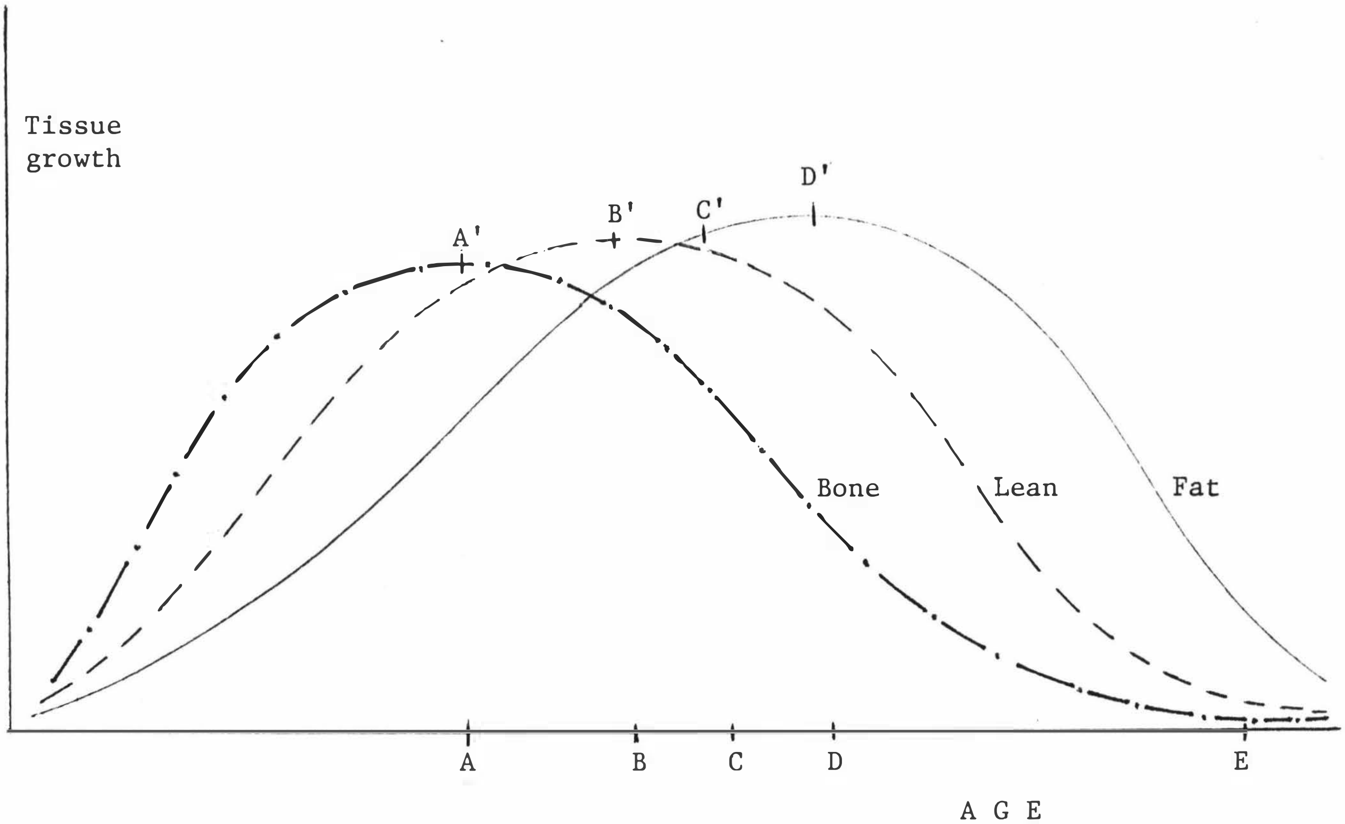

Fig. 1.2: An illustration of differential growth in the three major tissues of beef cattle (adapted from Goodwin, 1977).

Note: (1) The figure is not to scale and should be considered as an approximation only;

(2) A, B and D are the stages in the animal's life when the major component tissues grow fastest (bone, lean and fat, respectively);

(3) C is an arbitrary point of slaughter for production of "young, tender, lean meat", which is of high demand (see text);

(4) E is maturity stage by which time only fat deposition accounts for any appreciable weight changes; slaughter is advocated before this point to avoid over-fat carcasses.

The growth curves in Fig. 1.2 vary tremendously in shape for the same reasons as explained for Fig. 1.1. The implications of this variation are more vivid when an early-maturing cattle breed is compared with a late-maturing one (for example, Angus compared to Friesian as illustrated by Goodwin, 1977). It is important to appreciate this because it forms the basis for choice of slaughter point, at least theoretically.

A vital connection exists between growth phenomena and the eventual results that the producer has most interest in, namely, the carcass and meat. From scrutiny of Fig. 1.2 the producer should be advised to choose a slaughter point where most muscle growth has taken place efficiently (if this could be identified) since interest is in red meat production. An "optimum" amount of fat in the carcass is an important characteristic for most end uses of beef. For the production of "young, tender, lean meat" which is in high demand at the present time, it would be appropriate to advise slaughter at a point C, somewhere after muscle tissue growth has started to slow down (A in Fig. 1.2) and fat tissue growth is proceeding at a faster rate, but has not reached its peak, D. This would ensure that only a limited amount of fat deposition has occurred. For "prime" beef this amount of fat may still be below optimum and delayed slaughter may be necessary to a stage beyond the peak of fat tissue growth, but, by all means, before maturity. This stage is difficult to determine precisely because of variations between individual animals and since one cannot "see" the fat before the animal is slaughtered. This explains why there is always a need to trim off some fat on some carcasses before cutting them into prime cuts. Most carcass and meat characteristics to which marketing systems and consumers are sensitive are related to the proportions of fat and lean. Fat is by far the most variable tissue in the animal's body and any attempt towards producing a more acceptable carcass depends largely on controlling the level of fatness (Berg and Butterfield, 1976).

1.3 Post-slaughter Characteristics

Post-slaughter characteristics may be broadly divided into two categories. First there are those characteristics which refer to the entire carcass. According to the Meat Research Institute (1976), the carcass may be defined as:

> "the whole body of a slaughtered animal intact or split lengthwise in the approximate medial line of the vertebral column, after bleeding, skinning and evisceration, and removal of head ...".

However, the process of dressing beef cattle differs in fine details such as the amount of fat trimmed off, whether the tail is part of the carcass or removed and whether kidneys and their associated fat are part of the carcass or removed. Characteristics of the carcass include both physical measurements and subjective visual appraisal. Carcass weight is the most important single characteristic because it is directly related to meat yield, and monetary value. Dressing-out percentage is closely related to carcass weight although it may be considered as a separate characteristic. Other carcass characteristics concerning size include linear measurements (lengths, widths, circumferences and depths of anatomical structures, measurements on the eye muscle surface, and so on), amount of fat cover, and general visual features related to conformation. To these may be added other subjective attributes like fat and lean colour and signs of contamination.

Methods for objective carcass assessment differ widely between countries and, to some extent, between institutions within countries (depending on the objective of the exercise). This is evident in explanations contained in two publications on methods used in European countries (Agricultural Research Council, 1965; and Meat Research Institute, 1976).

The second category of post-slaughter traits consists of those characteristics that refer to meat. These may be further subdivided into raw and cooked meat characteristics. There are relationships between these two categories, but it would appear obvious that the latter is more important since it forms the basis for the final test of the quality of meat, namely, acceptability to the palate. But the characteristics of raw meat are important because consumers assess the appearance of raw meat "at the supermarket" and will buy what appeals to their eyes and avoid what does not if there is an alternative. Visual assessment is based on meat colour, amount of fat cover, visible intra-muscular fat (marbling) and inter-muscular fat, meat texture (related to size of muscle fibre bundles or "grain"), surface wetness characteristics and signs of contamination. Muscle pH is a characteristic that influences microbial activity on the surface of raw meat and discolouration. Sarcomere lengths in raw meat are related to tenderness and if they can be measured, they are a valuable source of information on meat in the raw state.

Cooked meat has various characteristics related to acceptability; meat tenderness is generally considered the most important of the eating characteristics of meat (Karmas, 1975; Gerrard, 1977). Other aspects that influence acceptability are juiciness (related to water-holding capacity, fatness, and cooking characteristics), flavour, and aroma. The last two are influenced by both the cooking method and addition of flavouring agents (spices) besides being inherent meat attributes *per se*. Meat colour depends to a greater extent on the cooking method and addition of colouring materials and spices.

1.4 Relationships between Beef Cattle Traits

The many factors that influence beef production can be divided into two categories. The first category is that which is determined by the animal's genetic potential. This explains variation due to differences ranging from that between species, strains, breeds, within-breed lines, individual sire lines to individual animal differences (each inherits half of its characteristics from the sire and half from the dam). The second category consists of all environmental factors - any not attributed to inheritance. These act through their influence on physiological processes as the animal grows. Most post-slaughter traits are influenced by these same factors because they are related to (or determined by) the physiological changes. Nutrition has a direct influence on growth and is one major environmental factor. Since physiological changes continue to occur as time passes, age is another factor. Differences due to the animal's sex (female, castrate or entire) form another aspect. Management, a broad term that includes handling, disease control and use of feed additives (such as antibiotics and hormonal formulations) affects beef cattle traits also.

Some traits are related to liveweight. This is especially true of post-slaughter traits (notably, those related to fatness), but may be generalized for all traits.

Observed variations in traits are therefore explained as having a genetic and an environmental source. Covariance between traits may also be explained in a similar way (Turner and Young, 1969). On the assumption that covariances due to genetic and environmental factors are independent (which is usually the case in practical situations) the phenotypic variance and covariance can be presented in the simplified algebraic expression,

$$P = G + E,$$

where P is the phenotypic value, G the genetic component and E the component from the common environment. Relationships between traits may be categorized in the same manner (Dalton, 1980) because they are defined by covariances and variances.

Because of the common influence of genetic and environmental factors on growth, carcass, and meat characteristics, it follows that relationships would be expected to exist between them. It is, however, not possible to measure all three types of relationship directly based on what the producer records in his herd in a short time. Whatever relationship is found between these characteristics under such a situation is true for that herd and contains a genetic as well as environmental component. These components are not easily separated except with a large body of data. An attempt to "partition" this phenotypic relationship where the number of observations is small is unacceptable because of the magnitude of error. Turner and Young (1969) suggested that in estimating genetic correlations the number (of parent-offspring pairs) should be at least 500 for the estimates to be meaningful.

Genetic, environmental and phenotypic correlations do not necessarily imply a "cause-and-effect" type of relationship between traits. They may exist because the traits have a common origin or common "cause-and-effect" relationship with other traits. But correlations indicate how close the tendency is of high values of one trait to be associated with high or low (positive or negative correlations) of the other and vice versa.

Genetic correlations between various traits have been studied in many species of animals. Falconer (1954), using different lines of mice, demonstrated the validity of genetic correlation between liveweight and tail length. Genetic correlations have been explained in basic genetics and animal breeding textbooks as arising from either or both of two well-established phenomena (see, for example, Falconer, 1960; Pirchner, 1969; Turner and Young, 1969). One is termed pleiotropy, the phenomenon whereby there is influence of one gene on two or more traits. The other is linkage between genes affecting different traits. The former is more permanent and may be considered the true source of genetic correlation (Dalton, 1979) whereas the latter is less important because its influence on the correlation coefficient diminishes from one generation to another due to segregation. Genetic correlations are important in selection because they give an indication of what the producer can expect as change in a trait not being selected for while selecting for a trait related to it. They may be used to plan selection against unwanted correlated responses. Where traits are not measurable, or are difficult to measure, a correlated trait may be selected for to improve the difficult one.

Phenotypic correlations between production traits are not as important as genetic correlations because they do not give a definite indication of what would be expected to happen as permanent change in the course of selection. In fact, suggestions based on phenotypic measures need to be confirmed by a look at the magnitude and direction (negative or positive) of the genetic component of the correlation. It is possible for the two types of correlation to be of opposite signs. This is the case where the environmental causes of variation are such that the phenotypic correlation is positive and masks a negative genetic correlation. For this reason, care should be exercised in interpretting and using phenotypic correlations until the size and direction of the corresponding genetic correlations are estimated.

Being directly measurable, phenotypic correlations are easy to obtain even with relatively few records. They show how the animal's phenotypic traits are associated in a particular situation. The square of the correlation coefficient (that is, the coefficient of determination) indicates a measure of the amount of variation in one trait that is accounted for by variation in a correlated trait. Ideally, this is as far as such correlation coefficients may be used in the absence of other parameters of a herd to which they refer. Phenotypic correlations are also used in selection equations and in generating estimates of other statistics of the herd.

1.5 The Objectives of this Study

The primary objective of this study was to generate phenotypic relationships between growth, carcass, and meat characteristics of Angus steers. The work is based on data collected under conditions with a variety of factors which would be expected to influence the phenotypic observations. This influence became a secondary aspect on which attention was focussed. Analysis of covariance was employed to determine whether some environmental factors and co-variates were significant sources of variation in the traits in order to throw some light on their relevance in this study.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Factors Influencing Beef Cattle Traits

Beef cattle production embraces many aspects and it is impossible in this thesis to cover more than just a small fraction of them. The various aspects of beef cattle production may generally be related to three main categories of traits of importance. First, one may identify reproductive traits such as sexual maturity, fertility, calving intervals, percentage calf crop (and calf survival) and characteristics or factors related to them. Secondly, production traits, including milk production and mature cow weight (on the female side) and liveweight, growth rate, and efficiency and other factors or characteristics relevant to the assessment of a slaughter animal. Finally, characteristics of the product (meat) in terms of quantity and quality should be identified and considered along with the foregoing traits. It is these traits and their inter-relations, relative economic values, heritabilities, and variation, in any given situation, that are of interest to the beef cattle breeder. The central aspects of this study (as stated in the introductory review in Chapter 1) fall into the last two categories of beef cattle traits, namely production and product traits.

The production and product traits in beef cattle are numerous, but may be conveniently divided into two categories, namely, growth and post-slaughter traits. The former embraces changes in pre-natal, pre-weaning, and post-weaning and the latter can be sub-divided into carcass and meat traits. A look at the factors that influence variation in the traits leads to an appreciation of the possible existence of relationships between the various traits. There is an extensive literature on various factors that influence growth carcass, and meat traits in farm animals, but only a few studies are covered in this review, in addition to a brief mention of major reviews accessed by the author. Interest in relationships between beef cattle traits has not been as great as that on the individual factors of production. This is reflected in the dearth of information, especially in the grazing-situation, on relationship between growth, carcass and meat traits in beef cattle.

The factors influencing any trait may generally be associated with a genetic or environmental origin. This classification of factors will be emphasized in this review as the main factors influencing the traits are discussed. It should be pointed out that, while the factors are well-agreed upon and their influence well-established as demonstrated through research, biological variation leads to contradictory reports from time to time as is evident in the literature. This review focusses on the main trend of research observations and few contradictory reports have been discussed at length.

2.1.1 Pre-natal Growth and Birth Weight

The importance attached to factors that influence growth is reflected in the extent of the published literature as evident in various reviews (for example, Preston and Willis, 1974). Most studies have dealt with post-natal growth. This may be because of the ease with which growth can be measured directly in this phase, compared to pre-natal growth.

2.1.1.1 Genetic Factors

Factors influencing pre-natal growth have been reviewed by Hafez (1963, 1969b) under the two broad categories: genetic and non-genetic. In the former, he included foetal gene complement and maternal gene complement mediated by cytoplasmic effects. Species differences, as well as differences between breeds, strains, and sires, were also mentioned. Such genetic differences may be traced to early embryonic stages as has been demonstrated in comparisons between small and large breeds of some animals (Hafez, 1969b).

2.1.1.2 Non-genetic Factors

The non-genetic factors on pre-natal growth are principally attributed to maternal influence/environment. These include age and size of dam, parity, health, and nutritional status during pregnancy, environmental stress (for example, due to heat stress) and other aspects. The influence of these maternal factors is generally acknowledged and hardly warrants any documentation. These maternal factors have been demonstrated in many kinds of animals, from mice and rabbits to livestock and humans. It has been generalized that maternal influence contributes up to 75% of the variability in foetal size (Hafez, 1963). The contention that,

> "the genetics of the sire determine the upper limit of size at birth when the mother is large, but the size of the placenta limits size in a small mother"

by Hafez (1969) may be strongly supported by some classical demonstrations in various animals, such as the study of a case of reciprocal crossing between the Shire horse and the Shetland pony (Walton and Hammond, 1938).

It may be argued that dam size determines placenta size and this in turn influences foetal growth. Dam size is a result of an interplay of the age, nutrition, health status and other environmental variables. Differences in pre-natal growth due to age of dam are partly explained by the competitive existance between the young dam and the foetus for nutrient resources. Various other explanations may be advanced to account for differences in foetal growth due to age and parity of the dam. Degree of development of the uterus appears to be the major reason.

Although nutritional effects are generally known to have appreciable influence on pre-natal growth (Hafez, 1963), maternal undernutrition is not always reflected in retarded foetal growth. The foetus may continue to grow normally at the expense of the mother. But if this is in late pregnancy the demand may excel and further undernutrition may lead to reduced foetal growth. In some cases premature parturition may result. It would seem that in monotocous animal species, like cattle, multiple pregnancies reduce pre-natal growth in much the same way (Hafez, 1969) although the exact mechanisms involved are not fully understood.

The influence of ambient temperature on pre-natal growth was demonstrated in sheep by Yeates (1958) in studies which separated the influence of malnutrition from that of temperature. This may generally be extrapolated in relation to cattle. Other effects of temperature relate to feed intake and metabolism (Hancock and Payne, 1955; Colditz and Kellaway, 1972; Kellaway and Colditz, 1975) of the dam. This may reflect indirectly on the growth of the foetus which draws its nourishment from the dam's nutritional sources.

The end result of pre-natal growth is measurable as birth weight. This is the earliest growth trait which is measurable directly on the individual animal. It is influenced by the factors that are known to have an influence on pre-natal growth. However, information on factors affecting birth weight appears to be more readily available in the literature, much of it without explicit reference to relevance of the same factors to pre-natal growth. It has been shown in some studies (Hafez, 1963) that as much as 50% of the weight at birth is gained in the last quarter of the gestation period. If for any reason gestation is prolonged, then this would reflect in higher birth weights. Noticeable growth has been reported in the calf's first 48 hours of life (Koch et al., 1955a). This means that time of recording birth weight (in relation to actual parturition time) should be considered to be a crucial factor in its variation.

Gestation length is known to vary between species and reports in the literature show that there is appreciable variation between cattle breeds (Andersen and Plum, 1965). This variation may be responsible for part of the differences in birth weight that have been reported between breeds and between crosses of cattle by various authors (Brown et al., 1967; Willis and Preston, 1968; Willis et al., 1972; Hight et al., 1971; Preston and Willis, 1974; Reynolds et al., 1980). However, gestation length has also been reported to vary by sex of calf, with bull calves being carried for slightly longer than heifer calves (Krasnov and Pak, 1937; Dawson et al., 1947; Schwark and Oehler, 1972; Preston and Willis, 1974), while sex of calf is another source of variation in birth weight.

Numerous reports strongly suggest that bull calves are born heavier than heifer calves (Krasnov and Pak, 1937; Dawson _et al_., 1947; Gregory _et al_., 1950; Koch and Clark, 1955a; Koch _et al_., 1973; Drewry _et al_., 1978; Reynolds _et al_., 1980; and others). Vesely and Robison (1971) found sex to be the most important source of variation on growth up to weaning.

Twin pregnancies are reported to have shorter gestation periods. This would appear to partly explain why twins are born lighter, although it is known that the combined weight of a twin-set is usually heavier than the average of singletons (Preston and Willis, 1974). Gestation length appears to be related to many factors (breed, sex of calf, age of dam, nutritional and other stress conditions and many other factors), which are themselves known to influence pre-natal growth. The effect of gestation length may, therefore, be confounded with that of these other factors in their influence on birth weight.

Age of dam is generally acknowledged as a factor on birth weight (Hafez, 1963, 1969; Preston and Willis, 1974). While many studies on birth weight have indicated that age of dam is a vital consideration (Koch and Clark, 1955a; Christian _et al_., 1965; Cardellino and Ephraim, 1971; Koch _et al_., 1973; Drewry _et al_., 1978; Reynolds _et al_., 1980), a number of reports in the literature have suggested that age of dam is a relatively unimportant factor on birth weight (Nelms and Bogart, 1956; Francoise _et al_., 1973; Singh _et al_., 1971). But the general trend of most results shows a clear indication that younger cows drop lighter calves while mature cows drop heavier calves and very old cows have lighter calves. This is most noticeable when extreme cases are considered. Young cows (2- and 3-year old first and/or second calvers) and very old cows (say, 10-year old and older) have lighter calves than medium-age mature cows, that is, 5- to 8-years old.

Age and nutrition of the cow, season and year of calving may be related to the size of the cow. Trail et al (1971a) reported that age of cow was a significant factor on cow weight both at calving and in the ensuing months (up to 12 months later). Hight (1966, 1968) studied the influence of cow nutrition on calf birth weight and reported that poor nutritional status of the cow in late pregnancy lowered birth weights and increased post-natal mortality. Feed availability varies from year to year and season to season, especially in a grazing situation. With more feed of higher quality the breeding cow would be expected to have a heavier weight. This supports the general observation that cow size (weight) bears some relationship with calf birth weight.

The reports of crossbreeding studies in Western Uganda (Trail et al., 1971a, b; and Sacker et al., 1971a, b) strongly suggested that year and season of birth were important sources of variation. The same studies also suggested a positive relationship between dam weight at calving and calf birth weight. In most studies where the relationship between dam weight and calf birth weight has been reported, it has ranged from low to moderately high (Krasnov and Pak, 1937; Dawson et al., 1947; Gregory et al., 1950; Koch and Clark, 1955c; Alexander et al., 1960; Sawyer et al., 1963; Reynolds et al., 1980). Some authors have considered this relationship to be important as a factor influencing birth weight, in effect suggesting that where comparisons have to be made between calves, adjustments need to be made for the influence of the dams' body weight on the birth weights of their calves.

2.1.2 Post-natal Growth to Weaning

The same categorization of the factors as used for pre-natal growth may be applied to describe factors that influence post-natal growth. The identification of genetic and non-genetic factors is envisaged as before. Moreover, factors influencing pre-weaning growth are mostly environmental, and pre-weaning growth has low to medium heritability as most reports reviewed in the literature suggest (Preston and Willis, 1974; Nicoll, 1975; Barlow, 1978; Msechu, 1979).

Because the main source of variation in the calf's nourishment during the suckling period is of maternal origin, it is generally accepted that pre-weaning growth is basically a maternal characteristic. Good mothering includes aspects of the dam's ability to feed, shelter and protect the offspring; these are aspects which are not objectively measurable, but pre-weaning growth and weaning weight are and have been adopted (Dalton, 1980) for assessing maternal ability. It is common observation that poor milkers have poor mothering instinct too and often lose their offspring.

2.1.2.1 Genetic Factors

The inter-play of the calf's direct genetic potential and the maternal ability is reflected in the level of pre-weaning growth and weaning weight. Besides its other influences, the genotype of the dam influences the level of milk yield. This, in turn, determines pre-weaning growth of her calf. These maternal genetic effects (Barlow, 1978) may, therefore, be looked upon as genetic factors augmenting the influence of the calf's genotype which is a more direct genetic source of variation in the calf's pre-weaning growth.

Influence of genetic factors on pre-weaning growth explains differences in growth between species, breeds and strains. These are common knowledge and need not be over-emphasized. Differences due to breed of sire, breed of dam, sire lines, or individual sire groups are due to genetic variability. Heterotic and inbreeding effects on growth are also of genetic origin. A search in the literature reveals very many studies which suggest that such genetic variability exists.

Several reports from crossbreeding studies carried out in Western Uganda by Sacker *et al*. (1971a, b, c) and Trail *et al*. (1971a, b, c) suggested that differences existed between breed groups as well as between breed of sire and breed of dam. These differences were reported for weights taken between birth and 24 months of age. Heterotic effects were also suggested as a source of variability of weaning weight in these investigations (Sacker *et al*., 1971c). The studies involved breeds with striking differences in mature size, namely the exotic *Bos taurus* (Angus and Red Poll) as compared to the indigenous *B. indicus* (notably the Small East African Zebu). Similar studies in Zambia (Thorpe *et al*., 1980a, b, c) based on different breeds (Friesian and Hereford as the *B. taurus* breeds and Angoni and Boran the *B. indicus* Zebu breeds) revealed differences between breeds also. In studies elsewhere on *B. taurus* breeds it has also been reported that breed differences are important sources of variation in animal growth.

Barton (1975) compared the growth of steers of several *B. taurus* breeds (Angus, Red Poll, Friesian and Jersey) and reported that there were distinct differences among the breeds. His results in that report were generally in agreement with earlier work involving beef, dairy-beef and dairy type animals (Barton, 1966, 1968, 1971, 1972, 1973 and Barton and Armstrong, 1974). With the exception of the Jersey breed, dairy type animals grew faster than beef types. Where similar comparisons have been made this general observation has been confirmed (for example, Hight et al., 1971; Dalton and Everitt, 1972; and Lewis and Davis, 1972) with the Friesian breed being found to be superior in growth rate. It would seem that the genetic potential of this breed for milk yield is largely responsible for their superiority. To this end, Hight et al. (1971) suggested that calves with high growth rate capacity are required,

> "... to exploit the milking potential of the Friesian as well as increases in efficiency of food conversion from high post-weaning growth rates."

The differences reported due to maternal breed effects favouring Friesian-mothered calves must largely be attributable to milk yield. However, such differences have at times been reported right from the start at birth (Hight et al., 1971) and could be attributed to various other characteristics of the breed.

Various recent reports in the literature (e.g., Jones et al., 1981) confirm the contention that breed differences in growth exist. In large-scale trials where breed evaluation has been attempted (e.g., Carter, 1977) there has invariably been suggestions of differences between breeds involved. In crossbreeding trials differences due to breed of sire and breed of dam may be due to heterosis. Crockett et al. (1979), working with Brahmans, Brangus, Beefmaster, Limousin, Simmental, and Maine-Anjou as the sire breeds on Angus, Brangus and Hereford cows, reported significant differences in pre-weaning growth and weaning weight due to breed, breed of sire, breed of dam and breed-of-sire x breed-of-dam interaction. Fredeen et al. (1981) studied growth patterns of first-cross cows and reported breed of sire and breed of dam differences in weaning weight of their calves.

The results of Pahnish (1961) suggested that sire effects were a significant source of variation in weaning weight. Mahmud and Cobb (1963) reported sire effects on pre-weaning gain and weaning weight also. Cunningham and Henderson (1965), in a study that assessed the importance of various factors, revealed significant sire effects on weaning gains, as well as weaning scores. These are just examples that suggest the importance of genetic variability in pre-weaning growth arising from sire differences.

2.1.2.2 Non-genetic Factors

Non-genetic factors that influence pre-weaning growth may have a direct effect or act indirectly through their influence on the dam's milk yield. Hafez (1963) summarizes the list of the factors as birth weight, milk of dam, maternal care, age of dam and age of calf at weaning. Among the various environmental factors on pre-weaning growth, maternal aspects feature prominently. These include age, size, feeding or nutritional regime, ambient temperature, health status and management criteria. All these have some influence on the dam's milk yield (and probably milk composition) and, therefore, play an important role in affecting the calf's growth. Preston and Willis (1974) reviewed some of these factors. Robison et al. (1978) investigated the influence of year, herd, and age of cow on milk yield of Hereford cows and reported these to be important sources of variation in milk yield. It would appear that the technique of estimating milk yield, as well as the stage of lactation, had some influence on the reported variation as it seems to have been the case in these authors' further work (Dillard et al., 1978). The results also strongly suggested that a relationship existed between milk yield and weaning weight.

In an analysis of Angus and Hereford records Nicoll and Rae (1977) reported appreciable age of dam effects ($P<0.001$) on weaning weight. The main differences were observed in 2-, 3- and 4-year old cows whose calves had weaning weights that deviated most from the mean (in both breeds). The influence of cow weight that has been reported in various studies (Preston and Willis, 1974) may have some association with that of age of cow. Based on results of a study on the relationship between cow weights and calf performance, Sawyer et al. (1963) concluded that:

> "... heavier cows tend to produce calves that gain more rapidly and are heavier from birth through 18 months of age."

These results were in agreement with the view expressed by other workers, that calves which are heavier at birth tend to maintain that superiority over a long period, well into the post-weaning period (Gregory et al., 1950; Notter et al., 1978b).

Folman (1977) emphasized management in relation to diseases, level of nutrition, and housing (or shelter) and their influence on pre-weaning growth. The influence of these factors varies between herds, year, and season of calving. The extent to which their influence is noticeable may depend on various other factors with which they interact, for example, climate and possibly breed (Willis et al., 1972). Frahm et al. (1981) recently compared various groups of crossbred cows and reported differences between herds. In their report two maternal aspects appear to have influenced pre-weaning calf performance. First, it seems that the crossbred cows incorporating Brown Swiss, Jersey and Simmental showed superior calf performance due to their higher milk yield potential. Secondly, calves from Simmental- and Brown Swiss-cross cows were heavier at birth and this seemed to have contributed towards their observed superiority at weaning. Cow size, notably that of the heaviest cross (Simmental) may have contributed towards this superiority too.

Non-maternal environmental factors on pre-weaning growth are numerous and they vary in economic importance depending on specific situations. The principal factors that have been studied widely (Preston and Willis, 1974; Hafez, 1963, 1969), are sex and age of the calf, feeding regime of the calf (including creep-feeding, feed additives and growth promotants), herd or management aspects, year of birth, and environmental stress. Growth was defined in Chapter 1 and Fig. 1.1 related changes in growth to advancement of age. Age of calf is, therefore, an important source of variation in aspects of calf growth. There is a curvilinear relationship implying that the changes are not a simple straight-line relationship. Generally, weight gains in a given time-period decrease with increasing age when consideration is of the major part of the animal's life. In fact a negative correlation has been reported between age and weight per day of age (Munro, 1962). But changes in growth rate at any particular stage or age vary widely due to influence of other factors. Age may have some relationship with nutritional aspects of the calf because of the decreased dependence of the calf on milk (suckling) with increasing age (ability to handle forage increases at the same time).

Differences in growth rate between sexes have been studied widely. Bulls, steers, and heifers have shown a definite ranking order in growth rate; bull calves are invariably heavier and grow faster than steers which are in turn superior to heifers (Preston and Willis, 1974). This general trend has been reported in the literature and sex is considered an important factor on all beef cattle traits and has, therefore, received a lot of research attention. It is probably a more important factor on growth than most other factors and appears to be second to only maternal/nutritional influences on pre-weaning growth. Numerous studies have reported differences in pre-weaning growth and weaning weight due to sex (Koch and Clark, 1955a; Clum et al., 1956; Mahmud and Cobb, 1963; Minyard and Dinkel, 1965; Christian et al., 1965; Cunningham and Henderson, 1965; Sacker et al., 1971a; Francoise and Vogt, 1973; Koch et al., 1973; Pell et al., 1978; Drewry et al., 1978). In one study, where various factors (year, sire, herd, age of dam and sex of calf) were envisaged to be the causes of variation, sex of the calf was found to be the most important source of variation (Vesely and Robison, 1971).

Feeding and nutritional regime may be viewed as causes of variation in pre-weaning growth through an effect on the dam's milk yield besides the direct effect on the calf's feed intake and subsequent metabolism. The importance of feeding on growth need not be over-emphasized with literature evidence. Creep-feeding has been shown to have an appreciable effect on pre-weaning growth and weaning weight (Hamann et al., 1963). Feed additives (growth promoters) have also been studied and their effect on growth is well-established (Walker et al., 1958; Smith et al., 1958; Potter et al., 1974; Oliver, 1975). Use of hormonal, antibiotic vitamin and other biologically-active formulations is practised to varying extents in different countries of the world.

Variation in growth rate due to season, year, and herd, or location, may be attributed to nutritional differences due to these factors, albeit indirectly. These factors may influence the calf's pre-weaning growth through the calf's nutrition directly or indirectly by influencing the dam's milk yield. Robinson et al. (1978) studied 1319 lactation records collected bi-monthly by the calf-suckling technique and reported a strong indication (P<0.01) that herd, year, herd x year (interaction), and age of the cow had an influence on measures of milk yield. Such influence would most likely have been reflected in differences in the calves' pre-weaning growth (due to the factors influencing milk yield). In studies where milk yield data are not recorded, such differences in calf growth are attributed to factors such as year, herd , age of dam, and season, sometimes without implicating milk yield.

2.1.3 Post-weaning Growth

The growth phase after weaning is of particular interest in a beef production situation because it is related to efficiency of feed utilization (Nelms and Bogart, 1955; Bogart et al., 1963; Cundiff et al., 1981) and it leads directly to the realization of the end-products, the carcass and meat. The rate of growth in this phase is dependent on earlier growth to some degree, but is largely controlled by the animal's genetic potential and ability to recover from a check at weaning and re-adjust to independent living.

Factors influencing post-weaning growth may be split conveniently into the same categories as was done with pre-weaning growth, namely, genetic and non-genetic. However, the relative importance of these factors may differ because of the change in nutritional requirements and largely due to the calf's reduced dependence on the dam for nourishment.

Hafez (1963) identified the main factors on post-natal growth as genotype, sex, level of weaning weight, nutrition, climate, adapatability and management. In a later review, the same author (Hafez, 1969a) listed the primary factors on post-weaning growth as hereditary factors, ambient temperature, the animal's ability to adapt to its environment, social stress, and feed availability.

2.1.3.1 Genetic Factors

Heritability estimates for post-weaning growth traits have been reported to range from medium to high, depending on what characteristic is considered. Liveweight recorded in the post-weaning growth phase is invariably reported to be highly heritable and most other traits are of medium to high heritability as suggested in work reviewed by various authors who focussed some attention on the subject (Warwick, 1958a; Dalton et al., 1970 Clifford and McDonald, 1972; Preston and Willis, 1974; Msechu, 1979). These levels of heritability suggest that the genetic factors causing variation in post-weaning growth traits are important.

Differences between species, breeds or strains, and lines within breeds, in post-weaning growth are well-known in farm animals and need not be over-stressed. Some of the variation may be of an indirect nature from the fact that similar differences arise in the pre-weaning phase of growth and may therefore be reflected in post-weaning performance, simply through carry-over effects. In his review of genetic variation in growth and development in cattle, Taylor (1968) stated that, besides such spectacular gene effects as those responsible for dwarfism or double-muscling in cattle,

> "... the dominant role of genetics in growth of cattle is most obvious in the wide range of breed sizes."

He then pointed out the extremes which demonstrate the sharp contrast between large breeds of cattle (Charolais, Chianina, and South Devon) and small breeds such as the West African Dwarf and the Iberian Degestan Mountain. The former have birth weights of around 45 kg and mature weights as high as 1400 kg; the corresponding weights of the latter are up to 14 kg and 200 kg, respectively. There is wide variation in breeds that have intermediate performance between these extremes.

Berg (1968) reviewed literature on the influence of genetic factors on growth in cattle based on growth and relative growth of the major carcass tissues, lean, fat, and bone. His work pointed out the differences in growth reported between breeds, types, and strains within breeds. Numerous studies in the literature have demonstrated significant genetic differences in post-weaning growth. A few examples will be discussed where any of the factors such as breed, line or strain, breed of sire, breed of dam type, heterosis and genotype x environment interactions have been reported to be significant.

In a study of the performance of British, Zebu, and dairy-type cattle by Cole et al. (1963), significant differences were found to exist between types and between breeds within type. Their study included Hereford, Angus, Brahman (and Brahman crosses), Santa Gertrudis, Holstein and Jersey breeds. A series of studies comparing dairy-type (mainly Friesian and Jersey) and beef-type (mainly Angus and Hereford) in New Zealand by Barton (1966 to 1975) revealed marked breed differences in various aspects of beef production including post-weaning growth. Similar results were obtained by Dalton and Everitt (1972) who found that Friesian bulls had superior liveweight compared to Angus bulls. These results were also in agreement with those of Hight et al. (1971) who compared the performance of reciprocal crosses between Angus and Friesian.

Recent comparisons between breeds and types of cattle have revealed considerable differences between Hereford, Highland (Canadian) and Angus cattle (Lawson, 1981) and between beef-type (Hereford) and dairy-type ("Dairy Synthetic") cattle (Jones et al., 1981). In the former study sire breed was found to be important in its influence on liveweight, but differences in average daily gain on feedlot were not significant. Results of the latter study suggested superiority of the dairy-type cattle over Herefords in liveweight at birth and weaning and between post-weaning average daily gains and liveweight gain per unit of feed intake.

Sacker et al. (1971a, b, c) and Trail et al. (1971a, b, c) reported differences in liveweight and post-weaning growth rate between breeds and breed groups. The results of the same studies revealed significant influence of breed of sire and breed of dam on growth beyond weaning. Heterosis was reported to have varied between 26.4% and 29.7% for liveweight up to 12 months of age. Results of a simulation study comparing cross-breeding strategies by Leigh et al. (1972) suggested that the choice of an optimum crossbreeding programme depended on the breed combinations, among other considerations.

In their study on Angus and Hereford cattle, Nelms and Bogart (1955) found significant effects of breeding lines on growth efficiency. Bogart et al. (1963) also reported an influence of breeding line on growth rate and efficiency of feed utilization, but such effects were not significant on feed consumption. Another study involving three Hereford lines (Kress, 1977) revealed that line influenced weaning score and efficiency, but suggested that there was no effect on weaning weight, post-weaning feed intake and gain, and final weight after a 168-day feeding period.

Baker et al. (1975) reported wide variation between sires in offspring performance. Smith and Cundiff (1976) analysed the relative growth rates of Hereford, Angus, and Shorthorn steers and from the results suggested sire, breed of sire, and breed of dam effects on post-natal and post-weaning growth rate. These authors cited previous work by other authors whose results supported their contention that,

> "Evidence shows considerable genetic variability in the shape of the growth curve in beef cattle ..."

Findings of other workers support the view that genetic variation arising from sire breed and dam breed is important in cattle growth (Hight et al., 1971; Crockett et al., 1979; Fredeen et al., 1981; and Cundiff et al., 1981).

2.1.3.2 Non-genetic Factors

Environmental factors on post-weaning growth have been studied widely and numerous reviews reflect the importance attached to such factors. Barlow (1978) remarked that the nutritional regime and period over which this growth phase is investigated varies considerably between studies. The age of the animal is undoubtedly a crucial factor in the assessment of variation in growth; this becomes evident in view of the shape of cattle growth curves (see Hafez, 1963; and Fig. 1.1 in Chapter 1).

Nutrition considerations are vital because poor feeding (quantity as well as quality) affects growth and other traits adversely. de Boer and Martin (1978) specially emphasized this aspect in their assertion that,

> "... growth cannot be studied properly without referring to a nutritional background ...".

and that feed intake and the growth curve are

> "... strict individual features of the animal and the diet."

The feeding or nutritional regime depends on whether management is intensive or extensive. Where there is dependence on grain or concentrate feeding, "balancing the ration" is an essential consideration; and in a situation where production is based on pastures, supplementation is sometimes a vital consideration. The addition of mineral and vitamin formulations to achieve required levels for specific rations (for example, a finishing ration) is a common management aspect. So is the provision of mineral licks in grazing conditions where this is considered necessary.

The advantages of adding into the feed what have become popularly known as growth promoters (mainly hormonal, antibiotic and other biologically active formulations) have been demonstrated by various authors (Smith et al., 1958; Oliver, 1975; Shorrock et al., 1978; Dyer et al., 1980; Ramsey et al., 1975, 1981). An attempt to determine whether animals treated with tranquilizer compounds were calmed and thus had superior growth due to saving energy otherwise wasted "... due to nervousness and unnecessary muscular activity" (Koch et al., 1958) failed to reveal such calmness. Increases in daily gain and feed efficiency were not significant, but no undesirable side effects were reported. It does not appear that major advantages have been demonstrated in the use of tranquilizers (Preston and Willis, 1974).

Use of growth promoters has been shown to have considerable advantages on growth and has found widespread application in some countries as feed additives and as implants, with variable success (Preston and Willis, 1974). However, the widespread use of hormonal formulations is a subject of legal control and has been banned in some countries due to the danger of human consumption of residues in the meat or the possible adverse effects of residues in the soil and crops. Some growth promoters with low residual levels in tissues are replacing controversial ones like diethylstilbestrol (Shorrock et al., 1978).

Some other environmental factors on growth are related to nutrition, feeding and management. These include what appears in the literature as effects of location, herd, year and/or season of birth or of weaning. The location of the farm determines the kind of feed available because different locations may have different pasture species or feed/forage of different quality. Variation between herds in feeding levels and quality of feeds available are inevitable for various other reasons. Weather conditions (in a season or year) influence pasture growth and quality. Year and season of birth have been shown to affect growth in the pre-weaning and post-weaning phases (see, for example, Sacker, et al., 1971a; Trail et al., 1971b; Brown et al., 1972; Kress, 1977; Crockett et al., 1979; and Lawson, 1981).

Brown et al. (1972) explained the influence of year of birth on liveweight up to maturity by reasoning out that,

> "The year at which an animal is born fixes the set of environmental circumstances to which it will be exposed".

The influence of climate alone could account for a lot of variation in feed intake and the availability of nutrients for animal growth (metabolism) as has been demonstrated by results of some studies (Colditz and Kellaway, 1972; Kellaway and Colditz, 1975). This is mainly due to the effect of temperature.

Compensatory growth is a phenomenon which may be recorded as one factor on post-weaning growth which is related to feeding and management. It is well-established that low levels of feeding (undernutrition) in the pre-weaning period are "compensated for" by faster post-weaning growth. This is supported by results of various studies (Butterfield, 1966; Scales and Lewis, 1971; Everitt, 1972; Morgan, 1972). However, it should be pointed out that various other studies have indicated that pre-weaning environmental effects due to differential feeding may have a lasting effect on lifetime growth performance in cattle (Everitt et al., 1969; Reardon and Everitt, 1972;

Martin et al., 1981). In a recent review based mainly on work carried out in New Zealand, Dalton and Morris (1978) concluded that environmental (principally feeding) differences as early as 3 to 4 months of age may have lasting carry-over effects on growth rate in beef cattle.

The importance of age in accounting for variation in growth in cattle has been explained under pre-weaning growth. Growth rate changes with age as suggested earlier in relation to the growth curve so that weight for age increases in a more or less curvilinear fashion with advancing age. Recently Jones and Hopkins (1980) estimated that there would have been a reduction of 6% in selection response for weight if age was ignored in the estimation procedures. Their study involved animals born over a period of only 33 days. Another recent study (Thorpe et al., 1980b) reported that date of birth had a significant effect on all weights in their study (birth to 3.5 years). These findings supported the view that age is an important factor.

The effect of age of dam on post-weaning growth has been considered to be relatively unimportant. But it is imperative that whatever advantages a calf has during the suckling period will give it a better chance of achieving a heavy weaning weight. Carry-over effects into the post-weaning phase, believed to be chiefly due to feeding differences (Baker and Morris, 1980) have been reported. As such, age of dam can have an influence through level of milk yield which varies with age as already stated. The reported relationship between dam weight and offspring weight (Swiger et al., 1963; Tanner et al., 1965) may be envisaged as having some relationship with cow age. Generally. the cow's weight increases with age. So, the relationship between cow weight and calf performance well into the post-weaning phase as reported in the literature (Swiger et al., 1963) might have partly been due to an "age of dam" effect.

Sex of the animal is considered a major source of variation in view of results accumulated in the literature. Nelms and Bogart (1955) reported differences between sexes in efficiency of gain, while Brown et al. (1972) found that sex had an influence on mature weight in cattle with males attaining weights that are 60% heavier than females. Chevraux and Bailey (1977) revealed that bulls gained faster than heifers. Various more recent reports have generally supported these findings. Rouquette et al. (1980) found that steers had superior gains when compared with heifers, and Thorpe et al (1980b) reported that sex was a significant factor on liveweight between birth and 3.5 years of age. The conclusion that Berg (1968) reached still seems to be entirely agreed on, that,

> "Sex is known to have a marked influence on the onset of fattening, with heifers fattening at lighter weights than steers, and steers at lighter weights than intact males."

2.1.4 Post-slaughter Characteristics

Factors responsible for variation in carcass and meat traits may be classified broadly as genetic and non-genetic. Genetic factors explain differences in these characteristics by species, breeds, breeding lines, sire breeds, dam breeds,and individual animal differences. However, some post-slaughter characteristics are influenced to a greater extent by non-genetic aspects, notably those close to the time slaughter and immediately post-mortem. Non-genetic factors explain the differences reported in the literature due to nutrition, age, sex, anatomical location of muscle and aspects of management, year of slaughter, and pre- and post-slaughter handling and processing.

Lawrie (1979) subdivided causes of variability in some post-slaughter characteristics into two broad classes of factors, namely, intrinsic and extrinsic. Species and breed differences were listed among the important intrinsic factors. The influence of species and breed is of genetic origin as was explained before. What Lawrie (1979) termed "inter-animal variability, the nature of which is little understood", may be attributed to genetic differences between animals, albeit partly. The rest of the intrinsic and extrinsic factors fall into the category of non-genetic or environmental factors. The list included such non-genetic factors on meat as sex, age, anatomical location and training or exercise. Plane of nutrition or food availability, fatigue, fear, pre-slaughter manipulation and environmental conditions at slaughter were considered extrinsic.

2.1.4.1 Genetic Factors

Species differences in some post-slaughter characteristics may appear to be a matter of common knowledge. For instance, it is known that beef is darker than pork or poultry meats; and that rabbit meat is generally more tender than hare meat. Such generalizations are supported by reports in the literature. Lawrie (1979) has reviewed work on species differences in chemical composition of muscle tissue in mature animals. It has been demonstrated that rabbit, sheep, pig, and ox meat differ considerably in fatness, percentage fat-free water, intra-muscular fat, myoglobin content (main pigment responsible for meat colour) and other components. Muscle pH has also been found to differ widely between species following rigor mortis, so that there is variation in ultimate pH ranging from pH 5.00 to pH 5.60 (Lawrie, 1979) from ox to lamb, with horse and pig meat having intermediate values. Time between exsanguination and onset of rigor mortis varies considerably between species and this has important implications to variation in meat characteristics.

Lawrie (1979) ranked breed differences second to species differences in importance as intrinsic factors on the biochemistry and constitution of muscle. Differences between dairy and beef breeds in many carcass and meat traits have been reported by many authors (Barton 1966a, 1975; Hight et al., 1971; Purchas and Barton, 1976; Lawrie, 1979; and others). Post-slaughter characteristics are numerous and an attempt at reviewing literature on factors influencing them individually would not serve a useful purpose. The characteristics are interrelated and have been studied in groups in most cases. A few of the results suggesting genetic differences in various traits will be recorded here. It appears that more attention has been paid to carcass attributes of carcass weight and composition, in particular; as these have some influence on many other post-slaughter characteristics.

In breed comparison studies at Massey University, concluded by the report of Barton (1975), differences between breeds in carcass weight, kidney and channel fat, dressing-out percentage, trimmed boneless meat, carcass fat, bone percentage, fat depth over eye muscle, eye muscle area and fat colour were demonstrated among other things. It was not indicated whether the differences were statistically significant, but the associated differences in monetary values appeared substantial (Barton, 1966a, 1967).

Andersen (1974) reported large differences between breeds in muscle: bone and muscle:fat proportions in a study which involved continental European breeds (Simmental, Charolais, Blonde de' Aquitane, Limousin, Romagnola, Chianina) and Hereford. The results did not, however, reveal an appreciable influence of breed variation on meat quality characteristics. Cundiff (1974) also reported that work in the United States had suggested differences between breeds in carcass composition.

Jeremiah et al. (1970), using carcass information from Angus, Hereford, Shorthorn, and crossbred steers, revealed significant breed effects on carcass weight, eye muscle area, kidney and channel fat percentage, conformation score, marbling score, quality grade (United States Department of Agriculture grade standards) and cutability index. Fat thickness and maturity scores were not significantly influenced by breed, but the authors cited earlier work by other workers where breed differences had been demonstrated in subcutaneous fat cover. Breed differences were also reported by Trail et al. (1971c), who found significant variation in carcass weight, but not in grade, or degree of finish. Breed of dam was important to carcass weight and dressing-out percentage and degree of finish (unadjusted for weight). Linear carcass measurements were invariably different by breed of sire and breed of dam. Heterotic effects were significant in a few linear measurements. Of the three component tissues of the carcass, only lean percentage was influenced by breed of sire (but not by breed of dam).

Further evidence of breed differences was revealed by Dalton and Everitt (1972) who found that Friesian bulls were superior to Angus bulls, not only in growth traits, but also in carcass weight (36 kg difference) and in amount of saleable meat (22 kg difference). Angus bulls had a higher percentage of lean in the carcass and a lower bone percentage, but the proportion of high price cuts did not differ between the two breeds. Charles and Johnson (1976) reported breed differences in carcass dissectible fat in comparisons they made between Hereford, Angus, Friesian, and Charolais crossbred cattle. Breed differences were also highly significant in subcutaneous fat and kidney and pelvic fat. In other studies (Berg et al., 1978a, b, c) growth patterns of the carcass tissues, namely, muscle, fat, and bone were found to differ between breeds. This led to breed differences in carcass composition in terms of these tissues when comparisons were made at a standard carcass weight.

More recent results confirmed that large differences do exist between breeds. Baker and Carter (1979) reporting on data collected over 4 years on 11 breeds of sire gave a ranking in carcass weights by sire breed showing a general indication of the breed differences. Crockett et al. (1979) showed that breed of sire influenced eye muscle area, fat thickness and yield grade of steer carcasses. Their study included Brahman, Brangus, Beefmaster, Limousin, Simmental and Maine-Anjou bulls on Angus, Brangus and Hereford cows. Breed of dam influenced marbling score, fat thickness, eye muscle area, quality grade and yield grade. Drewry et al. (1979) found that breed types displayed differences in eye muscle area, fat depth, carcass grade and marbling score as well as weights of separable lean, fat, and bone. No differences were found between breeds in cutability percentage, kidney, pelvic, and heart fat or in chemical composition characteristics. But Fortin et al. (1980) studied the carcass composition of Angus and Hereford cattle and found that significant breed differences existed.

Eversole et al. (1978) analysed data from two lines of Hereford cattle, Angus x Hereford x Charolais, and Angus x Hereford x Holstein crosses and reported significant differences in daily carcass protein and fat deposition. However, Jones et al. (1981) studied Hereford and "Dairy Synthetic" bull and heifer carcasses and concluded that breed was not an important factor on fat deposition and energy content of fat depots. Some workers have studied carcass and meat characteristics and found differences between breeds. Skelley et al. (1980) reported differences between breeds (Holstein, Simmental, and Polled Hereford sires on Angus dams) in carcass traits (fat depth over the eye muscle, eye muscle area, marbling, and grade) and sensory characteristic ratings. Lawson (1981) studied Hereford cattle and their crosses with Angus and Highland (Canadian) breeds and found appreciable breed differences in carcass (weight and length) and meat (muscle fibre diameter and tenderness) characteristics.

Breed differences in meat traits have been studied by numerous workers and there is an indication that such differences are important. In a review of literature on meat quality, Marsh (1964) listed breed as a major source of variation. He did not specifically emphasize the importance of species differences as distinct from breed differences as genetic sources of variability in meat quality. Species differences are probably sometimes taken for granted. Morgan and Everitt (1969) pointed out species and breed differences as the major genetic causes of variation in the fat colour of meat animals.

Various other workers have studied some aspects of meat and there is a strong indication that most meat quality characteristics, notably the palatability-related ones, vary between breeds and types of cattle although results to the contrary are not uncommon in the literature. Ramsey et al. (1973) studied differences between types and between breeds of cattle and found types and breeds within types were important sources of variation in meat tenderness. Their study included British beef (Hereford and Angus), dairy (Holstein and Jersey) and Zebu (Brahman, Brahman crosses and Santa Gertrudis) types of cattle. Tenderness was assessed by mechanical (using a shearing device) and taste panel methods.

Allen et al. (1976), reporting results from six years of research into the biology of fat in meat animals pointed out species and breed differences as main sources of genetic variability in carcass composition. They summarized several other workers' results that have shown carcass composition differences (in terms of tissue percentages) between breeds as well as fat distribution in meat. Fat distribution in meat influences palatability. In a recent review on factors influencing the flavour of muscle foods, Sink (1979) considered that species differences were well-established sources of variation in meat flavour, but breed as a factor was not as widely recognized in this respect. He emphasized the recognition of species in his assertion that, there was little doubt that species was the most important factor in meat flavour.

Purchas and Barton (1976) studied 171 steers from six breeds (Angus, Friesian, Jersey, Ayrshire, Galloway, and Red Poll) raised under New Zealand grazing conditions and found no appreciable breed differences in meat characteristics. The only difference that was significant in their study was the finding that Jersey meat was more tender as measured by the Warner-Bratzler method. This, however, was found only in one of the three comparisons. The authors cited literature in agreement with their observations and concluded that breed differences reported in the literature had "not been consistent" except in the cases where B. taurus meat has been compared with that from B. indicus. They felt that,

> "... there is little reason to expect any appreciable differences in the tenderness of meat from different breeds of B. taurus cattle."

However, Moore and Bass (1978) studied beef from Angus cattle and their crosses with Jersey, Simmental, Maine-Anjou, Blonde de Aquitane, Pie Rouge, Friesian, Hereford and Limousin from which they reported various breed differences in tenderness and general acceptability by a taste panel. Meat from Angus and from Jersey x Angus was found to be more tender and acceptable to the taste panel than that from Simmental and Limousin crosses. In their study, tenderness was assessed by the taste panel and by a mechanical device (shearing tenderometer), giving slightly inconsistent results between the methods of assessment. Various other breed differences reported in their study were relatively unimportant.

2.1.4.2 Non-genetic Factors

The most important intrinsic non-genetic factors in relation to carcass and meat traits are nutrition, sex, and age of the animal.

Their influence appears to be through an effect on growth. Nutrition is known to have a "marked influence on relative tissue growth" (Berg, 1968), such that a high plane of nutrition leads to an early fattening and *vice versa*. Sex also influences onset of fattening with heifers fattening at lighter weights than steers which in turn fatten at lighter weights than bulls (Berg, 1968).

Butterfield and Berg (1966a, b) classified bovine muscles and muscle groups according to relative growth patterns based on data from serial slaughtering and dissection. Differences in relative growth play an important role in determining characteristics of meat, hence variability in these characteristics by anatomical location and age of the animal. The importance of age may be apparent from consideration of changes and relationships depicted in Fig. 1.2 (Chapter 1). Fat, bone, and muscle rates of growth and proportions in the animal body vary with age (Barton, 1958). Such variations are associated with carcass and meat traits.

Numerous reports have suggested that nutritional differences are responsible for variation of not only carcass, but also meat traits. Aspects like herd, year or season of birth, and management may be confounded, in affecting post-slaughter characteristics, with feeding or what has been generally termed nutritional factors. They are, however, considered less important and will receive little attention while nutrition will be emphasized in this review.

Davis *et al*. (1963a) demonstrated differences in marbling score, separable rib joint fat and separable lean between steers on a full-fed and deferred-feeding regimes. But Davis et al. (1963b) found no appreciable differences in weight gains, efficiency of feed utilization or carcass traits of cattle fed two types of concentrate rations.

The influence of nutritional check on carcass traits was reported by Butterfield and Berg (1966) who found differences in relative growth of muscles due to levels of feeding in groups of calves. Butterfield (1966) revealed higher proportions of lean in the carcasses of animals that had experienced compensatory growth, but absolute lean weight was lower and the results did not suggest any such effect on muscle weight distribution. The latter result supported the findings reported by Butterfield and Berg (1966). Butterfield (1966) further concluded that during semi-starvation dissectible fat, carcass weight, and dissectible muscle decreased with fat being most affected and muscle least affected. During recovery, dissectible muscle increased most followed by carcass weight and fat, in that order. There was negligible change in bone weight.

Further evidence on the influence of restricted feeding or semi-starvation and subsequent re-alimentation was reported by Butterfield et al. (1966) who found that the animals that did not suffer a nutritional check had heavier carcasses, lean, and bone. There was no suggested evidence of differences in fatness except when comparisons were at standard carcass weights, in which case animals with retarded early growth had higher fat percentages. Morgan (1972) carried out a study, the results of which suggested that there was no influence of undernutrition on carcass characteristics. Dressing-out percentage, carcass length, muscle depth, fat depth on the tenth rib, carcass yield of saleable meat, sample joint distribution of saleable meat and proportions of muscle, fat, and bone were all not significantly influenced by under-nutrition. The results did not suggest any differences due to under-nutrition in the eating quality of the meat. Geay et al. (1976) investigated the effect of energy intake on various post-slaughter characteristics and found that there were appreciable differences in carcass weight and composition attributable to level of energy intake. However, when the composition characteristics were corrected for carcass weight the differences were reduced to negligible levels. In a recent study by Fortin et al. (1980), the level of energy intake was reported to have influenced the chemical composition of Angus and Holstein cattle carcasses.

The influence of nutrition on specific meat traits has been demonstrated in some studies. Davis et al. (1963a) found variation in meat tenderness (assessed by a shearing device) which they attributed to nutritional differences. However, when the meat was judged by a taste panel, such differences were not significant. The taste panel further failed to detect any differences in either flavour or juiciness which could be attributed to the nutritional differences.

Hill (1967) used data from Hereford x Shorthorn steers to study the effect of feed restriction and compensatory growth on carcass composition and meat tenderness. They found no difference in either of these traits. Zinn et al. (1970) reported that the number of days on feed was an important source of variation in the tenderness of various bovine muscles. Recent comparisons of chemical characteristics of meat from steers raised on low-energy and on high-energy (either on grass or on grain) by Brown et al. (1979) suggested the existence of variation in flavour and amount of free fatty acids due to level of energy intake. A selected taste panel allocated higher flavour scores to meat from steers finished on grain compared to that from grass-finished steers. Low-energy fed steers had meat with higher amounts of free fatty acids. Ground meat characteristics suggested differences in types of lipids which the authors attributed to feeding effects.

A report by Morgan and Everitt (1969) reviewed the factors that cause variation in fat colour in meat animals. Nutritional factors featured prominently in their influence of fat colour in cattle and diet and blood carotene levels were considered major aspects related to fat colour. The absorption of carotenoid pigments in the intestines was considered to be a key factor, and the carotene content in the diet would, therefore, appear to be of primary importance in influencing fat colour.

Results of studies on the influence of sex on carcass and meat traits have invariably suggested that differences exist between males, castrates, and females (Preston and Willis, 1974). Breidenstein et al. (1963) found differences between steers and heifers in carcass side weight, kidney and pelvic fat, rib-eye area, quality grade, and retail yield percentage. Carroll et al. (1975) compared steers with bulls and reported that bulls produced more carcass weight per day of age, had less fat content, less marbling, larger rib-eye area and higher conformation, but lower quality grade.

The effect of castration on growth, carcass, and meat traits has been reviewed by some authors (Robertson, 1966; Rhodes, 1969a, b; Preston and Willis, 1974). It is acknowledged that steers are fatter and have improved marbling compared to bulls which are known to yield more boneless meat of generally lower quality, but within the bounds of acceptable levels. Mickan et al. (1981) recently reported marked differences between Friesian bulls and steers in growth and carcass characteristics. Bulls grew faster, had heavier carcasses, higher dressing-out percentages and more saleable beef. Steer carcasses had higher fat percentages.

Differences between bulls and steers in meat quality are inconsistent and sometimes disputable. Lawrie (1979) reviewed literature on the influence of sex. It was evident from his review that differences existed in fatness-related characteristics. Steers were invariable reported to be the fattest, followed by heifers, while bulls had less fat. It has also been found that spayed females are usually fatter than entire females. Other differences appear in the literature, but they are not as critical in determining meat quality. Adams and Arthaud (1963) reported that beef from steers was more tender than that from bulls and that heifers produced beef of intermediate tenderness. Their results showed that heifer beef did not differ significantly in tenderness when compared to either steer, or bull beef. Zinn et al. (1970) found that variations in tenderness due to the influence of sex were dependent on age or stage of maturity and number of days on feed. Carroll et al. (1975) reported considerable differences between steers and bulls in various meat traits. Bull beef was darker and had more free moisture, but cooking losses were comparable to those of steer beef. Tenderness measured by a shearing device was comparable between steers and bulls, but panel scores favoured steers in tenderness, flavour and juiciness.

Changes in growth as associated with age were presented in Figs 1.1 and 1.2. Besides an increase in size, the associated adjustments in relative proportions of the major tissues (muscle, fat, and bone) largely determine the value of the carcass (Berg et al., 1978) and the meat therefrom. It has been reported that age has an influence on dressing-out percentage and gross weights of muscle and fat (Butterfield et al., 1966), and that the colour of fat on the carcass tends to vary with age (Barton, 1958). Colour of fat intensifies with advancing age and yellow fat is more prevalent in old than in young animals.

Many reports suggest that meat traits change with increasing age. Tuma et al. (1962) analysed meat data from Hereford cattle and reported that objective measurements as well as subjective scores of tenderness changed with advancing age. Meat was found to become less tender as age increased. A suggested influence of marbling on tenderness was also found to change with age. Meat from older animals was darker in colour. There were no appreciable changes in flavour and juiciness that could be attributed to the influence of age. Romans et al. (1963) revealed that maturity influenced myoglobin and hemoglobin as well as total pigment in meat.

Walter et al. (1963) carried out organoleptic tests and used mechanical devices in their study and concluded that meat tenderness and juiciness decreased with increasing maturity. Their results further suggested that cooking improved the tenderness of meat from young, but not that from old bulls. Results of Adams and Arthaud (1963) revealed a significant association between animal age and meat toughness (r = 0.29). But Zinn et al. (1970) suggested from their results that the influence of age on tenderness was dependent upon the number of days on feed and the anatomical location of the muscle on which tests are carried out.

Reagan et al. (1976) studied meat characteristics of Angus and Hereford cattle varying between 10 months and 27 years of age subdivided into three age groups. Differences in fat percentage, collagen content, shear force, panel score and amount of connective tissue were not significant between the age groups. Moisture content and soluble collagen content percentage were, however, different between age groups. The results also suggested that an increase in age was associated with a decrease in tenderness. Also that increasing collagen was associated with juiciness and decreasing tenderness and that sarcomere length was correlated with juiciness and collagen content, but not with tenderness. The authors concluded that sarcomere length did not appear to be related to tenderness in animals of such a wide range of ages.

Pre-slaughter animal management or handling and post-slaughter conditions and processing are a major source of variation in carcass and meat characteristics. Various pre-slaughter circumstances are known to affect carcass and meat characteristics (Lawrie, 1979). Stress and starvation are among these factors (CSIRO, 1972) and they arise during loading, transportation, and unloading of slaughter animals. Transport over long distances causes fatigue. Fighting between animals and other behavioural activities lead to stress and a resultant effect on meat characteristics (apart from physical bruising effects). The incidence of dark-cutting beef is known to be associated with such aspects (Lawrie, 1979; Price and Tennessen, 1981). These factors influence, not only meat colour but, also elevate ultimate pH which is, in turn, related to microbial activity on the surface of meat and keeping quality and tenderness (Preston and Willis, 1974). Pre-slaughter exercise or excitement, and stunning techniques, also have an important influence on meat characteristics. Use of tranquilizers to reduce the effects of stress, fighting, struggling, and other undesirable activity is realized (Lawrie, 1979), but has not been commercially widely accepted. The effect of injecting papain and other tenderizing agents immediately pre-slaughter has been demonstrated experimentally, but has not been adopted commercially (Preston and Willis, 1974).

The influence of rigor and post-rigor changes on muscle properties is known to be responsible for changes in the quality attributes of meat (Pearson, 1971), notably on tenderness. Pre-rigor meat is tender and as rigor sets in it toughens progressively until rigor mortis is complete. Aging causes the opposite effect thereafter. Cold shortening occurs when meat is cooled pre-rigor and is associated with toughness (Locker and Hagyard, 1963) and weight loss and shrinkage in cooking (Davey and Gilbert, 1975). Thaw rigor is associated with toughening when such meat thaws from the frozen state.

Basides being recognized as the most sought after meat characteristics (CSIRO, 1972, 1978; Gilbert and Davey, 1976; Purchas and Barton, 1976), tenderness is a variable meat characteristic which has received much attention in the literature. Research efforts into tenderness include attempts to develop techniques to counter the effects of cold shortening and thaw rigor. Aging is the most common way of tenderizing meat as has been pointed out or demonstrated by various authors (Price and Schweigert, 1971; CSIRO, 1972; Parrish et al., 1973; Preston and Willis, 1974; Davey et al., 1976; Gilbert and Davey, 1976; Joseph and Connolly, 1977; Ray et al., 1980).

Various other methods of tenderizing meat have been promising, including "tender stretch" hanging (CSIRO, 1972, 1978; Joseph and Connolly, 1977), the use of high-voltage electrical stimulation (ES) of carcasses (Davey et al., 1976; Gilbert and Davey, 1976). and low-voltage ES (Shaw and Walker, 1977; CSIRO, 1978), storage temperature control (Cliplef and Strain, 1976; Joseph and Connolly, 1977) and cooking method variation (Joseph and Connolly, 1977; Ray et al., 1980). Methods based on these techniques of manipulating carcasses and meat to improve eating quality have not received widespread acceptance commercially for various reasons. Others that have received some research attention, but not commercial application, have been the use of high pressure (CSIRO, 1972) and controlled (slow) chilling rate (Joseph and Connolly, 1977).

2.2 Relationships Between Traits

2.2.1 Introduction

The foregoing sections stand as a record of the premise that all the traits are influenced by genetic and non-genetic sources of variation. This serves to partly explain why genetic and phenotypic correlations would be expected to exist between the traits. For example, if breed of sire accounts for variation in growth traits as well as in carcass traits, then some relationship would be expected to exist between growth and carcass traits. Similarly, if nutrition influences growth and carcass composition traits, then again, a relationship between growth and carcass composition would be envisaged. This is apart from, or in addition to, the possible existence of "cause-and-effect" type relationships between some traits.

Relationships between beef cattle traits may arise in various ways. It is important to recognize direct and indirect determinants of the characteristics in this respect (Purchas, 1980, pers. comm.). Appreciation of this is necessary in attempting to manipulate various factors, or traits, to improve the quality of the final product, meat. Several hypothetical examples of how relationships may arise are considered here.

First, a direct determinant exists where one characteristic causes another. For instance, if it were known that muscle fibre diameter was the cause of toughness in meat, then the former would be a direct determinant while the latter may be said to be a dependent variable. This would be explained by a cause-and-effect relationship. Another case arises when a qualitative factor is the direct determinant. So, if breed directly affects tenderness it would be considered to be a direct determinant, but a cause-and-effect relationship would not exist. Secondly, an indirect determinant would be one that acts through another determinant of the characteristic under consideration. Thirdly, when two characteristics share a common determinant they will be associated. For example, if nutrition influenced growth rate and meat tenderness, then growth rate and tenderness will display a relationship. Finally, a relationship may exist when the trait being considered acts as the direct determinant, so that it is related to a dependent characteristic by a cause-and-effect relationship. In this case a change in the latter does not reflect in the former.

The existence of relationships between traits in the sense implied in this report does not necessarily imply that cause-and-effect relationships also exist. Two kinds of "relationship" must be put into their respective perspectives to avoid ambiguity. As may appear in statistical texts, the idea of "cause-and-effect" is explained by the concept of regression and regression coefficients. In this situation one variable influences or determines the other so that a value for one may be used to predict that of the dependent variable. But when studying existence of relationships the aim may be,

> "... to study the strength of relationship between two random variables, neither of which can be singled out as the cause of the other." (Bhattacharyya and Johnson, 1977).

This gives the concept of correlation and correlation coefficients. Regression and correlation type relationships often exist together, so one does not preclude the other in any given situation.

Another important matter in a study of relationships is the caution required in the interpretation of results in the literature. For example, where some component parts of the carcass have been found to be correlated with carcass weight, interpretation should consider the fact that one is part of the other. Wood (1970) considered the implications of "part : whole" relationships and warned that they should be borne in mind when interpreting correlation coefficients between such traits, particularly where they are claimed to be significant. Some published estimates of correlation coefficients between some growth, carcass, and meat characteristics will be summarized in the following sections.

2.2.2 Relationships Between Growth Traits

Estimates of genetic and phenotypic correlation coefficients between growth traits reported in the literature are positive and range from low to medium. There is wide variation of such estimates between reports (Preston and Willis, 1974; Barlow, 1978). Some of the published results will be summarized for pre-weaning and post-weaning growth traits. It must be pointed out, however, that the variation which exists in the estimations can not be clearly indicated in the summaries because they represent only small samples. Attention has been focussed on mainly genetic and phenotypic correlations while environmental correlation coefficients are to be found in numerous other reports.

2.2.2.1 Pre-weaning Growth Traits

Pre-natal growth, which determines the level of weaning weight, and growth during the suckling period are considered to be components of weaning weight (Barlow, 1978). Birth weight has generally been reported to be positively correlated to other growth traits. Its relationship with post-weaning ADG appears to be rather tenuous. On the basis of work reviewed by Preston and Willis (1974) there is a suggestion that the genetic correlation between birth weight and pre-weaning growth is greater than the phenotypic correlation between them. Estimates of the genetic correlation in that review ranged from 0.11 to a spurious 1.98, while those of phenotypic correlations were between -0.05 and 0.36. There is, however, more variation than these ranges would imply.

Alexander and Bogart (1961) analysed birth and growth data over the suckling period and reported an estimate of 0.11 for the phenotypic correlation between birth weight and gains. Swiger (1961) reported estimates ranging from 0.12 to 1.04 for the genetic correlation between birth weight and pre-weaning gains over five 28-day periods. The upper limit of the range of these estimates was spurious, but within reasonable limits of rounding error. Corresponding estimates of phenotypic correlation in his study varied from 0.11 to 0.31. The suggestion of a positive genetic correlation between growth in the 28-day periods from these results supported the conclusions reached by Lasley and Pugh (1956) and Lasley et al. (1961), that growth at various stages appears to be influenced by the same set of genes.

Although Auriol et al. (1963) revealed a significant positive correlation coefficient between birth weight and gain they implied that birth weight was not a good indicator of weight at various other stages of growth, except adult weight. The results and conclusions of Sawyer et al. (1963) contradicted this view with the contention that heavier cows tended to produce calves which were heavier at birth, gained weight more rapidly and retained their superiority even after weaning. This implied that there was a positive relationship between birth weight and pre- and post-weaning growth and that birth weight was a good indication of later weights.

It may be generalized that calves which are heavier at birth will tend to grow faster because they are more vigorous in their early life and consume more colostrum. Such an advantage would have important carryover effects during the suckling period. These may explain the existence of a positive correlation between pre-weaning growth and dam milk yield and that between birth weight and pre-weaning growth (Barlow, 1978).

Christian et al. (1965) reported highly significant correlation coefficient estimates between milk yield at two periods and pre-weaning ADG (r = 0.48 and r = 0.50). Their data suggested a correlation coefficient of 0.32 between birth weight and ADG in the first 2 months of life. Barlow (1978) warned that the level of correlation with milk yield should be interpreted with the understanding that it depends on various conditions. These include the technique of estimating milk yield (often estimated from what the calf consumes), the absolute level of milk production (usually not known), and the part of the lactation curve over which the estimates are made. He added that there was little direct evidence of the existence of a genetic correlation between growth rate and milk yield in beef cattle.

Holroyd et al. (1979), working with Brahman-cross and Shorthorn cattle, reported highly significant simple correlation coefficients between milk yield and pre-weaning growth. Data from 3 years of their study yielded correlation coefficients of 0.53, 0.58, and 0.53, between milk yield and ADG. Correlation coefficients between pre-weaning ADG and birth weight were 0.30, 0.22, and 0.22, respectively. Those between pre-weaning ADG and weaning weight were 0.90, 0.98 and 0.96, respectively.

Heavier birth weights are associated with calving problems (Flock et al., 1962; Preston and Willis, 1974; Barlow, 1978). The implications of this should be kept in mind when investigating the existence of a correlation between birth weight and later growth.

Table 2.1 is a summary of some published estimates of correlation between birth weight and pre-weaning growth.

Pre-natal and pre-weaning growth are known to have one major common source of variation, namely, maternal influence. Growth in the 2 phases determines the levels of birth and weaning weights. This would suggest the existence of a relationship between birth weight and weaning weight. Lasley and Pugh (1956) revealed that there was a positive genetic correlation between pre-natal and pre-weaning growth (r = 0.72). The data in their study, however, indicated a very low level of phenotypic correlation (r = 0.05). Later results on similar lines (Lasley et al., 1961) supported the former findings when a nearly perfect genetic correlation coefficient of r = 0.93 was reported between the 2 phases.

TABLE 2.1: SOME PUBLISHED ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATION OF BIRTH WEIGHT WITH PRE-WEANING GROWTH AND WEANING WEIGHT

Correlated trait	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Pre-weaning growth (gain or ADG)	0.46	0.23	Brinks *et al.*, 1964; Hereford cattle.
	0.11	0.12	Brinks *et al.*, 1962; ADG to 180 d.
	0.30	0.20	Pahnish *et al.*, 1964.
	0.55	0.36	Loganathan *et al.*, 1965.
	0.82	0.32	Berruecos & Robison, 1968.
	0.17	0.19	Burfening *et al.*, 1978; Simmental cattle.
	0.10	0.18	Koch *et al.*, 1973; Hereford bull data.
	0.28	0.27	Koch *et al.*, 1973; Hereford heifer data.
	0.16	0.18	Koch *et al.*, 1973; bull ADG to 135 d.
	0.20	0.24	Koch *et al.*, 1973; heifer ADG to 135 d.
	0.38	0.18	Nelsen & Kress, 1979; Angus bulls.
	0.41	0.32	Nelsen & Kress, 1979; Angus heifers.
	0.17	0.13	Nelsen & Kress, 1979; Hereford bulls.
Weaning weight	0.63	0.39	Koch & Clark, 1955b; Hereford cattle.
	0.69	0.31	Swiger *et al.*, 1961; Hereford cattle.
	0.86	0.35	Trail *et al.*, 1971b; various breeds and crosses.
	0.49	0.42	Vesely & Robison, 1971.
	0.41	0.35	Koch *et al.*, 1973; Hereford bull data.
	0.53	0.43	Koch *et al.*, 1973; Hereford heifer data.
	0.21	0.30	Brinks *et al.*, 1962; 180-d weaning weight.

TABLE 2.1 (continued):

Correlated trait	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
	0.60	0.41	Brinks *et al.*, 1964; Hereford cattle.
	0.42	0.42	Pahnish *et al.*, 1964; Hereford cattle.
	0.68	0.37	Shelby *et al.*, 1963; Hereford steers, 180-d weight.
	0.33	0.34	Burfening *et al.*, 1978; Simmental, 205-d weight.
	0.84	0.42	Berruecos & Robison, 1968.
	0.44	0.33	Nelsen & Kress, 1979; Angus bulls.
	0.61	0.46	Nelsen & Kress, 1979; Angus heifers.
	0.37	0.30	Nelsen & Kress, 1979; Hereford bulls.
	0.18	0.23	Pabst *et al.*, 1977; Herefords.
	0.45	0.21	Govindaiah & Singh, 1980; Hariana cattle.

Relationship between birth weight and weaning weight is invariably reported to be positive (Preston and Willis, 1974; Barlow, 1978), and in the range of medium to high magnitude. It would be imperative that birth weight is related to weaning weight if the estimates of correlation between birth weight and pre-weaning ADG are any indication of the real-life situation. In some instances, regression-type relationships have been claimed to exist. Auriol et al. (1963) found highly significant regression coefficients between birth weights and weights at 3, 6, and 9 months of age. The results of Christian et al. (1965) generally supported this view, and revealed highly significant multiple correlation coefficients between birth weight and pre-weaning gain, and weaning weight.

Wide variation exists in estimates of correlation between birth weight and weaning weight. One aspect for which there is ample evidence is the fact that genetic and phenotypic correlations between these weights are positive. Krasnov and Pak (1937) reported estimates of correlation between birth weight and weight in the first 6 months of life to range between 0.39 and 0.58 for bulls and 0.43 and 0.48 for heifers. There was wide variation in estimates, which the authors attributed to differences in feeding conditions.

The results published by Auriol et al. (1963) showed highly significant correlation coefficients between birth weight and weights at 3, 6, and 9 months. The same authors published highly significant regression coefficients between the weights, as did Krasnov and Pak (1937). Later results published by Christian et al. (1965) revealed highly significant multiple correlation coefficients between comparable traits. Analyses of Hereford and Angus data by Brown et al. (1972) showed high positive genetic and phenotypic correlation coefficients (r = 0.89 and r = 0.91, respectively) for Hereford cattle, but results from Angus cattle were different (r = -0.84 and r = 0.63, respectively). The values are within theoretical bounds, but the negative sign of the high estimate for genetic correlation in the Angus data is suspect.

2.2.2.2 Pre-weaning and Post-weaning Growth Traits

Trail et al. (1971b) found that estimates of correlation coefficients between birth weight and 3-monthly weights up to 24 months of age were positive and high. These were in the range of between 0.75 and 0.91, and 0.43 and 0.93, for genetic and phenotypic correlations, respectively. They warned that "part : whole" relationships may have been partly responsible for the high values.

Estimates of relationship between birth weight and post-weaning growth traits also vary widely. Trends in the literature strongly suggest that such a relationship is positive as concluded earlier (Msechu, 1979). However, from the fact that pre-natal growth (and, therefore, level of birth weight) depends to a great extent on maternal influence while post-weaning growth is little, if at all, affected by maternal influence, would suggest that any relationship that is reported has to be attributed to other (common) sources of variation. Genetic sources of variation would only explain part of this relationship, if it exists. Common climatic factors may also be responsible for causing part of the relationship. Table 2.2 is a summary of some estimates of correlation coefficients between birth weight and some of

TABLE 2.2: SOME PUBLISHED ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATION OF BIRTH WEIGHT WITH POSTWEANING GROWTH AND WEIGHTS

Correlated trait	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Post-weaning growth (gain or ADG)	0.06	0.04	Koch & Clark, 1955b; gain to yearling.
	0.42	0.31	Koch *et al*., 1973; Hereford bull data.
	0.30	0.34	Koch *et al*., 1973; Hereford heifer data.
	0.71	0.23	Brinks *et al*., 1962; 196-d test gain.
	0.07	0.11	Brinks *et al*., 1964; Hereford, gain to 12 months.
	0.29	0.30	Shelby *et al*., 1963; Hereford steers
	0.54	0.21	Nelsen & Kress, 1979; Angus bulls.
	0.00	0.25	Nelsen & Kress, 1979; Angus heifers.
	0.74	0.22	Nelsen & Kress, 1979; Hereford bulls.
Yearling weight (about 12 to 15 months)	0.40	0.34	Koch & Clark, 1955b; Hereford data.
	0.53	0.43	Koch *et al*., 1973; Hereford bull 452-d weight.
	0.45	0.51	Koch *et al*., 1973; Hereford heifer data.
	0.41	0.61	Koch, 1978; Hereford heifer data.
	0.76	0.80	Brinks *et al*., 1962; Hereford bull final weight, 196-d test.
	0.56	0.42	Brinks *et al*., 1964; Hereford, 12-month weight.
	0.79	0.36	Trail *et al*., 1971b; various crosses, 15-month weight.
	1.12	0.36	Trail *et al*., 1971b; various crosses, 12-month.
	0.26	0.25	Pabst *et al*., 1977; Hereford 400-d weight.

TABLE 2.2 (continued):

Correlated trait	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
	-0.41	0.18	Govindaiah & Singh, 1980; Hariana 12-month heifers.
Weight after 15 months	0.81	0.36	Trail *et al.*, 1971b; various crosses, 18-month weight.
	0.58	0.35	Trail *et al.*, 1971b; 21-month weight.
	0.64	0.35	Trail *et al.*, 1971b; 24-month weight.
	0.21	0.05	Govindaiah & Singh, 1980; Hariana 18-months.
	0.67	0.07	Govindaiah & Singh, 1980; 24-months.
	0.68	0.35	Nelsen & Kress, 1979; Angus bulls, final weight.
	0.54	0.51	Nelsen & Kress, 1979; Angus heifers.
	0.60	0.37	Nelsen & Kress, 1979; Hereford bulls.

the more important post-weaning growth traits.

Results of studies that have examined the relationship between weaning weight and other growth traits have suggested that such a relationship is positive and high in many cases. A notable contrast between the levels is that reported for the correlation between weaning weight and daily gains in either phase adjacent to weaning. Pre-weaning ADG is reported to have a very high positive correlation with weaning weight (Preston and Willis, 1974) while post-weaning ADG is more often found to have a low relationship with weaning weight. In some cases the latter is shown to be negative. Pre- and post-weaning are reported to be lowly correlated (Koch et al., 1973; Preston and Willis, 1974; Barlow, 1978). Some negative estimates of correlation also appear in the literature (Barlow, 1978).

Table 2.3 summarizes various published results of some investigations into relationships between weaning weight and growth pre- and post-weaning.

It may be argued that a low or negative relationship would be expected to exist between pre- and post-weaning growth because of the influence of compensatory growth as explained earlier. However, in some situations such an influence may not exist. Pre-weaning growth is also influenced by maternal factors, while post-weaning growth is a reflection of the potential of the animal with most influence being environmental, other than maternal. Folman (1977) reported a highly significant correlation coefficient (r = 0.53) between these traits.

TABLE 2.3: SOME PUBLISHED ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATION OF WEANING WEIGHT WITH PRE- AND POST-WEANING GROWTH

Correlated trait	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Pre-weaning growth (gain or ADG)	0.97	0.97	Barlow & Dettmann, 1978; Angus unadjusted data.
	0.99	1.00	Barlow & Dettmann, 1978; weight corrected for age.
	0.99	0.92	Brinks et al., 1962; Hereford 180-d weaning.
	0.95	0.98	Koch et al., 1973; Hereford bulls, weaned 200 d.
	0.96	0.98	Koch et al., 1973; heifers weaned at 200 d.
	0.90	1.08	Pahnish et al., 1964.
	0.92	1.00	Berruecos & Robison, 1968.
	0.93	0.97	Lehmann et al., 1961.
	0.93	0.88	Koch et al., 1973; bulls, ADG to 135-d age.
	0.98	0.90	Koch et al., 1973; heifers, ADG to 135-d age.
	0.96	0.97	Nelsen & Kress, 1979; Angus bulls.
	0.94	0.98	Nelsen & Kress, 1979; Angus heifers.
	0.97	0.97	Nelsen & Kress, 1979; Hereford bulls.
Post-weaning growth (gain or ADG)	-0.74	-0.10	Blackwell et al., 1962; Hereford steer data.
	0.61	-0.10	Blackwell et al., 1962; heifer data.
	0.06	0.17	Brinks et al., 1962; Hereford, 196-d test gain.
	0.77	0.17	Dinkel & Busch, 1973; Hereford steers.
	0.26	0.20	Koch et al., 1973; Hereford bulls weaned 200 d.
	0.49	0.13	Koch et al., 1973; Heifers weaned at 200 d.
	0.28	0.15	Wilson et al., 1963.

TABLE 2.3 (continued):

Correlated trait	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
	0.34	0.19	Wilson *et al*., 1962.
	0.66	0.24	Carter & Kincaid, 1959b; males.
	0.51	0.20	Carter & Kincaid, 1959b; females.
	0.83	0.20	Swiger *et al*., 1961.
	0.47	0.18	Swiger *et al*., 1962.
	0.77	0.18	Shelby *et al*., 1963.
	0.18	0.25	Nelsen & Kress, 1979; Angus bulls.
	-0.18	0.09	Nelsen & Kress, 1979; Angus heifers.
	0.65	0.09	Nelsen & Kress, 1979; Hereford bulls.
	-0.10	0.02	Koch, 1978; Hereford heifers.
	0.8	0.18	Dickerson *et al*., 1974.

However, they reviewed previous work that gave estimates which were negative or too small to be of any practical importance.

Koch et al. (1973) reported a high estimate of genetic correlation between pre- and post-weaning ADG, but the corresponding phenotypic correlation was low in their data. Wide variation exists in the estimates of correlation between growth in the 2 phases.

Estimates of correlation between weaning weight and subsequent weights are generally high and positive (Preston and Willis, 1974). Variation exists, but published results strongly suggest that a positive genetic and phenotypic correlation exists.

Table 2.4 summarizes published estimates of correlation between weaning weight and weight recorded at various ages after weaning.

2.2.2.3 Post-weaning Growth Traits

The correlation between post-weaning growth traits has been estimated to be positive and high although wide variation is evident in the literature (Preston and Willis, 1974). There are many aspects that may be considered in the general context of post-weaning growth traits. Growth, defined as weight gain over a specified period, usually a "test period", and ADG over such a period are common criteria of measuring post-weaning growth that appear in the literature. These are studied with weight recorded at various stages after weaning.

The various stages in the post-weaning growth phase bear names which often appear in the literature. Yearling refers to the animals

TABLE 2.4: SOME PUBLISHED ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATION BETWEEN WEANING WEIGHT AND LATER WEIGHTS

Correlated trait	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Yearling weight (up to 15 months)	0.70	0.73	Koch *et al.*, 1973; Hereford bulls, 452-d weight.
	0.79	0.74	Koch *et al.*, 1973; Hereford heifers.
	0.75	0.91	Trail *et al.*, 1971b; 6- & 9-month weights.
	0.51	0.87	Trail *et al.*, 1971b; 6- & 12-month weights.
	0.42	0.76	Trail *et al.*, 1971b; 6- & 15-month.
	0.87	0.91	Trail *et al.*, 1971b; 9- & 12-month.
	0.87	0.86	Trail *et al.*, 1971b; 9- & 15-month.
	0.38	0.57	Pabst *et al.*, 1972; Angus 400-d weight.
	0.68	0.66	Pabst *et al.*, 1977; Devon 400-d weight.
	0.58	0.61	Pabst *et al.*, 1977; Hereford cattle.
	0.37	0.57	Pabst *et al.*, 1977; Sussex cattle.
	0.80	0.68	Govindaiah & Singh, 1980; Hariana heifers.
	0.67	0.75	Nelsen & Kress, 1979; Angus bulls.
	0.62	0.79	Nelsen & Kress, 1979; Angus heifers.
	0.84	0.69	Nelsen & Kress, 1979; Hereford bulls.
	0.94	0.82	Dickerson *et al.*, 1974.
	0.41	0.61	Koch, 1978; Hereford heifers.
Weight recorded after 15 months	0.55	0.80	Trail *et al.*, 1971b; 6- & 18-month weight.
	0.04	0.70	Trail *et al.*, 1971b; 6- & 24-month.
	0.95	0.84	Trail *et al.*, 1971b; 9- & 18-month.

TABLE 2.4 (continued):

Correlated trait	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
	0.89	0.79	Trail *et al.*, 1971b; 9- & 21-month.
	0.44	0.72	Trail *et al.*, 1091b; 9- & 24-month.
	0.83	0.62	Dinkel & Busch, 1973; Hereford, final weight.
	0.67	0.62	Brinks *et al.*, 1962; Hereford, final weight.
	0.10	0.70	Blackwell *et al.*, 1962; steers, 18 months.
	0.18	0.57	Blackwell *et al.*, 1962; heifers, 18 months.
	0.22	0.61	Govindaiah & Singh, 1980; Hariana, 18 months.
	0.29	0.58	Govindaiah & Singh, 1980; 24-months.

in the age group covering a period around 12 to 15 months, rising 2-year-old includes older animals that have not reached 24 months of age by which time they would be referred to as 2-year olds. Later stages may be described by number of years and/or months (or days) until a "final", slaughter, or mature weight is attained. In this review the ages at which weights were recorded are stated where this information was available. In many cases "final weight" refers to the weight recorded at the end of a post-weaning test period. It may be, and often it is, at the yearling stage.

The level of relationship between weights depends on how close to each other they were recorded in terms of time duration (Trail et al., 1971b). Generally, the closer they are, the higher the relationship. However, the level of most estimated correlations between all weights post-weaning is high, so that this trend does not warrant further explanation. Yearling weight is one of the more important post-weaning growth traits in the New Zealand scene because it has been reported to be strongly related to all other weights (Carter, 1971; Baker et al., 1975), and to be moderately highly heritable.

Some estimates of correlation between post-weaning growth traits found in the literature are summarized in Table 2.5.

2.2.3 Relationships Between Growth and Post-slaughter Characteristics

Results of studies in which the relationship of growth with carcass and meat characteristics has been investigated are not as numerous as those of studies on the relationships between growth traits.

TABLE 2.5: SOME PUBLISHED ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATION BETWEEN SOME POST-WEANING GROWTH TRAITS

Correlated trait	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Post-weaning gain to post-weaning weight	0.74	0.58	Blackwell et al., 1962; Hereford steers, 18 months.
	0.97	0.58	Blackwell et al., 1962; Hereford heifers, 18 months.
	0.87	0.81	Koch et al., 1973; Hereford bull data.
	0.92	0.75	Koch et al., 1973; Hereford heifer data.
	0.87	0.80	Koch, 1978; Hereford heifers, yearling.
	0.83	0.79	Nelsen & Kress, 1979; Angus bulls, final weight.
	0.48	0.64	Nelsen & Kress, 1979; Angus heifers.
	0.77	0.65	Nelsen & Kress, 1979; Hereford bulls.
	0.95	0.82	Dickerson et al., 1974.
Post-weaning weights at various stages	0.91	0.87	Trail et al., 1971b; 12- & 15-month weight.
	0.89	0.90	Trail et al., 1971b; 12- & 18-month weight.
	0.76	0.86	Trail et al., 1971b; 12- & 21-month weight.
	0.31	0.79	Trail et al., 1971b; 12- & 24-month weight.
	0.79	0.89	Trail et al., 1971b; 15- & 18-month weight.
	0.88	0.84	Trail et al., 1971b; 15- & 21-month weight.
	0.46	0.80	Trail et al., 1971b; 15- & 24-month weight.
	0.40	0.87	Trail et al., 1971b; 18- & 24-month weight.
	0.69	0.65	Govindaiah & Singh, 1980; Hariana, 12- & 18-month.
	0.48	0.52	Govindaiah & Singh, 1980; 12- & 24-months.

TABLE 2.5 (continued):

Correlated trait	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
	0.96	0.64	Govindaiah & Singh, 1980; 18- & 24-months.
	0.66	0.78	Swiger *et al*., 1963; 396-d & 550-d bull weights.
	0.93	0.87	Swiger *et al*., 1963; 452-d & 550-d bull weights.
	0.99	0.91	Swiger *et al*., 1963; 508-d & 550-d bull weights.
	0.97	0.83	Swiger *et al*., 1963; 396- & 550-d, heifers.
	0.82	0.91	Swiger *et al*., 1963; 396- & 550-d, steers.

Most estimates between growth and post-slaughter characteristics have been on work done in the United States of America where animals are usually slaughtered at a fixed age, after a test period. They include post-weaning growth, but information on relationship with pre-weaning growth is scanty.

A summary table constructed from the literature reviewed by Preston and Willis (1974) appears as Table 2.6. Only part of the sources reviewed by Preston and Willis (1974) is included, leaving out any sources that did not have an estimate of the genetic as well as that of the phenotypic correlation.

2.2.3.1 Growth and Carcass Traits

Preston and Willis (1974) reviewed several sources of information and observed that there was a suggestion of a high genetic correlation between growth and measures of carcass fatness. This implied that selection for faster growth would be expected to lead to increased fatness of the carcass. There was, however, an indication from other work that selection for growth would lead to larger mature size and delayed maturity, so that animals may, in fact, be slaughtered earlier when they are leaner. This would be the case where animals are slaughtered on the basis of size rather than at a fixed age. Cundiff et al. (1964), after discussing the levels of genetic correlation estimates between growth and carcass traits revealed by their data, stated that,

> "... genes for rapid growth are not antagonistic to those for the production of desirable carcasses, except that a slight increase in backfat thickness may be expected."

TABLE 2.6: ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATION BETWEEN GROWTH AND CARCASS TRAITS. (ADAPTED FROM PRESTON AND WILLIS, 1974.)

Correlated traits	Correlation		Authors
	Genetic	Phenotypic	
Weaning weight with:			
carcass grade	-0.04	0.09	Shelby *et al.*, 1963.
	0.84	0.23	Carter & Kincaid, 1959b.
	0.92	0.11	Blackwell *et al.*, 1962.
Gain on test with:			
carcass grade	0.25	0.37	Shelby *et al.*, 1963.
	0.78	0.43	Blackwell *et al.*, 1962.
	0.85	0.31	Carter & Kincaid, 1959b.
fat thickness	0.30	0.14	Cundiff *et al.*, 1964.
first quality (%)	-0.45	-0.16	Cundiff *et al.*, 1964.
Final weight to:			
carcass grade	0.88	0.36	Blackwell *et al.*, 1962.
fat thickness	0.31	0.29	Shelby *et al.*, 1963.
first quality	-0.25	-0.21	Swiger *et al.*, 1965.
Carcass weight per d of age to:			
carcass grade	0.47	0.16	Cundiff *et al.*, 1964.
fat thickness	0.15	0.31	Cundiff *et al.*, 1964.
first quality	0.02	-0.26	Cundiff *et al.*, 1964.
L. dorsi area	-0.02	-0.39	Cundiff *et al.*, 1964.
Feed conversion to:			
carcass grade	0.16	0.16	Carter & Kincaid, 1959b.

Evidence of relationship of pre-weaning growth with carcass and meat traits is lacking. Reviews accessible to this author seemed to have paid little attention to this aspect. Results reported by Shelby et al. (1963) estimated the genetic and phenotypic correlation of birth weight with various post-slaughter characteristics. The genetic and phenotypic correlation coefficients with dressing-out percentage were -0.25 and -0.02, with cold carcass weight 0.39 and 0.40, with eye muscle area -0.01 and 0.17, with fat over eye muscle -0.16 and -0.04, and with eye muscle colour -0.12 and 0.00, respectively.

Results reported by Andersen (1978) showed a positive estimate of genetic correlation between birth weight and some post-slaughter traits of Danish cattle. Birth weight was shown to have a very low correlation coefficient with dressing-out percentage and lean : bone (L/B) ratio (r = -0.05 and 0.04). The genetic correlation with lean : fat (L/F) ratio was higher, r = 0.55, but that with eye muscle area (EMA) was low, r = 0.10. The ratio of lean in the "pistol cuts" to total lean (LP/LT) had moderate genetic association with birth weight, r = 0.54.

Pre-weaning gain was not included in the Danish work (Andersen, 1978), but gain between 1.5 months and 11 months was studied. This was ADG during the period over which bull performance testing was carried out in Danish dual-purpose cattle. The genetic correlation between this trait and carcass traits was estimated. Dressing-out percentage, L/T ratio, and EMA all yielded negative estimates : r = -0.61, -0.34, and -0.05, respectively. The standard error for the last estimate was relatively high suggesting that the estimate may have been biased by sampling error. The estimated genetic correlation with L/F and LP/LT were positive : r = 0.52 and r = 0.24, respectively.

It is rather difficult to pool results obtained from various studies of relationships between live animal and carcass traits into a tabular summary because of the many different characteristics that have been considered as carcass traits. However, the efforts have all been towards determining whether live animal traits could be used as indicators of some attributes of the carcass that are of economic importance. It has been realized for a long time that while the scientist can come "... close to estimating the dressing percentage and grade ..." (Weseli et al., 1958), these aspects may not be good indicators of the amount of lean meat in the carcass, which is, of course, of primary concern.

Jeremiah et al. (1970) used Angus, Hereford, Shorthorn and crossbred cattle data to study the relationship between slaughter weight and carcass characteristics. The simple correlation co-efficients with carcass weight, dressing-out percentage, eye muscle area, fat thickness, internal fat, and cutability index were: 0.92, 0.19, 0.38, 0.36, 0.24, and -0.37, for Angus steers; 0.93, 0.15, 0.47, 0.37, 0.16, and -0.37, for Herefords; 0.95, 0.16, 0.42, 0.34, 0.19, and -0.35, for Shorthorns; and 0.95, 0.26, 0.47, 0.42, 0.16, and -0.41, for crossbred steers, respectively. These results were not as inconsistent between breeds as was the case with the relationships between growth traits. The results of Mikulec et al. (1978) were in close agreement with the foregoing as far as the relationship of slaughter weight with dressing-out percentage ($\bar{c}$f r = 0.45), and fatness/internal fat ($\bar{c}f$ r = 0.16) were concerned.

Regression-type relationships were studied by Berg et al. (1978a) between animal weight and the 3 component carcass tissues: muscle, fat, and bone. The data used were from young bulls of eight breeds. Data were transformed into logarithms and the analyses indicated that pre-slaughter weight accounted for a good proportion of variation in all the tissues (R^2 = 0.97, 0.90, and 0.95 for muscle, fat, and bone, respectively).

Barlow (1978) reviewed a few sources of information which clearly showed that the relationship between growth and carcass traits was dependent on whether slaughter was at constant age, or at constant weight. For example, the estimated relationship between weaning weight and fat thickness, marbling score, and bone weight, were negative when considered at constant weight, but positive when considered at constant age. More recent work by Koch (1978) supported this general finding. It was found that by considering relationships at constant weight the trends in changes in carcass weight, eye muscle area and fat thickness were reversed compared to trends when consideration was at constant age.

Direct comparison of results of different studies should be discouraged, unless conditions under which the studies were undertaken are known clearly. Barlow (1978) summarized results from the literature showing the relationship of 205-day weight, post-weaning daily gain, and yearling weight with carcass fat thickness, marbling score, fat trim, eye muscle area, bone weight, retail product, and

TABLE 2.7: SOME ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATION BETWEEN GROWTH AND CARCASS TRAITS

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Weaning weight with:			
carcass weight	0.52	0.67	Wilson et al., 1976; carcass weight/d age.
	0.48	0.59	Koch, 1978; Hereford heifer data.
dressing-out %	-0.81	-0.09	Dinkel & Busch, 1973.
eye muscle area	0.46	0.04	Dinkel & Busch, 1973.
	-0.39	0.05	Wilson et al., 1976.
	0.16	0.23	Koch, 1978; genetic r SE ± 0.50.
fat thickness	-0.12	0.25	Wilson et al., 1976.
	-1.00	-0.13	Dinkel & Busch, 1973.
	0.59	0.12	Koch, 1978.
fat trim	-1.20	-0.11	Dinkel & Busch, 1973.
	0.40	0.35	Koch, 1978.
lean	1.11	0.08	Dinkel & Busch, 1973; edible portion.
	1.08	0.12	Dinkel & Busch, 1973; cutability.
	-0.45	0.28	Wilson et al., 1976; edible portion/d age.
	0.37	0.59	Koch, 1978; genetic r SE ± 0.36.
bone	0.55	0.64	Koch, 1978.
Pre-weaning ADG with:			
carcass weight	1.00	0.96	Wilson et al., 1976; carcass weight/d age.
	0.78	0.74	Koch, 1978.
dressing-out %	-0.08	-0.18	Dinkel & Busch, 1973; weight/d age.
eye muscle area	0.49	0.03	Dinkel & Busch, 1973.
	-0.16	0.09	Wilson et al., 1976; weight/d age.
	-0.07	0.27	Koch, 1978.

TABLE 2.7 (continued):

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
fat thickness	-0.25	-0.03	Dinkel & Busch, 1973; weight/d age.
	-0.38	-0.32	Wilson et al., 1976; slaughter weight/d age.
	0.62	0.32	Koch, 1978.
fat trim	-0.81	-0.09	Dinkel & Busch, 1973.
	0.64	0.62	Koch, 1978.
lean	0.48	0.11	Dinkel & Busch, 1973; edible portion.
	0.50	0.09	Dinkel & Busch, 1973; cutability.
	0.26	0.38	Dinkel & Busch, 1973; trimmed round.
	0.83	0.93	Wilson et al., 1976; edible portion/d age.
	0.73	0.62	Koch, 1978; retail product.
bone	0.49	0.44	Koch, 1978.
Final weight with:			
carcass weight	0.96	0.94	Koch, 1978.
dressing-out %	-0.23	-0.18	Dinkel & Busch, 1973.
eye muscle area	0.54	0.05	Dinkel & Busch, 1973.
	0.01	0.35	Koch, 1978; genetic r SE ± 0.46.
fat thickness	-0.56	-0.12	Dinkel & Busch, 1973.
	0.86	0.33	Koch, 1978.
fat trim	-1.02	-0.16	Dinkel & Busch, 1973.
	0.78	0.70	Koch, 1978.
lean	0.80	0.15	Dinkel & Busch, 1973; edible portion.
	0.74	0.16	Dinkel & Busch, 1973; cutability.
	0.85	0.84	Koch, 1978; retail product.
bone	0.72	0.73	Koch, 1978.

cutability estimate.

Some results of studies relating post-weaning growth to carcass traits are presented in Table 2.7.

The results summarized in Table 2.7 will serve to show how variable the levels of estimates have been. The precise circumstances under which the estimates were made were not clearly explained in the various reports. It was, therefore, felt that no direct comparisons between the estimates would be justified in this present review.

2.2.3.2 Growth and Meat Traits

Information on relationship between growth and meat attributes was lacking in the sources of information available. From the few results of studies that assessed the relationship between growth and only a few of the meat traits it is not possible to make any generalizations. It would appear, however, that there is wide variation between studies and between methods of assessment of meat traits. The level of relationship would also depend on whether it was estimated on a constant age or a constant weight basis.

Some of the results in the literature are summarized in Table 2.8. It should be pointed out that the estimates in the summary are from American studies and that results of similar work with the grazing animal could well give a different picture.

2.2.4 Relationships Between Carcass and Meat Traits

Studies on relationships between post-slaughter traits are

TABLE 2.8: SOME ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATION BETWEEN GROWTH AND MEAT CHARACTERISTICS

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Weaning weight with:			
marbling	-0.40	-0.12	Dinkel & Busch, 1973.
	-0.85	-0.21	Wilson et al., 1976; 200-d weight: marbling score.
	-0.69	-0.37	Dickerson et al., 1974; weight constant; Barlow, 1978.
	-0.29	0.03	Dickerson et al., 1974; age constant; Barlow 1978.
	-0.02	-0.05	Koch, 1978; genetic r SE ± 0.47.
tenderness	-0.83	0.06	Wilson et al., 1976; W-B shear force.
	0.07	-0.15	Wilson et al., 1976; taste panel.
juiciness	-0.34	-0.17	Wilson et al., 1976; taste panel.
flavour	-	-0.13	Wilson et al., 1976; taste panel.
lean colour	-0.31	0.01	Shelby et al., 1963.
	-0.99	-0.06	Dinkel & Busch, 1973.
Post-weaning ADG with:			
marbling	0.15	0.10	Dinkel & Busch, 1973.
	-0.52	-0.32	Dickerson et al., 1974; weight constant.
	-0.09	0.18	Dickerson et al., 1974; age constant.
	-0.88	-0.24	Wilson et al., 1976; weight/d age.
	-0.62	0.20	Koch, 1978; genetic r SE ± 0.35.
tenderness	0.57	0.03	Wilson et al., 1976; W-B shear.
	-0.22	-0.11	Wilson et al., 1976; taste panel.

TABLE 2.8 (continued):

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
juiciness	-0.29	-0.15	Wilson *et al.*, 1976; taste panel.
flavour	-	0.03	Wilson *et al.*, 1976; taste panel.
lean colour	-0.01	-0.07	Shelby *et al.*, 1963.
	0.13	0.16	Dinkel & Busch, 1973.
Yearling weight with:			
marbling	0.01	0.02	Dinkel & Busch, 1973; final weight.
	-0.65	-0.45	Dickerson *et al.*, 1974; weight constant.
	-0.16	0.15	Dickerson *et al.*, 1974; age constant.
	-0.57	0.13	Koch, 1978.
lean colour	-0.03	-0.04	Shelby *et al.*, 1963; final weight.
	0.04	-0.04	Shelby *et al.*, 1963; slaughter weight.
	-0.29	0.06	Dinkel & Busch, 1973.

difficult to summarize because many authors have considered different aspects. An attempt to include all the information in a tabular form would give rise to a very large table which may fail to be informative. Some literature was, therefore, reviewed in this section and a selected few sources of information were summarized in Tables 2.9 and 2.10 for the relationships between carcass and meat traits. Estimates of the correlations between some meat traits were summarized separately.

2.2.4.1 Carcass Traits

Simple correlation and prediction types of relationship between carcass traits are reported in the literature (Taylor, 1964; Preston and Willis, 1974). Most relationships that are in the literature may be taken to be a reflection of the relative growth changes of fat, muscle, and bone tissues which were explained by Berg and Butterfield (1976). The most variable tissue is known to be fat, and most studies on relationships have included a measure of fatness.

Carcass weight, dressing-out percentage, eye muscle area, fat thickness, and amounts (sometimes also percentages) of fat trim, lean, and bone in the carcass are among the more prevalent characteristics for which relationships have been reported.

Table 2.9 summarizes a number of results of investigations into relationships between these traits. Some of the literature sources were reviewed by Preston and Willis (1974), but an attempt has been made to include more recent information to supplement their review.

TABLE 2.9: SOME PUBLISHED ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATIONS BETWEEN CARCASS TRAITS

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Carcass weight with:			
dressing-out %	0.35	0.44	Shelby *et al*., 1963; cold carcass.
eye muscle area	0.15	0.46	Shelby *et al*., 1963.
	-0.06	0.18	Wilson *et al*., 1976; carcass weight/d.
	0.02	0.37	Koch, 1978; genetic r SE ± 0.46.
fat thickness	0.45	0.36	Shelby *et al*., 1963.
	-0.42	-0.35	Wilson *et al*., 1976; carcass weight/d.
	0.95	0.42	Koch, 1978.
fat trim	0.90	0.82	Koch, 1978.
lean	0.84	0.91	Wilson *et al*., 1976; with edible portion/d.
	0.21	0.27	Wilson *et al*., 1976; with trimmed round.
	0.80	0.84	Koch, 1978; with retail product.
bone	0.57	0.68	Koch, 1978.
Dressing-out % with:			
eye muscle area	0.40	0.32	Shelby *et al*., 1963.
	0.47	0.07	Dinkel & Busch, 1973.
fat thickness	0.61	0.28	Shelby *et al*., 1963.
	0.25	0.14	Dinkel & Busch, 1973.
fat trim	-0.02	0.12	Dinkel & Busch, 1973.
lean	0.64	-0.07	Dinkel & Busch, 1973; with edible portion.
	-0.23	-0.09	Dinkel & Busch, 1973; with cutability.
Eye muscle area with:			
fat thickness	0.30	0.05	Shelby *et al*., 1963.
	-0.59	-0.28	Dinkel & Busch, 1973.

TABLE 2.9 (continued):

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
	-0.47	-0.30	Wilson *et al.*, 1976.
	0.03	-0.08	Koch, 1978; genetic r SE ± 0.44.
fat trim	-0.37	-0.32	Dinkel & Busch, 1973.
	0.10	0.07	Koch, 1978; genetic r SE ± 0.38.
lean	0.20	0.41	Dinkel & Busch, 1973; with edible portion.
	0.72	0.59	Dinkel & Busch, 1973; with cutability.
	0.17	0.29	Wilson *et al.*, 1976; with edible portion.
	0.54	0.49	Wilson *et al.*, 1976; with trimmed round.
	-0.02	0.55	Koch, 1978; genetic r SE ± 0.64.
bone	-0.36	0.34	Koch, 1978; genetic r SE ± 0.42.
Fat thickness with:			
fat trim	0.86	0.66	Dinkel & Busch, 1973.
	0.95	0.65	Koch, 1978.
lean	-0.88	-0.53	Dinkel & Busch, 1973; with edible portion.
	-0.75	-0.63	Dinkel & Busch, 1973; with cutability.
	-0.56	-0.45	Wilson *et al.*, 1976; with edible portion.
	-0.47	-0.50	Wilson *et al.*, 1976; with trimmed round.
	0.65	0.07	Koch, 1978; genetic r SE ± 0.42.
bone	0.30	0.02	Koch, 1978; genetic r SE ± 0.33.
Fat trim with:			
lean	-0.94	-0.88	Dinkel & Busch, 1973; edible portion.
	-0.82	-0.70	Dinkel & Busch, 1973; cutability.
	0.46	0.38	Koch, 1978; retail product.

TABLE 2.9 (continued):

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
bone	0.22	0.26	Koch, 1978; genetic r SE ± 0.26.
Lean with:			
bone	0.78	0.79	Koch, 1978; retail product.

It is desirable that the most important relationships among carcass characteristics are those connected in some way to the economic value of the carcass. Yield-related aspects would be of more practical application in this respect. Miller et al. (1965) reported correlation coefficients between trimmed round and total retail yield of the carcass side. Their estimates of correlation ranged between 0.85 and 0.91. When yield was expressed as a percentage, the correlation was much lower, between 0.43 and 0.47. They also presented estimates of correlation between eye muscle area and retail yield, varying from 0.64 to 0.85 with yield expressed as weight, and 0.34 to 0.46 with percentage yield. Correlation between measurements recorded on the left and right sides was found to be high. The findings indicate that comparison of results is unjustified if assessments are from different sides or expressed differently, as was the case with weights and percentages.

Carcass weight is reported to be correlated with most other attributes of the carcass. It is important to view this cautiously in cases where a possible involvement of part : whole relationships may be envisaged. This would be the case where carcass weight is related to other quantitative aspects, such as, amounts of fat, lean, or bone in the carcass. Relationship of carcass weight with cutability or yield of retail product should also be viewed in the same light. Correlation between aspects like specific gravity and carcass composition, or bone proportion, such as was reported by Preston et al. (1974) should be treated likewise.

Callow (1949) studied relationships between fat and muscle tissue percentages in sheep and cattle carcasses and arrived at regression equations relating these two carcass tissues. For sheep carcasses, the estimated phenotypic correlation varied between -0.9754 and -0.9957. Estimates from 4 groups of cattle varied from -0.9583 to -0.9768. A pooled estimate from 28 lamb and 21 cattle carcasses was -0.9782. Regression equations of whole carcass or side muscle weight on individual muscles was also reported to be high, but it would seem appropriate to suspect that part:whole relationships were the major reason for such association.

Butterfield (1962) computed regression equations relating side muscle weight to selected muscle and muscle-group weights and reported correlation coefficients of between 0.9550 and 0.9908. Such relationships, as well as those given later by Butterfield (1965) relating fat weight with fat thickness, and carcass weight, total muscle with shin muscle, fat thickness and carcass weight, and side bone with radius, ulna, and carcass weight must be largely due to part:whole relationships. Simple correlation coefficients reported by Butterfield (1965) between various bones and total bone weight were above 0.96. Relationships reported between the weights of the various bones were equally high and corresponding values for muscle tissues were of the same magnitude.

Butterfield (1965) implied that the uniformly high relationships in the aspects of bone studied were sufficient ground for recommending that any limb bone was a good index of total carcass bone. He suggested, in addition, that shin muscle was a practical index of total muscular tissue in the carcass. Kidney and channel fat was strongly associated with total side fat (r = 0.91), but for practical purposes kidney fat alone was suggested as an index of total side fat because channel fat is known to be subject to trimming variations.

Relationships of carcass linear measurements with aspects of carcass composition have been presented by various authors (Kennick et al., 1963; Preston and Willis, 1974; Bass, 1981; and many others cited earlier). Bass (1981) found that the inclusion of fat depth in a prediction equation for carcass composition improved precision, compared to prediction by carcass weight alone. Tissue depth did not improve precision significantly when it was used in the place of fat depth. Fat depth ("thickness") and area of the surface of lean exposed at the position of quartering the carcass, referred to in this thesis as eye muscle area, are among the most common measurements of the carcass that appear in the literature. While relationships between linear measurements with composition or meat quality may remain the centre of controversy, the linear measurements have gained popularity as is evident in the literature. They have become important in their own right, not necessarily because of their relationship to carcass composition or meat quality.

2.2.4.2 Carcass and Meat Traits

Relationships between measures of carcass fatness, grade, and composition have been studied extensively (Ramsey et al., 1962; Kennick et al., 1963; Cundiff et al., 1964; Jeremiah et al., 1970; Nelms et al., 1970; Preston and Willis, 1974; Berg et al., 1978a). From the amount of published material it seems appropriate to generalize that there is strong evidence for the existence of relationships between many of the carcass and meat traits associated with fatness.

Measures of fatness have received considerable attention in the studies that have examined the relationships between composition, yield, and quality characteristics. Fatness criteria have invariably been found to have a negative correlation with yield of lean. Relationships with eating characteristics have also been reported in some studies. Some palatability characteristics, notably flavour, are complex, not only to define precisely, but also to explain their observed relationship with other traits (Blumer, 1963). Sources of variation in such traits are not well understood. Table 2.10 is a summary of a number of the results from investigations on relationships between carcass and meat traits.

2.2.4.3 Meat Characteristics

Many published relationships between meat characteristics are of little direct practical application. They are, however, important in explaining variation in some of the traits that determine meat acceptability to the consumer. Many methods of assessment of meat characteristics are subjective, commonly involving taste panels.
The finding of a relationship from subjective assessments needs careful interpretation because subjective "measurements" are usually not highly repeatable. Results of different studies should not be compared without due consideration of the influence of subjectivity where relevant.

Some investigations have employed objective and subjective methods of assessment of meat tenderness and examined relationships between them.

TABLE 2.10: SOME PUBLISHED ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATION BETWEEN CARCASS AND MEAT TRAITS

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Carcass weight with:			
marbling	-0.33	0.18	Koch, 1978; genetic SE ± 0.39.
	-0.19	-0.21	Wilson et al., 1976; weight/d.
tenderness	0.29	0.05	Wilson et al., 1976; W-B shear.
	0.20	-0.02	Wilson et al., 1976; taste panel.
juiciness	0.24	-0.01	Wilson et al., 1976; taste panel.
flavour	-	0.01	Wilson et al., 1976; taste panel.
lean colour	0.00	-0.08	Shelby et al., 1963; cold carcass.
Dressing-out % with:			
marbling	0.50	0.06	Dinkel & Busch, 1973.
lean colour	0.09	-0.09	Shelby et al., 1963.
	0.47	0.04	Dinkel & Busch, 1973.
Eye muscle area with:			
marbling	-0.17	-0.01	Dinkel & Busch, 1973.
	-0.38	-0.15	Wilson et al., 1976.
	-1.34	-0.03	Koch, 1978; genetic SE ± 0.99.
tenderness	-0.09	-0.06	Wilson et al., 1976; W-B shear.
	0.30	-0.03	Wilson et al., 1976; taste panel.
juiciness	0.04	0.05	Wilson et al., 1976; taste panel.
flavour	-	0.02	Wilson et al., 1976; taste panel.
lean colour	0.04	-0.09	Shelby et al., 1963.
	1.00	0.13	Dinkel & Busch, 1973.

TABLE 2.10 (continued):

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Fat thickness with:			
marbling	0.38	0.09	Dinkel & Busch, 1973.
	0.37	0.17	Wilson et al., 1976.
	0.73	0.25	Koch, 1978.
tenderness	-0.29	-0.19	Wilson et al., 1976; W-B shear.
	0.32	0.12	Wilson et al., 1976; taste panel.
juiciness	0.01	0.11	Wilson et al., 1976; taste panel.
flavour	-	0.08	Wilson et al., 1976; taste panel.
lean colour	-0.01	-0.14	Shelby et al., 1963.
	0.81	0.06	Dinkel & Busch, 1973.
Fat trim with:			
marbling	0.09	0.15	Dinkel & Busch, 1973.
	0.33	0.35	Koch, 1978; genetic SE ± 0.31.
lean colour	0.72	0.07	Dinkel & Busch, 1973.
Lean with:			
marbling	0.02	-0.13	Dinkel & Busch, 1973; edible portion.
	-0.32	-0.09	Dinkel & Busch, 1973; cutability.
	-0.29	-0.35	Wilson et al., 1976; edible portion/d.
	-1.10	-0.04	Koch, 1978; genetic r spurious, SE ± 0.77.
tenderness	0.22	0.05	Wilson et al., 1976; edible portion/d, W-B shear.
	0.11	0.10	Wilson et al., 1976; trimmed round, W-B shear.
	0.17	-0.04	Wilson et al., 1976; edible portion/d, taste panel.
	-1.00	-0.15	Wilson et al., 1976; trimmed round, taste panel.

TABLE 2.10 (continued);

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
juiciness	0.27	0.03	Wilson *et al*., 1976; edible portion/d.
	-1.00	-0.11	Wilson *et al*., 1976; trimmed round.
flavour	-	-0.05	Wilson *et al*., 1976; edible portion/d.
	-	-0.11	Wilson *et al*., 1976; trimmed round.
Bone with:			
marbling	-1.14	-0.09	Koch, 1978; genetic r spurious, SE ± 0.69.

Tuma et al. (1962) studied the relationship between muscle fibre diameter and tenderness. Tenderness was measured by subjective and objective methods, that is, by taste panel and by the Warner-Bratzler (W-B) shear device. They reported a significant correlation coefficient when the age of the animals was not taken into consideration. When data were corrected for age, the correlation coefficient estimated from the same material was low and unimportant. It is generally known that muscle fibre diameter increases with chronological age while tenderness decreases as age advances.

Attempts have been made to relate various other physical attributes of meat to tenderness. Hill (1967) found that intra-muscular collagen content was related to tenderness assessed by Warner-Bratzler shear values ($r = 0.58$ and $r = 0.56$ for 2 different muscles). Intramuscular fat was only slightly related to tenderness ($r = 0.04$ and 0.17, respectively). Possible relationship between meat tenderness and hexosamine hydrochloride was also investigated and found to be low and non-significant.

Histological and chemical traits of meat were studied by Reagan et al. (1976) in an effort to uncover associations with tenderness. The animals used in their study varied widely in age. Among the more important observations were that sarcomere length was related ($P < 0.05$) to juiciness, amount, and solubility of connective tissue, and fat percentage in the carcass, but not to tenderness. Age of the animal and amount of connective tissue in the muscle were related to tenderness. Moisture content was not associated with either juiciness or tenderness, but collagen content was related to both these attributes.

Juiciness was found to increase with increasing amounts of collagen in *Longissimus dorsi* muscle and subjectively evaluated tenderness decreased. Multiple regression equations showed that age had a high predictive value for most carcass traits studies. Age and fat percentage accounted for nearly one quarter of all variation in shear force value (R^2 = 0.22).

The most commonly studied meat traits are marbling, tenderness, juiciness, flavour, and colour of lean. The first and last mentioned characteristics are sometimes considered as carcass traits.

Results of some work on relationships between meat traits are summarized in Table 2.11.

TABLE 2.11: SOME PUBLISHED ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATION BETWEEN MEAT CHARACTERISTICS

Correlated traits	Correlation estimate		Source of information and comment
	Genetic	Phenotypic	
Marbling with:			
tenderness	-0.36	-0.27	Wilson *et al*., 1976; W-B shear.
	-0.20	0.27	Wilson *et al*., 1976; taste panel.
juiciness	-0.81	0.21	Wilson *et al*., 1976; taste panel.
flavour	-	0.05	Wilson *et al*., 1976; taste panel.
lean colour	0.22	0.24	Dinkel & Busch, 1973.
Tenderness with:			
juiciness	-0.30	-0.32	Wilson *et al*., 1976; W-B shear force.
	1.00	0.77	Wilson *et al*., 1976; taste panel scores.
flavour	-	-0.27	Wilson *et al*., 1976; W-B shear force.
	-	0.79	Wilson *et al*., 1976; taste panel scores.
Juiciness with:			
flavour	-	0.74	Wilson *et al*., 1976; taste panel scores.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Source of Data

Data were collected from 117 steers born in the years 1975 and 1976 at the Massey University hill country farm, "Tuapaka". These steers were slaughtered in 1978 and 1979, respectively, at an average age of 30 months. For convenience these years are referred to as "year 1" (1975 births or 1978 slaughterings) and "year 2" (1976 births or 1979 slaughterings). Information recorded on steers fell into three general categories namely, growth, carcass, and meat characteristics. Some recorded information on dams of the experimental steers was included in the analyses.

Growth data were recorded on each steer at specified ages following a routine management schedule. These included birth date, birth weight, pre-weaning milk consumption, weaning (200-d.) weight, yearling weight, two-year weight, finish (30-month) weight, and the immediate pre-slaughter weight. Post-slaughter data collected on the same two groups of steers differ slightly due to changes necessitated by circumstances prevailing at the time of slaughter and during the ensuing data collection period.

Carcass details were collected in much the same way in both years except where it was not feasible as specified later. Data included warm carcass weight (sum of both carcass side weights), dressing-out percentage, carcass grade, kidney knob and channel fat weight, eye muscle width, eye muscle depth, fat depth over eye muscle, eye muscle area in year 2 and fat colour assessment of the warm and chilled carcass in year 2. Carcass yield was obtained in year 2 only, based on the component tissues of the right side of the carcass: fat trim, bone and lean (percentages by weight were calculated).

3.2 Experimental Animals - Management and Data Collection

3.2.1 Cows

3.2.1.1 Management

The cows included in this study, aged between 3 and 12 years, were managed under typical North Island of New Zealand hill country conditions. They were identified with plastic numbered eartags and grazed on hill pasture all the time except between immediately pre-calving (about three weeks before the expected beginning of the calving season) and up to 40 days post-calving when some cows were held in a sawdust pad for experimental purposes. This was done to determine if calving on a sawdust pad influenced the performance of the cows and/or their calves as compared with traditional pasture calving. The cows that calved on the sawdust pad were moved on to hill pasture at different times as detailed in the study of Msechu (1979).

To facilitate management, cows (with calves at foot) were held in three mobs while on hill pasture. These mobs were made up as calving advanced, so that the first one was composed of the earliest calving cows, with only few exceptions. No supplementary feeding was supplied at any time while cows were on pasture. Feeding on the sawdust pad was basically the same in both years and consisted of meadow hay and a supplement of 4.5 kg barley meal per beast per day. Amounts of supplementary feeding were based on recommendations from results of previous work where immediate post-calving nutrition was investigated on similar types of animals between 1971 and 1974 (Pleasants and Barton, 1979).

3.2.1.2 Recording

Information kept regarding the cows included identification eartag numbers, age at calving (in years), periodic liveweight (including pre-calving autumn liveweight, immediate pre-calving liveweight and immediate post-calving liveweight). Other information entered against each cow's eartag number was the calving management regime (hill pasture *versus* sawdust pad), calving data (calf birth date), hill pasture herd/ mob, calf identification eartag number, sex of calf and other calf information. Most of this information held in the recording ledger helped in identifying and counterchecking steer information. For purposes of this study, cow information included in statistical analyses was cow age, pre-calving autumn liveweight, calf birth date (calving date), calving management regime, herd grouping (yearly cow/calf mobs on hill pasture) and year of calving.

3.2.2 Steers

3.2.2.1 Management

The early management of the experimental steers followed closely the procedure described for cow management in the previous section. The shifting of cows from the sawdust pad to hill pasture and from one paddock to another determined movement of their respective calves. Each calf was identified with a plastic numbered eartag and weighed within 24 h of birth. This weighing was effected by suspending the calf in a sling attached to clock-face scales supported by an iron bar. Castration was done by a bloodless method, using rubber rings. The rubber rings were slipped over the calf's scrotum using an elastrator at the time birth weight was recorded and remained in place (as the calf grew) until the scrotum and testicles atrophied and sloughed off.

Each year the steer calves remained in their dam's management mobs until weaning. They were weighed routinely (at least once a month) and weaned into a single steer herd. Weaning was done on the same date for all steers regardless of differences in age due to various birth dates. Post-weaning management was common for the steers (within year) until their terminal ("finish") off-pasture weights were recorded and different pre-slaughter fasting procedures were adopted for experimental purposes.

The identification number on the eartag that was clipped on to the calf's ear within its first 23 h of life remained associated with that calf/steer throughout its life. It must be pointed out, however, that several steers lost their eartags quite early in life. Where this happened the tags were replaced. In such cases both the replacement tag number and the original one were referred to each time the animal was dealt with. The replacement eartag number was placed in parenthesis wherever it appeared in the records. The dam identification number was shown alongside the calf number in the list appearing in the records ledger.

Further identification was at slaughter where a works number was allocated to each steer as they came to the beginning of the slaughter chain. At this time care was taken to ensure that the "current" eartag number was recorded along with the works number since all post-slaughter recording was associated with works numbers only. This information was later matched with eartag numbers alongside the works numbers to complete the set of records on individual steers.

3.2.2.2 Recording

3.2.2.2.1 Growth Data

Growth records of the steers were recorded routinely from birth to slaughter. Birth date was recorded in coded form as "day" in a 365-day year calendar (coding was such that 1 stood for 1 January and 365 for 31 December). This was done after the birth weight was recorded at which time birth date was recorded as actual date, specifying date, month and year of birth. Liveweight was then taken on a monthly basis and included weights recorded at selected periods which have been used for the analyses included in this study. These selected weights were recorded at weaning, yearling, two-year, finish, and pre-slaughter time. Weights were taken on the same day for all steers (within year) regardless of their differing ages.

Estimates of milk consumed by individual steers were made on three occasions in the pre-weaning period. This was done at the time of recording liveweight when the steers were an average of 25, 45 and 65 days of age. The procedure for the estimation was the "weigh-suckle-weigh" method after calves had been separated from their dams overnight. This was only a "rough-estimate" procedure as estimates are influenced by known and unknown factors. Such factors as the calf's appetite, dam's milk yield, milk let down, psychological influence of the separation overnight and others are likely to have influenced the estimates. For this reason the author believed that the estimates would be of limited use. However they were the most feasible records that could be obtained under field conditions at the time of the study.

Finish weight was recorded on all steers due for slaughter on a predetermined day (on 20 April 1978 and 29 April 1979, for the two steer groups, respectively). To avoid ambiguity "finish" weight will be defined as the final weight recorded off-pasture prior to subjecting the experimental steers to different pre-slaughter fasting procedures. Pre-slaughter weight, on the other hand, was the last weight recorded on the steers, whether off-pasture (for non-fasted steers) or not, prior to loading the steers into trucks for transport to the abattoir. This last weight was recorded after imposing preferential treatment on some steers by fasting. As soon as it was recorded the steers were loaded into the trucks. When the steers arrived at the abattoir they were held in pens without feed for about 24 h before slaughter. Table 3.1 shows the distribution of steers by sub-class as explained. The pre-slaughter procedures and subsequent recording are explained in the section that follows.

TABLE 3.1: SUB-CLASS NUMBERS OF STEERS FOR WHICH GROWTH DATA (POOLED OVER 2 YEARS OF STUDY) WERE ANALYSED

Dam age group	Treatment group	Herd group 1	2	3	4	5	6	Totals by dam age group
1	1	11	6	3	5	4	7	41
	2	0	1	2	2	0	0	
2	1	5	5	7	2	0	0	48
	2	6	9	5	4	5	0	
3	1	0	1	0	2	1	1	28
	2	2	0	0	8	11	2	
Totals by herd group		24	22	17	23	21	10	Grand total 117

Note: Total numbers by treatment group have been omitted above for clarity. Total number of steers in treatment 1 was 60, and that in treatment 2 was 57.

3.2.2.2.2 Pre-slaughter Procedure

Subsequent to the recording of finish weight it was planned that 2 pre-slaughter fasting durations be subjected to random halves of the steer group (within year). One half was fasted as is traditional practice ("control"), where steers were fasted for 1 day at the abattoir yards prior to slaughter. The other was fasted over a period of 3 days before transfer to the yards at the abattoir for slaughter after a day's fasting. Liveweight was recorded daily for steers fasted for the longer period.

The control group was returned to pasture after finish weight was taken. One day prior to slaughter, the control group was weighed along with the fasted group. This was done in the morning and the animals (one slaughter lot) were lorried to the abattoir. This plan was such that at the time of recording the pre-slaughter weight, the control group would not have been fasted at all while the fasted group would have had about 72 h of fasting. The same plan was intended for all slaughter lots although inevitably it could not have possibly been identical for each slaughter lot. The same could be said of the overnight fasting at the abattoir yards. For this reason, slaughter lot was suspected to be a source of variation in post-slaughter characteristics as will be explained under mathematical model construction and statistical procedures.

Due to industrial action at the Longburn meat works some year 1 slaughter steers were fasted a little longer than planned. Because of this the control group was fasted for 1.5 days instead of the intended 1 day. This is one of the reasons why pooled analysis (both years' data) of post-slaughter data was considered rather questionable. There were also slight differences in post-slaughter handling of carcasses (and meat) and the way in which information was collected. These differences are set out in Sub-section 3 below.

3.2.2.2.3 Slaughter and Post-slaughter Procedures

Slaughter procedure followed common practice in two commercial meat works which handled the slaughter of the steers. In 1978 slaughter was at the Co-operative Wholesale Society (C.W.S.) freezing works at Longburn. Post-slaughter handling of the carcasses and recording were done in the facilities available at the same works for that year. Year 2 (1979) slaughterings were at the abattoir of the Borough of Feilding.

Subsequent boning-out and data collection were carried out at Evans Export Ltd, a meat export concern adjacent to the abattoir. In both slaughter-houses (Longburn in 1978 and Feilding in 1979) steers were stunned using the captive bolt pistol. As they left the stunning box their eartag numbers were recorded together with works number, tooth-eruption information and any other observation that would aid identification and further recording. Works numbers ran serially starting from 1 for any particular slaughter day as a routine in both slaughter-houses. By prior arrangement with management at the slaughter-houses the steers for this study went through the slaughter chain before all other cattle were slaughtered. They were therefore identified with work numbers starting from 1 and running to whatever the total number was in the particular slaughter of the day. The head and feet were removed after allocation of the works number.

The recorder was responsible for recording the identification (eartag numbers and works numbers) as well as tooth eruption information. The head and the body were processed in different lines, the former going by the recorder when most of the skin had been removed from it, thereby exposing the incisor teeth. It was originally intended to record all permanent dentition on the lower jaws of each steer. However, due to hesitation and doubt on the reliability of information recorded on the first slaughter lot on pre-molars, the author considered it desirable to use information on incisor teeth only. In some cases it was not easy to determine whether the pre-molars were decidual or permanent, while with incisors it was very each to distinguish the permanent and temporary teeth. Delays that would have been necessitated by checking and double-checking full-mouth information could have caused some confusion in the initial identification/recording process and subsequently of records taken further down the slaughter line. This first stage of post-slaughter recording had to be correct if any data collected subsequently was to be valid. The number of permanent incisors was therefore recorded and later used as the sole basis for the assessment of the maturity status of the steers for the purposes of this study.

Each carcass carried the works number through all recording points. One recorder at an appropriate location on the chain recorded the works number and the weight of kidney knob and channel fat of each side. The weight of each carcass side was recorded by a final recorder, again against the respective works number. The same recorder assessed the colour of subcutaneous fat and recorded it along with the grade allocated to the carcass. Fat colour was subjectively judged as normal (coded N), slightly yellow (coded SLY) and yellow (coded Y). Grading was done by the works grader and his grading was checked by a Supervising grader of the New Zealand Meat Producers Board.

The identified sides were then railed into the chillers for overnight chilling, as is the practice commercially. In the morning of the day following slaughter each side was split between the 12th and 13th rib and further recording was done. Circumstances at the Longburn works did not allow for complete splitting of the carcasses into quarters. It was however, possible to take linear measurements on the eye muscle for purposes of this study. Quarter weights were recorded (at Feilding in 1979) and linear measurements recorded. The width (measurement "A") and depth (measurement "B") of the eye muscle as well as fat depth over the eye muscle were each recorded in millimeters in both years. Area of the eye muscle was not recorded in 1978 since the sides were not quartered completely. In 1979 the surface of the eye muscle was traced with pencil on transparent film. The area of eye muscle was determined from the tracing by using a plannimeter. All these measurements were taken from the right side of the carcass. Meat samples (of about 0.5 kg) were obtained from the eye muscle in the same side of the carcass for assessment of a number of meat quality characteristics.

It was not possible to obtain meat yield characteristics in year 1 because boning out was not done. But in year 2 the right side quarters of each carcass were boned out. Individual quarter weights were recorded. The weight of trimmed off fat from each quarter was recorded and after boning-out, bone weight was taken. Commercial lean weight was obtained by difference. Percentages (by weight) were calculated for fat trim, bone, and commercial lean in the right side of the carcass.

3.2.2.2.4 Measurement of Meat Characteristics

The meat samples collected after the carcasses had been chilled for 1 day were taken to the meat laboratory at Massey University and held at a known temperature regime until time of assessment of a variety of meat characteristics. The procedures involved in storage and handling were slightly different between the two slaughter years, notably regarding storage temperature, duration and cooking procedures.

Meat colour determinations in year 1 were made on 2 sub-samples after storage at different temperature conditions in clearly identified plastic bags. One sub-sample was stored at 20°C (equivalent to room temperature) for 10 days while the other was stored at around 0^{o}C for the same duration. In year 2 storage was at a slightly different set of conditions, 2 to 4^{o}C for a period of 6 days. The procedure for measuring meat colour was adopted from the results reported by Strange et al. (1974), based on the measurement of percentage reflectance on a spectrophotometer at a light wavelength of 630 nm. The choice of this wavelength was based on the fact that results in the above report suggested a strong relationship between the reflectance measurement at 630 nm and consumer acceptability of meat colour (r = 0.78).

Muscle pH was assessed after laboratory storage as explained above. For year 1 sub-samples, a homogenate was prepared out of 2 to 3 g of muscle tissue by using a mortar and pestle and adding a weak neutral solution of sodium benzoate. A pH meter with a combined glass electrode was used to obtain the pH of the homogenate. For year 2, determinations were made on 2 sub-samples of unequal size, one of 1 g and the other 0.5 g and the average of the two was used for purposes of the analyses in this study because there was hardly any variation between sub-sample pH values.

Sarcomere length was determined by using an RCA Helium-Neon laser (1 mW, 632.8 nm wavelength) 0.8 mm-wide beam. This technique is as detailed by Bouton et al. (1973). This was carried out on strips of muscle teased out on a microscope slide in a drop of fuggered sucrose solution. Ten such determnations were made on each preparation and their average was used for purposes of statistical analysis. Various other studies have used similar equipment and procedures (see, for example, Stromer and Goil, 1967; and Purchas and Barton, 1976).

Intramuscular fat percentage was determined by ether-extraction of 3, 10 to 12 g sub-samples per carcass. The sub-samples were freeze-dried over a 48 h period. The dry sub-samples were weighed and then transferred into petroleum ether (boiling point 40 to 60°C) for extraction in Soxhlet apparatus. The extraction process ran for 9 hours. The weights of the fat in the 3 sub-samples were determined by taking the difference in weight (dry) of a flask (in which extraction was carried out) - weight before extraction and after extraction being recorded to the nearest 0.001 g. The average of the 3 weights obtained per carcass expressed as a percentage of the total sub-sample weight was used in the statistical analyses.

Meat tenderness was measured using a Warner-Bratzler shear instrument fitted with a clock-face scale with a capacity of 25 kg (shear-force) rising by 50 g graduations. Samples of meat were cooked in the plastic bags in which they had been stored. Cooking was carried out in a regulated temperature water bath before splitting the samples into sub-samples for replicated tenderness measurements. For year 1 cooking was done in a constant temperature water bath at 70°C for 90 min. Two cooking temperatures were used in year 2, 50°C and 70°C, also for 90 min. Ten sub-samples (13 mm square cross-section cores) were cut out of each cooked sample making sure that they represented the full length of the muscle from periphery to the part nearest the attachment to bone. The 10 measurements obtained were averaged to obtain one figure representing tenderness of the relevant carcass. It should be emphasized that from the foregoing explanation each steer would have had two figures for tenderness. Year 1 steers had a figure based on samples stored at 0°C and another one for 20°C storage, while year 2 steers had one for samples cooked at 70°C.

The number of steers for which post-slaughter data were analysed varied widely between year of study and by slaughter lot, maturity category and pre-slaughter fasting group. Distribution of steers by these criteria is presented in Table 3.2, below:

TABLE 3.2: SUB-CLASS NUMBERS[1] OF STEERS FOR WHICH POST-SLAUGHTER DATA WERE ANALYSED

Slaughter lot	Maturity category	Pre-slaughter fasting group				Totals by slaughter lot	
		1		2			
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
1	1	3	9	3	4	23	28
	2	8	4	9	11		
2	1	2	3	1	6	20	26
	2	8	11	9	6		
Totals by fasting group		21	27	22	27	Grand totals 43	54

[1] Total numbers by maturity category were left out of the table to avoid confusion. Numbers of steers in category 1 were 9 and 22 for year 1 and year 2; those in category 2 were 34 and 32 for year 1 and year 2, respectively.

3.3 Statistical Procedures

3.3.1 Introduction

The data used in this study were unbalanced (including empty sub-classes) and accordingly, analyses of variance (ANOVAs) were constructed using the method of fitting constants introduced by Yates (1934). In view of the non-orthogonality of the reductions in sums of squares pertaining to factors included in the linear model, due consideration was given to the order of fitting factors in the model when tests of hypotheses were conducted. A detailed example which highlights this is presented in Appendix B. The linear models were initially constructed on the basis of major (identifiable) sources of variability in the biological system responsible for the variable concerned. The significance, or otherwise, of factors initially included in a model was determined by the statistical analyses.

3.3.2 Data Classification

Growth data on each steer were classified according to herd (3 management mobs each year of birth), age of dam (3 age groups in all), and peri-natal treatment (whether born on hill pasture or on sawdust pad). The categories of age of dam were from a sub-division of the range of dam age at calving into 3 age groups, namely, young (up to 4 years of age), medium-age (5 to 7 years of age) and old (8 or more years of age) dams. The previous parous state of the dams was initially considered, but later omitted because of likely confounding with the effect of age of dam. Age was considered to be the more meaningful factor.

Post-slaughter data were classified according to slaughter lot (2 lots slaughtered each year), pre-slaughter fasting procedure (traditional 1-day fast or extended 4-day fast) and maturity category (based on number of permanent incisors at time of slaughter). Two such categories were used for purposes of this study. One consisted of steers that had less than 2 central permanent incisors on either side of the lower mandible (relatively immature steers) while the other category was of steers with 2, or more, permanent incisors on either side of the mandible (more mature steers).

In view of previous studies with animals of the same breeding raised under similar circumstances (Pleasants, 1974 and Msechu, 1979), interactions between main classification criteria were not anticipated except between age of dam and per-natal treatment. Because of the nature of the relationships amongst some variables under consideration, covariance analysis procedures were required. Variables classified as covariates were autumn liveweight of the dam, steer date of birth, steer birth weight, milk consumption in the pre-weaning period, steer growth rate, and steer carcass weight.

3.3.3 Linear Model Construction

For the analyses of growth data, factors included in the model were herd-group, age-of-dam, peri-natal treatment, dam age-by-treatment interaction and certain covariates. A representative model (fully fixed-effects model) for the analyses of growth data was:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \theta_k + (\beta\theta)_{jk} + \sum_{q=1}^{c} b_q\, x_{qijkl} + e_{ijkl}, \ldots \qquad (3.1)$$

where

Y_{ijkl} = the growth record of the l^{th} steer in the k^{th} peri-natal treatment group, j^{th} age-of-dam group, and i^{th} herd group;

μ = a general mean;

α_i = the effect of the i^{th} herd/group, i=1, 2, ..., 6; (where data were pooled over 2 years with 3 herd groups in each year, the effects of year were not separated from herd effects);

β_j = the effect of the j^{th} age of dam group, j=1, 2, 3;

θ_k = the effect of the k^{th} peri-natal treatment group, k=1, 2;

$(\beta\theta)_{jk}$ = the effect of the interaction between age of dam and peri-natal treatment;

b_q = the regression coefficient of y_{ijkl} on the covariate x_{qijkl}, q = 1, 2, ..., c, (c is the number of such covariates in the model);

x_{qijkl} = the value of the q^{th} covariate recorded on the same animal as y_{ijkl};

e_{ijkl} = the effect of a random residual error peculiar to the record y_{ijkl}. The errors were assumed to have expected value zero and a constant variance and to be uncorrelated; for purposes of testing hypotheses, they were further assumed to have a multi-variate normal distribution.

In the case of post-slaughter data an analogous linear model included a general mean (μ), slaughter lot (θ_i, i=1, 2), pre-slaughter fasting (Ψ_j, j=1, 2), maturity category (ω_k, k=1, 2) and covariates q=1, 2, ..., c). This generated the model represented by equation (3.2) below:

$$Y_{ijkl} = \mu + \theta_i + \Psi_j + \omega_k + \sum_{q=1}^{t} b_q\, x_{qijkl} + e_{ijkl}, \dots \qquad (3.2)$$

Equations (3.1) and (3.2) may be written more generally in matrix notation as follows:

$$\underset{\sim}{y} = \underset{\sim}{X}\underset{\sim}{a} + \underset{\sim}{Z}\underset{\sim}{b} + \underset{\sim}{e}, \dots \qquad (3.3)$$

where

$\underset{\sim}{y}$ = the nxl vector of observations;

$\underset{\sim}{X}$ = a known nxp incidence matrix;

$\underset{\sim}{a}$ = a pxl vector of unknown fixed effects comprising the general mean, factor level and interaction effects (where applicable);

$\underset{\sim}{Z}$ = a known nxq matrix of concomitant data values;

$\underset{\sim}{b}$ = a q x l vector of regression coefficients to be estimated; and

$\underset{\sim}{e}$ = an nxl vector of unobservable random residual error effects, assumed to have as its expected value the null vector and variance-covariance matrix $\underset{\sim}{I}\sigma^2$; and for purposes of testing hypotheses, further assumed to have a multi-variate normal distribution.

The model defined by equation (3.3) <u>et seq</u>. is a general representation of all models in the analyses of this study. Accordingly, it will be referred to from hereon as the general model. All specific models adopted following modification of the general model were distinguished by the numbering as sub-model (1), sub-model (2), and so on.

Sub-model (1) was constructed for preliminary analyses of the growth data pooled over 2 years of study. The maximal sub-model (1) included 6 herd-groups (3 per year), 3 age-of-dam groups, 2 peri-natal treatment groups and age-of-dam x treatment interaction effects. Covariates included were steer date of birth, steer birth weight, and 3 estimates of milk consumption (recorded at 25-, 45-, and 65-d age).

Sub-model (2) was used for within-year analyses of all growth data. It included 3 herd groups, 3 age-of-dam groups and 2 treatment groups as the fixed-effects. Covariates were dam autumn liveweight, steer birth weight and one estimate of milk consumption (recorded at 25-d age).

Sub-model (3) was constructed for within-year analyses of post-slaughter data with the main aim of drawing inferences on the influence of slaughter lot and maturity. Slaughter lot (2 each year) and maturity categories (2 each year) were the fixed-effects in the model. Pre-weaning average daily gain (hereon abbreviated as ADG), post-weaning ADG, and carcass weight were included as covariates in the model.

Sub-model (4) was also for within-year analyses of post-slaughter traits, but was aimed at drawing inferences about the influence of pre-slaughter fasting. The maximal sub-model (4) contained pre-slaughter fasting (2 procedures each year) as fixed-effects, and carcass weight, as the sole covariate.

Sub-model (5) was used for generating estimates of variance which were required for calculating correlation coefficients. It was constructed for within-year analyses of all characteristics under study. It included herd group, age-of-dam, and treatment groups as the main fixed-effects factors, one interaction (age-of-dam x treatment), and one covariate (steer date of birth).

3.3.4 Analyses

3.3.4.1 Least Squares Equations and Solutions

Applying ordinary least squares procedures to the general model (3.3) generates the following normal equations to be solved for the vectors $\tilde{a}$ and $\tilde{b}$:

$$\begin{bmatrix} X'X & X'Z \\ Z'X & Z'Z \end{bmatrix} \begin{bmatrix} a^o \\ \hat{b} \end{bmatrix} \quad \begin{bmatrix} X'y \\ Z'y \end{bmatrix}, \ldots \qquad (3.4)$$

The coefficient matrix in the left hand side of equations (3.4) does not have full rank.

The equations, therefore, do not have a unique solution (the coefficient matrix does not have an inverse). However, by invoking appropriate constraints, a solution leading to a unique estimate of any estimable function of the vector $[a' \ b']'$ can be obtained. The constraints used in this case involved judicious setting to zero of particular effects. Rather than obtain an inverse of the coefficient matrix, the use of constraints permitted calculation of a generalized inverse (Searle, 1971), satisfying:

$$A \, G \, A \quad = \quad A \; ,$$

where G is a generalized inverse of A. A solution was then obtained by pre-multiplying the corresponding elements of the right hand side of (3.4) by the generalized inverse. The choice of constraint should aim to simplify the arithmetic involved.

Procedures for obtaining a solution in this exercise were that a generalized inverse of the sub-matrix $X'X$ was obtained to generate a non-unique solution of the corresponding elements of the vector a by using the model without covariates. This was then substituted in the normal equations (3.4) to obtain $\hat{b}$. The vector b is estimable and, therefore, invariant of the generalized inverse of $X'X$ and the value of vector a^o.

3.3.4.2 Sums of Squares and ANOVA Table Construction

The basic aim of the statistical analyses was to determine whether or not those factors included in the model contributed significantly to the observed variability in the data. A product between the transpose of the solution vector and the corresponding elements of the right hand side of equations (3.4) gives the reduction in sums of squares associated with fitting the particular model to the data. In the terminology of Searle (1971) this would be the "reduction in sums of squares due to fitting the factor" concerned. Sums of squares obtained in this way are invariant to the generalized inverse used (and the solution vector).

Use of the "reduction in sums of squares" principle and corresponding R( )-notation is a convenient method of explaining the structure of analyses of variance for unbalanced data. The procedures employed for constructing ANOVA tables were based upon the judicious fitting of models and sub-models thereof. Sums of squares were partitioned according to sources of variation, mean squares were calculated and tests for significance were performed. A key point is that the reduction in sums of squares accompanying the fitting of a factor in the model is dependent upon the order of fitting. When data are non-orthogonal this fact must be taken into account in the analyses of variance. For instance, fitting a factor α after factor β need not lead to tests of the same hypotheses as when the same factors are fitted in the reverse order. This point is examplified in the next section.

3.3.4.3 Alternative Orders of Fitting Factors in a Model

To illustrate the alternative orders of fitting, a hypothetical model with two fixed-effects (α and β), their interaction (γ) and one covariate (x), is considered. Some reductions in sums of squares that may be calculated are given in the alternatives that follow:

Sums of Squares	Description	Computational formulae
Alternative I:		
$R(\mu)$	Fitting μ alone	$n..(\bar{y}..)^2$
$R(\alpha/\mu)$	Fitting α after μ	$R(\mu,\alpha) - R(\mu)$
$R(\beta/\mu,\alpha)$	Fitting β after μ and α	$R(\mu,\alpha,\beta) - R(\mu,\alpha)$
$R(\gamma/\mu,\alpha,\beta)$	Fitting γ after μ,α, and β	$R(\mu,\alpha,\beta,\gamma) - R(\mu,\alpha,\beta)$
$R(x/\mu,\alpha,\beta,\gamma)$	Fitting x after μ,α,β and γ	$R(\mu,\alpha,\beta,\gamma,x) - R(\mu,\alpha,\beta,\gamma)$
Residual	Error[a] sums of squares	$\underset{\sim}{y}'\underset{\sim}{y} - R(\mu,\alpha,\beta,\gamma,x)$
Total	Total uncorrected[b] sums of squares	$\underset{\sim}{y}'\underset{\sim}{y}$
Alternative II:		
$R(\mu)$	As in Alternative I	
$R(\beta/\mu)$	Fitting β after μ	
$R(\alpha/\mu,\beta)$	Fitting α after μ and β	
$R(x/\mu,\alpha,\beta)$	Fitting x after μ,α and β	$R(\mu,\alpha,\beta,x) - R(\mu,\alpha,\beta)$
$R(\gamma/\mu,\alpha,\beta,x)$	Fitting γ after μ,α,β and x	$R(\mu,\alpha,\beta,x,\gamma) - R(\mu,\alpha,\beta,x)$
Residual	As in Alternative I	
Total	As in Alternative I	

Further alternatives may be obtained by changing the orders of fitting α, β and x. But one can not envisage an alternative where either or both of the main factors are fitted after the interaction. This becomes clear when one imagines what models/sub-models would give rise to reductions in sums of squares whose difference is calculated (as shown for the alternatives in the example) for the order of fitting implied. For example, fitting factor α after μ, β and γ implies calculating:

$$R(\mu,\alpha\ \beta\ \gamma\ ) - R(\mu,\beta,\gamma)$$

[a] The part of total sums of squares unaccounted for after fitting the maximal model.

[b] Some authors prefer "corrected" sums of squares, $\underset{\sim}{y}'\underset{\sim}{y} - R(\mu)$, and omit $R(\mu)$ from the table.

The latter R( )-term implies a model which includes μ, β and the interaction between α and β, only. But, the interaction can be defined only when both α and β are included in the model. Searle (1971; Chapt. 7) discusses this point and the various orders of fitting in more detail.

Mean squares calculated from the sums of squares may be used for tests of significance with the residual mean squares as the denominator. But the hypotheses tested are not immediately obvious from the R( )-notation. Due to non-orthogonality, $R(\alpha/\mu)$ and $R(\alpha/\mu,\beta)$, for example, are different sums of squares which lead to tests of different hypotheses although they are associated with fitting the same factor α. A special case occurs with orthogonal designs, where the analogous sums of squares are identical to each other and test the same hypothesis.

The various hypotheses that may be tested are explained in the literature (Searle 1971, 1979; Carlson and Timm, 1974; Speed and Hocking, 1976; and others). In the present study, tests were based on mean squares calculated from reductions in sums of squares in the case where the term concerned was fitted after all other terms included in the maximal sub-model. Hence, the presentation of preliminary results in Appendix B3. Factors tested were indicated in words without explicit reference to the order of fitting.

3.3.4.4 Methods for Generating Estimates of Correlation Coefficients

The final stage of the analyses was aimed at generating correlation coefficients between the characteristics under study. The correlation estimates were calculated using functions of the residual vectors having fitted a common full model (sub-model (5), defined in sub-section 3) to the variables involved. The nature of data required within-year analyses for this purpose.

The approach adopted involved the "variance of a sum of variables" (hereafter referred to as variance of a sum) principle; namely, given the variables y_1 and y_2,

$$Var(y_1 + y_2) = Var(y_1) + Var(y_2) + 2cov(y_1 y_2), \ldots \quad (3.5)$$

$$\therefore \quad cov(y_1 . y_2) = \tfrac{1}{2}[Var(y_1 + y_2) - Var(y_1) - Var(y_2)], \ldots \quad (3.6)$$

Thus, by fitting the same model to the variables y_1, y_2 and $(y_1 + y_2)$ an estimate of covariance between y_1 and y_2 (and therefore an estimate of correlation) can be obtained. The principle may be generalized for more variables.

None of the factors included in the model was envisaged to be a significant source of variability in all variables. It was therefore decided to generate estimates of correlation coefficients for the same data, but disregarding the factors and covariates (defined in sub-model (5)) to act as supplementary information for purposes of discussion. Discussion of the correlation coefficients was based on the analyses using sub-model (5) and, where necessary, mention was made of the supplementary correlation coefficients. The latter are given in Appendix C.

C H A P T E R   F O U R

RESULTS AND DISCUSSION

4.1 Analyses of Variance

Statistical analyses carried out to determine the importance of factors and variables included in the models defined in Chapter 3 are reported and discussed briefly here. Because of the exploratory nature of this part of the study a rather low level of significance was adopted in the tests conducted ($P < 0.10$). Where the factors were found to be significant at that level this was described as "approaching significance" in line with published terminology and the level was indicated to avoid ambiguity.

4.1.1 Growth Traits

Results from analyses of growth data were presented in two parts, covering the pre-weaning and post-weaning characteristics and their associated factors. The analyses were based on sub-model (2), where data were classified by herd, age of dam group, and treatment as explained in Chapter 3. Three covariates were investigated namely, dam weight, calf birth weight, and milk consumption at 25 days of age.

Analyses of pre-weaning characteristics provided results which are summarized in Table 4.1.

The results were inconsistent between years of birth as far as the effect of herd on pre-weaning traits was concerned. Herd effects

TABLE 4.1: ANALYSES OF PRE-WEANING GROWTH TRAITS. MEAN SQUARES USED IN TESTING FOR SIGNIFICANCE ARE SHOWN WITHIN YEAR (ALONG WITH LEVEL OF SIGNIFICANCE, WHERE APPLICABLE).

Source of variation	d.f.	Birth weight[1]		Milk consumption[1], 25 d.		Pre-weaning ADG[2]		Weaning weight	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Herd	2	2.5	11.6	3.40**	1.92	0.015*	0.006	300	2676**
Age of dam	2	7.3	10.4	0.33	0.11	0.000	0.003	20	65
Treatment	1	15.4	8.0	0.00	0.05	0.001	0.000	170	23
Dam autumn weight	1	0.2	2.0	0.02	0.09	0.008	0.000	154	8
Calf birth weight	1	--	--	1.51	4.61*	0.000	0.030*	471†	1916**
Milk consumption at 25 d age	1	--	--	--	--	0.017†	0.006	768*	644†
Residual: Year 1 Year 2	31 28	7.2	14.8	0.61	0.88	0.004	0.006	147	194

** P <0.01

* P <0.05

† P <0.10

[1] Because birth weight and milk consumption were not included in the model as covariates where either was being analysed, the residual degrees of freedom were different from those shown above. For birth weight, the residual degrees of freedom were 33 and 30 (year 1 and year 2, respectively) and for milk consumption they were 32 and 29, respectively.

[2] ADG = Average daily gain in this and subsequent tables in which it appears.

on birth weight were unimportant. Calf milk consumption and pre-weaning ADG were influenced by herd differences in year 1 ($P<0.01$ and $P<0.05$, respectively). In year 2 such effects were not important, except on weaning weight ($P<0.01$).

While it would be logical to envisage herd-grouping effects due to factors such as paddock differences and behavioural relationships of the cows (and of their calves) in the mobs, such effects were not clearly evident in these results. The differences in the results between years may have been due to differences in weather conditions in the two years. The analysis of birth weight may be taken to have been a way of confirming that there was no bias in the allocation of calves (with their mothers) into herds.

The influence of herd on weaning weight reflected by year 2 data may be attributed to chance or other sources because a genuine effect of herding would be expected to have acted through an influence on milk consumed or pre-weaning ADG. However, the fact that the estimation of milk yield (or calf milk consumption) may have been grossly inaccurate would tend to invalidate this reasoning.

Age of dam group did not influence pre-weaning traits. This was contradictory to many reports in the literature (Preston and Willis, 1974; see also review in Chapter 2 of this thesis). However, cow ages in the present study were rather uniform and no cows fell in either extreme of the age scale, namely 2-year olds or over 10 years of age. Most cows were in the age group of 5 to 8 years.

Calving on sawdust pad and in some cases managing cows and calves there for up to 40 days post-partum did not affect any of the pre-weaning traits studied. These results agree with earlier findings (Pleasants, 1974; Pleasants and Barton, 1974; Msechu, 1979). The earlier results compared different durations on the pad, and found that this management alternative had no influence on calf performance.

Regression of pre-weaning growth traits on dam autumn weight was not significant. These results disagree with the suggestion made by Anderson (1977) that such regression was important as a source of variation in weaning weight. However, it was noteworthy that the cows in the study of Anderson (1977) included young first calvers, and this may partly explain the contradiction between the results of Anderson and those presented here.

Calf birth weight was an important source of variation on milk consumption and pre-weaning ADG ($P<0.05$) and weaning weight ($P<0.001$) in year 2. However, year 1 data suggested that regression on birth weight was relatively unimportant, approaching significance in the case of pre-weaning ADG only ($P<0.10$). These results appear to reflect possible year differences in weather conditions. However, this explanation is based on logical speculation only, because meteorological data were not available for this study. Birth weight would normally be expected to influence pre-weaning growth as the review in Chapter 2 suggested.

The regression of pre-weaning ADG and weaning weight on milk consumption was significant, suggesting that milk was a source of variation on these traits. This had one exception, namely pre-weaning ADG in year 2 (P>0.10). Regression on milk consumption was significant for weaning weight in year 1 while it approached significance in year 2, as did regression of pre-weaning ADG on milk consumption in year 1 (P<0.10).

Results of analyses of post-weaning data using the same sub-model fitted to pre-weaning data gave rise to analysis of variance tables that are summarized in Table 4.2.

The analyses of yearling weight reflect important herd effects in both years of birth (P<0.10 and P<0.01). In view of the results in Table 4.1 it was surprising that herd effects should strongly influence yearling weight (P<0.01) rather than earlier growth traits. Two possible explanations may be suggested for this. First, the influence of the compensatory growth phenomenon may have been involved in some way. Secondly, these results could be attributed to sampling error and chance effects. The suggestion of a treatment influence on post-weaning ADG (P<0.01) and finish weight (P<0.05) in year 1 may also be accounted for by chance, in view of the results in Table 4.1 and the fact that treatment effects were non-existent in yearling weight and 2-year weight (P>0.10).

Age of dam group was not significant on any of the post-weaning traits. The regression of post-weaning growth traits on dam pre-calving autumn weight was also non-significant. Analyses of year 2 data suggest that regression of yearling weight on calf birth weight

TABLE 4.2: ANALYSES OF POST-WEANING GROWTH TRAITS. MEAN SQUARES USED IN TESTING FOR SIGNIFICANCE ARE SHOWN WITHIN YEAR (ALONG WITH LEVELS OF SIGNIFICANCE, WHERE APPLICABLE).

Source of variation	d.f.	Post-weaning ADG		Liveweight at various stages					
				Yearling		Two-year		Finish (30 months)	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Herd	2	0.002	0.006	890†	4107**	287	963	367	2024
Age of dam	2	0.003	0.011	49	488	42	2339	968	3243
Treatment	1	0.030**	0.007	35	514	2031	36	5733*	1690
Dam autumn weight	1	0.003	0,005	453	230	2104	83	1600	1301
Calf birth weight	1	0.000	0.001	609	3641*	161	652	790	3618
Milk consumption at 25 d age	1	0.013	0.000	981†	789	62	4098†	1054	1935
Residual: Year 1	31	0.004	0.007	279	597	963	1325	1178	1926
Year 2	28								

** P <0.01

* P <0.05

† P <0.10

was an important source of variation ($P<0.05$). This may be explained by carry-over effects from the influence on pre-weaning growth traits reported in Table 4.1. Regression on milk consumption approached significance for yearling weight in year 1 and 2-year weight in year 2 ($P<0.10$). This may again be explained by carry-over effects from its influence on pre-weaning growth characteristics.

4.1.2 Carcass and Meat Traits

Post-slaughter characteristics were analysed with the adoption of sub-models (3) and (4). Results from analyses in which the former sub-model was adopted indicated the importance of maturity and slaughter lot in accounting for variability in these data adjusted for carcass weight, pre-, and post-weaning ADG. When sub-model (4) was fitted, the results indicated the effect of pre-slaughter fasting on data adjusted for carcass weight only.

4.1.2.1 The Influence of Maturity and Slaughter Lot

Analyses of carcass measurements using sub-model (3) resulted in several observations which are summarized in Table 4.3.

Results presented in Table 4.3 suggest that maturity influenced only one carcass measurement, namely, eye muscle depth, in year 2 ($P<0.05$). Tooth eruption information collected in this study and used as an indication of maturity, may have not been a satisfactory criterion in view of reports by Andrews (1973, 1975a, b) on the variability of dentition in cattle. Variation in the ages of the steers used in both years of the present study were apparently not wide enough to show large differences in maturity in carcass measurements.

TABLE 4.3: ANALYSES OF CARCASS MEASUREMENTS. MEAN SQUARES USED IN TESTING FOR SIGNIFICANCE ARE SHOWN WITHIN YEAR (ALONG WITH LEVELS OF SIGNIFICANCE, WHERE APPLICABLE).

Source of variation	d.f.	Eye muscle width		Eye muscle depth		Fat depth		Eye muscle area[1]
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 2
Maturity	1	1.8	4.0	0.2	3.2*	10.0	7.0	0.83
Slaughter lot	1	971.6***	56.7	0.2	24.5	6.5	16.2	0.22
Carcass weight	1	30.8	51.4	45.3	105.2*	1.3	46.5*	7.52***
Post-weaning ADG	1	0.7	13.2	8.5	15.4	3.8	0.2	2.41†
Pre-weaning ADG	1	12.8	131.5†	1.6	99.6*	7.0	4.3	0.32
Residual: Year 1 Year 2	37 48	50.0	41.2	17.4	21.9	4.9	6.9	0.63

*** P <0.001

** P <0.01

* P <0.05

† P <0.10

[1] Eye muscle area was not recorded in year 1.

These results support the view held by Andrews (1975b) on the limitations of use of dentition in assessing age and maturity. Tooth eruption is better left to livestock judges and carcass graders as a rough indication of age, maturity, or stage of development when the need arises to resolve controversies on these matters among show animals or their carcasses at slaughter.

Slaughter lot was an important source of variation in eye muscle width in year 1 ($P<0.05$). It is recognized that differences in details of procedure in handling carcasses and taking linear measurements may lead to variation in these carcass traits between lots. However, differences reflected in the analyses in Table 4.3 do not suggest this to be the case. It would appear that the procedures between lots were identical (for practical purposes) as was intended.

Tests of significance of regression of carcass measurements on carcass weight gave inconsistent results between years. Analyses of year 2 data suggested that it was significant ($P<0.001$), but such an influence was not revealed from year 1 data. The difference between years cannot be explained.

Regression on pre- and post-weaning ADG were not as important as that on carcass weight. Pre-weaning ADG had some relationship with eye muscle depth ($P<0.05$), while it only approached significance in the case of eye muscle width in year 2 ($P<0.10$). Post-weaning ADG approached significance with eye muscle area in year 2 ($P<0.10$) and was otherwise an unimportant covariate.

TABLE 4.4: ANALYSES OF SOME CARCASS COMPOSITION CHARACTERISTICS. MEAN SQUARES USED IN TESTING FOR SIGNIFICANCE ARE SHOWN WITHIN YEAR (ALONG WITH LEVELS OF SIGNIFICANCE, WHERE APPLICABLE).

Source of variation	d.f.	Kidney and channel fat weight		Dressing-out %		Fat trim %	Bone %	Lean %
		Year 1	Year 2	Year 1	Year 2	Year 2	Year 2	Year 2
Maturity	1	0.02	0.55	0.8	3.7	0.2	2.8	2.2
Slaughter lot	1	1.60	1.39	30.9**	14.9*	10.0†	6.9*	35.6***
Carcass weight	1	8.61†	14.35***	17.9*	49.9***	40.0***	23.4***	2.0
Post-weaning ADG	1	0.05	0.09	0.6	6.6†	9.4†	3.3†	1.3
Pre-weaning ADG	1	0.26	2.02	6.2	13.5*	8.2†	7.2*	0.0
Residual: Year 1	37	2.27	0.96	4.0	2.2	2.7	1.1	1.9
Year 2	48							

*** P <0.001

** P <0.01

* P <0.05

† P <0.10

[1] Fat trim, bone, and lean percentages were not recorded in year 1.

Table 4.4 summarizes results from the analyses of carcass composition characteristics classified as described by sub-model (3).

Maturity was not an important source of variation in carcass composition characteristics. Slaughter lot had an appreciable influence on dressing-out percentage in both years of study ($P<0.01$ and $P<0.05$). Lean, and bone percentages recorded in year 2 were also significantly different between lots ($P<0.05$ and $P<0.001$), while the effect of slaughter lot on fat trim percentage was significant ($P<0.10$).

Regression of carcass composition characteristics on carcass weight was significant, while pre- and post-weaning ADG were relatively unimportant as covariates. Exceptions worth emphasizing were the regression of lean percentage in year 2 and kidney and channel fat in year 1 on carcass weight ($P>0.10$ and $P<0.10$, respectively). Regressions of dressing-out, and bone percentages on pre-weaning ADG from year 2 data were significant ($P<0.05$) and that of fat trim percentage on pre-weaning ADG approached significance ($P<0.10$). Post-weaning ADG, as a covariate, was a rather important source of variation in dressing-out, fat trim, and bone percentages ($P<0.10$). Kidney and channel fat was not influenced by pre- or post-weaning ADG.

In Table 4.5 are summarized the analyses of variance for meat characteristics using sub-model (3). Results derived from meat included the samples stored at around freezing point (0^{o} to $4^{o}C$), and where relevant, cooked at $70^{o}C$ for 90 minutes.

TABLE 4.5: ANALYSES OF MEAT CHARACTERISTICS. MEAN SQUARES USED IN TESTING FOR SIGNIFICANCE ARE SHOWN WITHIN YEAR (ALONG WITH LEVELS OF SIGNIFICANCE[1] WHERE APPLICABLE).

Source of variation	d.f.	Sarcomere length		Intra-muscular fat %		Tenderness		Muscle pH		Muscle colour	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Maturity	1	0.000	0.003	1.72	0.75	24.13	1.07	0.00	0.00	3.24	3.08
Slaughter lot	1	0.000	0.011	1.43	3.05	0.01	87.90**	0.04	0.07**	16.52	4.41
Carcass weight	1	0.000	0.347**	0.63	15.14**	0.28	44.77†	0.08	0.01	1.52	2.27
Post-weaning ADG	1	0.006	0.111	0.60	4.08	7.55	8.37	0.05	0.02	0.04	0.25
Pre-weaning ADG	1	0.018	0.002	4.76	6.66*	13.12	20.59	0.01	0.00	4.10	1.28
Residual: Year 1 / Year 2	37 / 48	0.011	0.047	1.81	1.51	13.62	11.69	0.04	0.01	8.13	5.02

** P <0.01

* P <0.05

† P <0.10

[1] Sarcomere length, meat tenderness, muscle pH, and colour were measured on meat refrigerated (between $0^{o}C$ and $4^{o}C$) for about 1 week (10 days in year 1 and 6 days in year 2). Unless indicated otherwise, all results reported on these characteristics are based on measurements obtained under these conditions.

Maturity did not influence any of the meat traits presented in Table 4.5. Slaughter lot was a significant source of variation in Warner-Bratzler shear values (tenderness) and muscle pH in year 2 ($P<0.01$). These differences are difficult to explain because conditions were not varied between slaughter lots and the recording personnel were the same each year.

Carcass weight influenced sarcomere length, intra-muscular fat percentage, and tenderness ($P<0.01$, $P<0.10$ and $P<0.10$, respectively) in year 2 data, but it was unimportant in year 1. The cause of the differences between years is not known. Muscle pH and colour were not influenced by any of the covariates. Regressions of all meat characteristics (except intra-muscular fat percentage) on pre-weaning ADG were significant ($P<0.05$).

4.1.2.2 <u>The Influence of Pre-slaughter Fasting</u>

Analyses of all post-slaughter traits were repeated with data classified by the description in sub-model (4). This sub-model was explained in Chapter 3, and the main aim was to determine whether pre-slaughter fasting was responsible for variation in the traits analysed.

Table 4.6 summarizes the results obtained in the analyses of carcass measurements.

Results in Table 4.6 show inconsistent trends of the influence of fasting. Data from year 2 suggest that fasting affected eye muscle width and area ($P<0.05$ and $P<0.10$), but it was otherwise unimportant.

TABLE 4.6: ANALYSES OF CARCASS MEASUREMENTS FOR INFLUENCE OF PRE-SLAUGHTER FASTING. MEAN SQUARES USED IN TESTING FOR SIGNIFICANCE ARE SHOWN WITHIN YEAR (ALONG WITH LEVELS OF SIGNIFICANCE, WHERE APPLICABLE).

Source of variation	d.f.	Eye muscle width		Eye muscle depth		Fat depth		Eye muscle area[1]
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 2
Fasting	1	16.08	245.86*	6.73	14.71	0.70	0.03	2.18†
Carcass weight	1	288.96†	76.29	47.60	176.61*	5.70	103.56***	7.37**
Residual: Year 1	37	74.73	42.75	16.49	27.83	5.53	7.02	0.68
Year 2	34							

*** P <0.001

** P <0.01

* P <0.05

† P <0.10

[1] Eye muscle area was not recorded in year 1.

The influence of carcass weight as a covariate was also inconsistent between years. Regression on carcass weight was significant for fat depth ($P<0.001$), eye muscle depth ($P<0.05$), and area ($P<0.01$). Year 1 data analyses revealed a possible influence of carcass weight on eye muscle width only ($P<0.10$).

Analyses of carcass composition data using sub-model (4) gave the results summarized in Table 4.7.

Dressing-out percentage was influenced by pre-slaughter fasting in year 1 ($P<0.001$), but such an influence was not found in year 2 data. No other composition-related trait was affected by fasting. The influence revealed on dressing-out percentage may have arisen from the effect of fasting on pre-slaughter weight upon which calculation of dressing-out percentage was based. This would be expected from the information reviewed by Hughes (1976). The contradictory results between years is difficult to explain since, if fasting was to have influenced any factor, it would have been expected in year 2 rather than year 1 in view of the wider difference between fasting periods in that year compared to those in year 1.

Regressions of carcass composition traits on carcass weight were significant except that of lean percentage in year 2. This was in close agreement with the results presented in Table 4.4. Carcass weight has a high predictive value of composition, but the results suggested that it was a poor predictor of lean percentage. The connection between carcass weight and composition traits is mainly explained by part:whole relationships.

TABLE 4.7: ANALYSES OF SOME CARCASS COMPOSITION[1] CHARACTERISTICS THAT MAY HAVE BEEN INFLUENCED BY PRE-SLAUGHTER FASTING. MEAN SQUARES USED IN TESTING FOR SIGNIFICANCE ARE SHOWN WITHIN YEAR (ALONG WITH LEVELS OF SIGNIFICANCE, WHERE APPLICABLE).

		Kidney and channel fat weight		Dressing-out %		Fat trim %	Bone %	Lean %
Source of variation	d.f.	Year 1	Year 2	Year 1	Year 2	Year 2	Year 2	Year 2
Fasting	1	0.02	0.91	53.3***	7.4	2.62	2.86	0.005
Carcass weight	1	20.18**	15.77***	71.1***	25.3**	31.74**	19.32***	1.518
Residual: Year 1 Year 2	37 34	2.24	1.14	3.4	2.8	3.11	1.33	2.991

*** P <0.001

** P <0.01

[1] The right side of the carcass was trimmed and boned-out in year 2.

TABLE 4.8: ANALYSES OF MEAT CHARACTERISTICS[1] FOR INFLUENCE OF PRE-SLAUGHTER FASTING.

Source of variation	d.f.	Intra-muscular fat %		Sarcomere length		Meat tenderness		Muscle pH		Muscle colour	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Fasting	1	0.835	0.412	0.017	0.321**	0.217	58.44*	0.001	0.015	5.55	0.081
Carcass weight	1	0.468	7.295†	0.012	0.264*	1.468	19.12	0.085	0.003	3.47	1.182
Residual: Year 1 Year 2	37 34	2.038	1.974	0.011	0.038	14.040	12.92	0.039	0.009	8.03	3.801

** P <0.01

* P <0.05

† P <0.10

[1] Sarcomere length, tenderness, muscle pH, and colour were recorded on meat refrigerated as explained in the footnote to Table 4.5 (q.v.).

Analyses of meat characteristics using sub-model (4) are presented in Table 4.8.

Fasting was an important source of variation in sarcomere length and tenderness in year 2 ($P<0.01$ and $P<0.05$). It would have been of interest to determine whether the mean values were increased or decreased by prolonged fasting but this was outside the scope of this study. It seems appropriate to speculate that prolonged fasting may have led to a shrinking effect on the muscle fibres, resulting in shorter sarcomeres and consequent toughening and so higher Warner-Bratzler shear values.

4.2 Relationships Between Characteristics Studied

Simple correlation coefficients generated from residual mean squares obtained by fitting sub-model (5) to all data are summarized in this section. All the correlation coefficients have been rounded to 2 significant figures.

4.2.1 Growth Characteristics

Table 4.9 is a summary of correlation coefficients from year 1 and year 2 data.

It was noteworthy that the correlation coefficients in Table 4.9 were different between years and that these differences did not suggest a consistent trend. With few exceptions only the correlation coefficients were medium to high and significant. They were comparable in sign and magnitude to those reported by other workers with pasture-raised animals (Brumby et al., 1963; Carter, 1971; and Trail et al.,

TABLE 4.9: SUMMARY[1] OF CORRELATION COEFFICIENTS[2] BETWEEN SOME GROWTH CHARACTERISTICS[3].

	1	2	3	4	5	6	7
1. Birth weight	\	0.40	0.31	0.14	0.20	0.22	0.04
2. Weaning weight	0.63	\	0.72	0.53	0.34	1.00	-0.08
3. Yearling weight	0.48	0.62	\	0.66	0.40	0.68	0.12
4. Two-year weight	0.34	0.47	0.74	\	0.85	0.55	0.67
5. Finish weight	0.37	0.38	0.56	0.81	\	0.45	0.95
6. Pre-weaning ADG	0.45	1.00	0.58	0.38	0.32	\	0.08
7. Post-weaning ADG	0.14	0.00	0.35	0.15	0.83	-0.04	\

[1] Figures above the diagonal are correlation coefficients for year 1 and those below the diagonal are for year 2 (34 and 45 degrees of freedom, respectively).

[2] Correlation coefficients higher than |0.34| and |0.29| are significantly different from zero ($P<0.05$), for those above or below the diagonal, respectively.

[3] Numbers in the column headings represent the respective characteristics appearing with their numbers in the left-hand column.

A correlation coefficient of -0.0017 between variables 2 and 7 in year 2 was rounded to zero.

1971b), and generally in agreement with other reported estimates from American studies (see summaries in Chapter 2).

As was explained in Chapter 2, it was noted that differences in management conditions influence levels and sometimes direction of correlation coefficients. For this reason direct comparisons of the results of the present study with American studies was avoided because the latter were mostly obtained from feedlot cattle. They will be viewed only as supporting information for purposes of this discussion.

It was observed that the correlation between birth weight and other growth traits was generally low and in some cases non-significant in year 1. The particularly low estimates of the correlation between birth weight and post-weaning ADG were comparable with those reported by Carter (1971) under New Zealand conditions, between birth weight and ADG from weaning to yearling and weaning to slaughter at 20 months (cf $r = 0.08$ and $r = 0.12$, respectively). These results, together with information reviewed in Chapter 2 from American work, suggest that there is little or no relationship between birth weight and post-weaning ADG.

The present study found that weaning weight was lowly correlated with post-weaning ADG. Carter (1971) reported similar results. A negative estimate was obtained for the correlation between weaning weight and post-weaning ADG from year 2 data.

Another notable aspect of Table 4.9 was the suggestion of a perfect positive correlation coefficient between pre-weaning ADG and weaning weight in both years of the study. Possible existence of such a high correlation may be explained by the influence of part:whole relationships between the two traits. Results from American studies reviewed in Chapter 2 have invariably shown a near-perfect positive genetic and phenotypic correlation between these two traits. The correlation estimates in the present analyses were comparable with the estimate of Carter (1971), who reported a phenotypic correlation of 0.98. Unadjusted data presented here showed exactly the same level of correlation (r = 0.98, see Appendix C) as that of Carter (1971).

Estimated correlation coefficients between weaning weight and later weights were comparable with those obtained in similar studies elsewhere (Brumby et al., 1963; Carter, 1971; Trail et al., 1971b). Figures obtained in the present work tended to be slightly lower in some cases. These observations, however, were not in conflict with those from work carried out with cattle under feedlot conditions. The latter have tended to be much higher in some cases (see, for example, Brown et al., 1972a).

4.2.2 Growth and Post-slaughter Traits

A summary of estimates of phenotypic correlation coefficients between growth and carcass traits was presented in Table 4.10.

The levels of correlation between growth and post-slaughter traits appeared to be low in many cases. Birth weight was not appreciably related with any of the carcass traits considered (P>0.05). The only association that may be of some practical value was with carcass weight which approached significance. The same general

TABLE 4.10: SUMMARY OF CORRELATION COEFFICIENTS[1] BETWEEN SOME GROWTH AND CARCASS CHARACTERISTICS

	Kidney and channel fat		Carcass weight		Dressing-out %		Eye muscle width		Eye muscle depth		Fat depth		Eye muscle area	Fat trim %	Bone %	Lean %
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 2	Year 2	Year 2	Year 2
Birth weight	-0.13	-0.08	0.21	0.28	-0.06	-0.26	0.07	0.10	-0.19	-0.04	0.05	0.00	0.10	-0.11	0.05	0.07
Weaning weight	0.02	0.10	0.29	0.41	0.00	-0.08	0.12	0.35	0.01	-0.08	-0.27	0.13	0.21	0.09	-0.07	-0.08
Yearling weight	0.19	0.14	0.37	0.57	0.04	0.07	0.20	0.37	-0.04	0.10	-0.11	-0.03	0.36	0.07	-0.18	0.05
Two-year weight	0.39	0.50	0.80	0.85	0.25	0.30	0.30	0.22	0.16	0.20	0.03	0.20	0.34	0.27	-0.45	0.02
Finish weight	0.33	0.58	0.92	0.92	0.34	0.38	0.32	0.19	0.21	0.22	0.10	0.52	0.33	0.45	-0.53	-0.11
Pre-weaning ADG	0.04	0.13	0.25	0.39	0.02	-0.03	0.11	0.38	0.05	-0.07	-0.30	0.14	0.21	0.13	-0.09	-0.10
Post-weaning ADG	0.34	0.58	0.86	0.80	0.36	0.45	0.29	0.06	0.21	0.27	0.23	0.51	0.27	0.45	-0.54	-0.09

[1] Correlation coefficients higher than $|0.34|$ and $|0.29|$ (year 1 and year 2 data, respectively) are different from zero ($P < 0.05$).

observation was made with weaning weight where the correlation with carcass weight, and that with eye muscle width were more important ($P<0.05$) in year 2.

It was noted that the relationships of carcass weight with weight for age were progressively stronger with weights recorded closer to slaughter. Yearling weight, 2-year weight, and finish weight were all significantly correlated with carcass weight. The trend of stronger correlation coefficients with weights closer to slaughter may be explained by the fact that part:whole relationships follow the same trend. Such association would be expected to have very little influence in the case of the correlation with birth weight and its maximum influence would be on the correlation estimated between immediate pre-slaughter weight and carcass weight.

Estimates of the correlation coefficient between yearling weight and carcass traits (other than weight) were low and unimportant except that with eye muscle width and area from year 2 data ($P<0.05$). These results should be interpreted with care in view of a general lack of supporting information from similar studies on grazing animals. Two-year weight was appreciably associated with kidney and channel fat, eye muscle area, and bone percentage. Correlation with the last-named trait was negative.

The significant positive correlation coefficient estimates of finish weight with kidney and channel fat, and dressing-out percentage in both years of study were noteworthy. Fat depth, eye muscle area, and fat trim percentage all had significant positive correlation coefficients with finish weight in year 2. The same data suggested a negative correlation between finish weight and bone percentage ($P<0.05$).

The correlation coefficients estimated for pre-, and post-weaning ADG with carcass characteristics were different between years. Higher estimates were obtained between post-weaning ADG and the weight-related carcass traits, as well as carcass composition traits. The estimated correlation coefficients of pre-weaning ADG with carcass traits was generally low, and, where significance was attained, it was inconsistent between years.

It was noted that none of the growth traits included in this study was appreciably correlated with lean percentage. The results suggested that there was little, if any, relationship. In the absence of results from comparable studies it is reasonable to assume that such relationships would be tenuous.

Estimated phenotypic correlation coefficients between growth and meat traits are given in the summary in Table 4.11.

No strong associations were revealed between growth and meat traits in these analyses. Birth weight showed some negative correlation with muscle pH ($P<0.05$, in year 1), but was not related to other meat traits. Weaning, yearling, and 2-year weights were weakly associated with meat traits. None of them was significantly correlated to any meat characteristic.

TABLE 4.11: SUMMARY OF CORRELATION COEFFICIENTS[1] BETWEEN SOME GROWTH AND MEAT CHARACTERISTICS

	Intra-muscular fat %		Sarcomere length		Meat tenderness		Muscle pH		Muscle colour	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Birth weight	0.14	0.16	-0.14	-0.18	0.29	0.15	-0.40	-0.28	0.09	-0.19
Weaning weight	0.24	0.03	-0.23	0.19	0.17	0.04	-0.21	-0.06	-0.21	-0.06
Yearling weight	0.20	0.18	-0.10	0.20	-0.03	-0.09	-0.30	-0.14	-0.08	0.01
Two-year weight	0.11	0.28	0.00	0.28	-0.10	-0.15	-0.17	-0.13	-0.18	0.18
Finish weight	-0.03	0.36	0.13	0.33	-0.12	-0.46	-0.19	-0.23	-0.05	0.19
Pre-weaning ADG	0.23	-0.01	-0.22	0.25	0.12	0.01	-0.15	-0.03	-0.24	-0.02
Post-weaning ADG	-0.13	0.38	0.27	0.27	-0.21	-0.27	-0.11	-0.17	0.04	0.23

[1] Correlation coefficients higher than |0.34| and |0.29| (for year 1 and year 2 data, respectively) are significantly different from zero (P<0.05).

[2] An estimate of -0.002 between two-year weight and sarcomere length for year 1 was rounded to zero.

Pre-weaning ADG was only marginally associated with meat characteristics. The estimates of correlation coefficients reflecting this were too low to be of any practical importance. Post-weaning ADG, on the other hand, had slightly higher estimated correlation coefficients, but only that with intra-muscular fat percentage recorded in year 2 was significant.

Finish weight was more strongly associated with meat characteristics. This was particularly so in year 2 data from which the estimated correlation coefficients with intra-muscular fat percentage, sarcomere length, and meat tenderness were notably higher and significant. Differences in the level and direction of the correlation estimates may partly be explained by differences in age and chemical maturity at slaughter. The animals slaughtered in year 2 were slightly older than those slaughtered in year 1.

A literature search revealed a paucity of information on relationships between growth and meat traits compared to the volume of results published on the other traits and their relationships considered in the present study. There were no investigations carried out under comparable conditions to provide a basis for discussing the estimates presented here. These estimates suggest strongly that relationships are tenuous, if they in fact, exist.

4.2.3 Carcass and Meat Traits

Post-slaughter characteristics were more strongly correlated among themselves than they were with growth traits. For purposes of this report the association estimated between carcass and meat traits was summarized into three tables for carcass, carcass and meat, and meat traits separately.

A summary of the estimates of phenotypic correlation between carcass traits are presented in Table 4.12.

Correlation coefficients presented in Table 4.12 were generally significant, but inconsistent between years. It was noteworthy, for example, that kidney and channel fat was significantly positively correlated with carcass weight, but the level of the correlation co-efficient was different between year 1 and year 2 (cf $r = 0.39$ and $r = 0.62$, respectively).

Carcass weight was the only trait appreciably associated with kidney and channel fat in year 1. Several carcass characteristics were significantly correlated to kidney and channel fat in year 2, namely, dressing-out percentage, fat depth, fat trim percentage, bone percentage, and lean percentage. The last two were negatively correlated to kidney and channel fat. Linear measurements on the eye muscle were weakly correlated with kidney and channel fat.

Carcass weight had a strong association with most other carcass attributes. The correlation coefficient estimates of carcass weight with eye muscle depth and fat depth were not significant in year 1. The positive relationship between carcass weight and all fatness traits from year 2 data was high and significant.

TABLE 4.12: SUMMARY OF CORRELATION COEFFICIENTS[1] BETWEEN SOME CARCASS TRAITS[2].

	1	2	3	4	5	6	7	8	9
1. Kidney and channel fat	\	0.39	0.09	-0.13	0.05	0.24	--	--	--
2. Carcass weight	0.62	\	0.46	0.34	0.29	0.12	--	--	--
3. Dressing-out %	0.57	0.51	\	0.32	0.26	0.15	--	--	--
4. Eye muscle width	0.02	0.26	0.10	\	0.12	-0.41	--	--	--
5. Eye muscle depth	0.27	0.33	0.25	-0.15	\	-0.04	--	--	--
6. Fat depth	0.55	0.53	0.53	-0.08	0.20	\	--	--	--
7. Eye muscle area	0.26	0.49	0.32	0.37	0.69	0.24	\	--	--
8 Fat trim %	0.68	0.53	0.38	0.10	0.25	0.61	0.32	\	--
9. Bone %	-0.50	-0.64	-0.61	-0.20	-0.32	-0.47	-0.42	-0.61	\
10. Lean %	-0.42	-0.11	0.08	0.05	-0.03	-0.36	-0.02	-0.71	-0.12

[1] Year 1 and year 2 (above and below the diagonal) correlation coefficients higher than |0.34| and |0.29| are different from zero ($P < 0.05$).

[2] Traits numbered 7, 8, 9 and 10 were not obtained in year 1.

Lean percentage was negatively correlated with fatness traits ($P<0.05$), namely, with kidney and channel fat, fat depth, and fat trim percentage. The relationship between lean percentage and other carcass traits was low and non-significant. Bone percentage was negatively correlated with all other carcass traits. The estimates of correlation coefficients with bone percentage were high and significant except that with eye muscle width.

In general, the correlation coefficients between carcass characteristics were within the levels reported by other workers. However, direct comparisons were avoided for two basic reasons. First, the data of other workers were from animals managed differently, mostly derived from feedlot cattle. Secondly, the results of the present study were inconsistent between years. Furthermore, there is also wide variation in the estimates obtained by other workers.

Relationships between carcass and meat traits were summarized and presented in Table 4.13.

The estimates of correlation in Table 4.13 were inconsistent between years. In general, estimates from year 1 data were lower and non-significant compared to those from year 2 data. With the exception of the correlation coefficient between eye muscle width and muscle pH, estimates from year 1 were weak and relatively unimportant ($P>0.05$).

Kidney and channel fat was significantly correlated with intra-muscular fat, sarcomere length, and muscle colour in year 2. All correlation coefficients between kidney and channel fat and meat

TABLE 4.13: SUMMARY OF CORRELATION COEFFICIENTS[1] BETWEEN SOME CARCASS[2] AND MEAT CHARACTERISTICS.

	Intra-muscular fat %		Sarcomere length		Meat tenderness		Muscle pH		Muscle colour	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Kidney and channel fat	-0.01	0.52	0.11	0.37	-0.22	-0.24	0.05	0.01	0.21	0.33
Carcass weight	-0.03	0.61	0.08	0.43	-0.09	-0.28	-0.24	-0.18	-0.11	0.19
Dressing-out %	-0.23	0.57	0.07	0.38	-0.08	-0.22	-0.08	0.15	-0.17	0.30
Eye muscle width	-0.03	0.02	-0.15	0.11	0.23	-0.04	-0.44	0.06	0.10	0.19
Eye muscle depth	0.12	0.27	-0.16	0.18	-0.04	-0.18	-0.004	-0.31	-0.15	0.21
Fat depth	0.12	0.55	0.25	0.37	-0.27	-0.23	0.03	0.01	0.28	0.07
Eye muscle area	--	0.26	--	0.36	--	-0.30	--	-0.08	--	0.08
Fat trim %	--	0.68	--	0.40	--	-0.46	--	-0.11	--	0.14
Bone %	--	-0.50	--	-0.38	--	0.22	--	0.12	--	-0.23
Lean %	--	-0.42	--	-0.18	--	0.38	--	0.04	--	0.03

[1] Correlation coefficients higher than $|0.34|$ and $|0.29|$ (for year 1 and year 2, respectively) are different from zero ($P < 0.05$).

[2] Eye muscle area, fat trim %, bone %, and lean % were not obtained in year 1.

traits from year 1 data were low and non-significant. The differences in the estimates between years are quite remarkable in some cases. For example, the association of kidney and channel fat with intra-muscular fat was weak and negative (r = -0.01) when estimated from year 1 data, but it was high and positive when determined from year 2 data (r = 0.52).

The correlation coefficients of carcass traits with muscle pH and colour were weak. Besides those mentioned earlier, only the correlations of dressing-out percentage with muscle colour, and eye muscle depth with muscle pH from year 2 data were significant. It was tempting to view these relationships as arising from chance. In fact, owing to the paucity of information on such associations it was felt that it would be unjustifiable to speculate any further.

Dressing-out percentage was appreciably correlated to intra-muscular fat, sarcomere length, and muscle colour as revealed in the year 2 data. Carcass linear measurements had weak associations with meat traits, but eye muscle area was significantly positively correlated to sarcomere length and meat tenderness. Fat trim percentage had a significant positive correlation with intra-muscular fat, sarcomere length, and meat tenderness. Bone percentage was negatively correlated to intra-muscular fat and sarcomere length. Lean percentage had a negative correlation with intra-muscular fat and meat tenderness ($P<0.05$; r = 0.38 with Warner-Bratzler shear value in the assessment of the latter).

The results generally suggested that the commonly-recorded carcass characteristics such as carcass weight, dressing-out percentage, eye muscle area, fat trim percentage, bone percentage, and lean percentage bore some association with a number of meat traits. These relationships were inconsistent between years, making it difficult to generalize on the observations especially in the absence of supporting published work conducted under comparable conditions.

The summary in Table 4.14 was constructed from estimates of correlation coefficients between meat traits obtained from analyses of year 1 and year 2 data.

Estimates of correlation between meat traits varied widely, but were more consistent in the two years of study than those between carcass and meat traits. Intra-muscular fat and sarcomere length were positively correlated with meat tenderness. The positive correlation coefficient estimated, from year 2 data, between intra-muscular fat and sarcomere length was significant while that from year 1 data was not. Results from year 1 data revealed a positive correlation between sarcomere length and muscle colour, but year 2 data analyses suggested a weak, non-significant association between the same traits.

Meat tenderness was positively correlated to muscle pH as revealed by results from year 1 data, but such an association was not found in year 2 data. All other correlation coefficients between meat traits, other than those covered earlier, were low and unimportant.

TABLE 4.14: SUMMARY OF CORRELATION COEFFICIENTS[1] BETWEEN SOME MEAT CHARACTERISTICS.

	1	2	3	4	5
1. Intra-muscular fat %	\	0.26	-0.41	0.11	-0.08
2. Sarcomere length	0.34	\	-0.60	0.25	0.37
3. Meat tenderness	-0.39	-0.66	\	-0.47	0.07
4. Muscle pH	-0.27	0.09	-0.07	\	-0.24
5. Muscle colour	0.20	0.17	-0.15	-0.17	\

[1] Year 1 and year 2 (above and below the diagonal) correlation coefficients higher than $|0.34|$ and $|0.29|$ respectively, are different from zero ($P<0.05$).

CHAPTER FIVE

CONCLUSIONS

It is difficult to draw conclusions from the results presented in Chapter 4 because they were inconsistent and, in some cases, contradictory between years. Whatever inferences are drawn should be regarded as no more than tentative due to the inconsistency among the results between years and lack of supporting information in the literature. This is particularly the case when considering relationships between a number of traits.

5.1 Factors Influencing the Traits Studied

5.1.1 Growth Traits

Conclusions made from the analyses of growth data were based on results which were not fully explainable by known phenomena connected with the management of the experimental animals. Grouping of the cows and their calves into one of three herds was concluded to be an important source of variation in steer performance to the yearling stage. Birth weight and milk consumption were important in their influence on pre-weaning growth. It was further concluded that dam age and weight, and calving management on a sawdust pad did not influence steer performance. Therefore, data would have required correcting for herd effects, birth weight, and calf milk consumption, if valid comparisons were to have been made between the experimental steers.

5.1.2 Carcass and Meat Characteristics

Some carcass and meat traits were influenced by differences in slaughter lot and fasting, but most variation in these traits was attributed to differences in carcass weight. Although the results were inconsistent between years it was concluded that work carried out under conditions similar to those reported here should include adjustments for slaughter lot and carcass weight. The other factors were concluded to be unimportant.

One conclusion that was of particular importance was the influence of pre-slaughter fasting on various carcass and meat traits. It seemed appropriate to conclude that a 4-day fasting period did not influence the characteristics studied. In view of the results of published work on the adequacy of a short period of fasting, it was concluded from the present results that fasting for longer than one day was unnecessary. This is in line with traditional practice.

5.2 Relationships Between Traits

Relationships between the traits were generally within the range of those reported by other workers. The literature, however, reflected a general lack of information regarding relationships between growth and meat traits, especially in the grazing situation. This made it difficult to draw general conclusions.

5.2.1 Growth and Post-slaughter Traits

There was a strong indication that growth characteristics, notably weight for age, were strongly correlated among themselves. Information in the literature supported this observation. There was enough evidence to conclude that selection for liveweight, at any age, would lead to a positive response in weight at other ages.

The relationship of birth weight with weight at other growth stages, except weaning, was low and non-significant in year 1. In view of the support of such a trend in the literature it was concluded that birth weight may be lowly correlated to weight recorded later in life and that this study showed that the relationship with weaning weight was strong enough to warrant further investigation. This is important because of its practical implications.

An apparently spurious positive correlation between pre-weaning ADG and weaning weight fell within acceptable limits of rounding error, namely r = 1.0. This perfect correlation was viewed suspiciously. Estimates in the literature for this relationship were also positive and nearly perfect in many cases. It was, therefore, concluded that pre-weaning ADG had a strong (theoretically only near-perfect) positive correlation with weaning weight. Since pre-weaning ADG and weaning weight are generally regarded as maternal characteristics, mainly controlled by environmental factors, information available would indicate that this relationship may have originated largely from environmental sources rather than from a maternal influence.

The estimated relationships between growth and carcass traits reported here, were judged to be mostly low and unimportant. Except for the correlation coefficients of growth characteristics with carcass weight levels of relationship were inconsistent between years, making it difficult to draw general inferences. It was concluded that relationships between growth and carcass weight were high enough to be of practical importance. Published work indicating a strong association between growth and carcass traits not connected with size are not supported by the results of the present work.

The paucity of information on relationships between growth and meat traits was noted. There was no evidence to suggest antagonism between growth and meat traits. On the other hand, there did not appear to be strong enough relationships to suggest a conclusion to the contrary. Because of this it must be concluded that if selection were to have been based solely on one, or more of the growth traits investigated, then no dramatic associated responses would have been reflected in the meat traits. Any such response would be small and of little consequence for practical purposes.

5.2.2 Carcass and Meat Traits

It was concluded that there was a strong indication of relationships between carcass traits. While inconsistencies in the results between years complicated the picture in some cases, one general observation worth emphasizing was that carcass weight was correlated with most other traits. The proportion of variation in carcass traits accounted for by variation in carcass weight gives a clearer indication of this (Appendix D).

The inconsistencies in the correlation coefficients estimated between carcass and meat traits were so prominent that it is unreasonable to make any general conclusions. This position is made more difficult by the lack of supporting published information. It is recommended that further work be carried out along similar lines before any conclusions are advanced. Yield attributes of the carcass, for example, lean weight, and fat weight should feature more prominently than their proportions in subsequent work.

Conclusions regarding correlation coefficients between meat traits were also of limited value because of the inconsistencies shown between years. It was concluded that the association of intra-muscular fat percentage and sarcomere length with meat tenderness were strong enough to warrant further investigation aimed partly at documenting the practical implications of such relationships, if indeed they do, in fact, exist.

APPENDIX A: DATA SUMMARIES

It was not possible to include raw data in this report to indicate how variable they were. This would have made any similarities or differences implied in the analyses reported in Chapter 4 easier to comprehend. However, simple means of some of the principal traits have been calculated and are presented here for this purposes. Least squares means could not have been obtained in some of the analyses due to non-orthogonality (including empty sub-classes). This was particularly the case with the growth data.

Appendix A1:

Tables identified as Appendix Tables A1.1 through A1.3 were constructed from liveweight data pooled over both years of the investigation. Empty cells appear in several sub-classes.

APPENDIX TABLE A1.1: SUB-CLASS MEANS (± S.D.) OF WEANING (200-DAY) WEIGHT FROM DATA POOLED OVER BOTH YEARS OF STUDY. SUB-CLASS NUMBERS OF STEERS ARE SHOWN IN PARENTHESES.

Dam age group	Treatment group	Herd Group						Overall age group means
		1	2	3	4	5	6	
1	1	183 ± 17.9 (11)	178 ± 28.9 (6)	190 ± 20.9 (3)	190 ± 19.2 (5)	176 ± 7.6 (4)	161 ± 8.8 (7)	180 ± 19.6 (41)
	2	-	186 (1)	177 ± 12.7 (2)	195 ± 26.9 (2)	-	-	
2	1	210 ± 7.8 (5)	206 ± 22.2 (5)	198 ± 15.2 (7)	196 ± 19.1 (2)	-	-	198 ± 16.0 (48)
	2	203 ± 17.1 (6)	200 ± 11.5 (9)	184 ± 8.5 (5)	192 ± 20.2 (4)	189 ± 18.8 (5)	-	
3	1	-	206 (1)	-	200 ± 4.2 (2)	160 (1)	177 (1)	186 ± 20.7 (28)
	2	197 ± 9.2 (2)	-	-	198 ± 16.1 (8)	183 ± 17.5 (11)	144 ± 1.4 (2)	
Herd Group Overall mean		195 ± 18.7 (24)	195 ± 21.7 (22)	190 ± 15.1 (17)	195 ± 16.4 (23)	182 ± 16.7 (21)	159 ± 11.8 (10)	

Note: Treatment group overall means (omitted from the table to avoid confusion) were:

Treatment group 1: 187 ± 21.5 (60)
Treatment group 2: 190 ± 18.5 (57)

APPENDIX TABLE A1.2: SUB-CLASS MEANS OF YEARLING WEIGHT FROM DATA POOLED OVER BOTH YEARS OF STUDY. SUB-CLASS NUMBERS OF STEERS ARE SHOWN IN PARENTHESES.

Dam age group	Treatment group	Herd Group						Overall age group means
		1	2	3	4	5	6	
1	1	232 ± 17.5 (11)	220 ± 24.9 (6)	237 ± 6.7 (3)	298 ± 23.6 (5)	280 ± 21.0 (4)	265 ± 29.2 (7)	252 ± 36.1 (41)
	2	-	231 (1)	219 ± 14.1 (2)	313 ± 33.2 (2)	-	-	
2	1	256 ± 20.1 (5)	236 ± 23.0 (5)	241 ± 16.4 (7)	307 ± 29.0 (2)	-	-	257 ± 32.0 (48)
	2	258 ± 17.5 (6)	243 ± 20.0 (9)	230 ± 16.0 (5)	299 ± 26.8 (4)	295 ± 37.7 (5)	-	
3	1	-	250 (1)	-	273 ± 55.9 (2)	277 (1)	261 (1)	281 ± 30.8 (28)
	2	249 ± 7.1 (2)	-	-	302 ± 22.8 (8)	286 ± 19.5 (11)	230 ± 48.1 (2)	
Herd group Overall mean		245 ± 20.8 (24)	235 ± 22.4 (22)	234 ± 15.4 (17)	299 ± 26.2 (23)	286 ± 23.9 (21)	258 ± 32.3 (10)	

Note: Treatment group overall means (omitted from the table to avoid confusion) were:

Treatment group 1: 252 ± 31.9 (60)
Treatment group 2: 270 ± 35.8 (57)

APPENDIX TABLE A1.3: SUB-CLASS MEANS OF FINISH (30-MONTH) WEIGHT FROM DATA POOLED OVER BOTH YEARS OF STUDY. SUB-CLASS NUMBERS OF STEERS ARE SHOWN IN PARENTHESES.

Dam age group	Treatment group	Herd Group 1	2	3	4	5	6	Overall age group means
1	1	499 ± 40.5 (11)	483 ± 60.7 (6)	484 ± 65.6 (3)	514 ± 35.6 (5)	521 ± 2.3 (4)	483 ± 44.9 (7)	496 ± 44.7 (41)
	2	-	457 (1)	477 ± 21.2 (2)	537 ± 80.6 (2)	-	-	
2	1	506 ± 39.7 (5)	477 ± 37.3 (5)	487 ± 38.1 (7)	540 ± 0 (2)	-	-	499 ± 40.0 (48)
	2	516 ± 24.6 (6)	507 ± 38.9 (9)	506 ± 22.8 (5)	497 ± 67.1 (4)	474 ± 52.7 (5)	-	
3	1	-	472 (1)	-	483 ± 24.7 (2)	514 (1)	483 (1)	494 ± 40.1 (28)
	2	513 ± 27.6 (2)	-	-	491 ± 26.7 (8)	507 ± 51.8 (11)	438 ± 4.2 (2)	
Herd group Overall mean		506 ± 34.8 (24)	490 ± 44.4 (22)	491 ± 36.8 (17)	504 ± 41.8 (23)	502 ± 46.8 (21)	474 ± 41.3 (10)	

Note: Treatment group overall means (omitted from the table to avoid confusion) were:

Treatment group 1: 495 ± 40.5 (60)
Treatment group 2: 499 ± 42.6 (57)

Appendix A2:

Tables identified as Appendix Tables A2.1 through A2.7 were constructed from post-slaughter data recorded in each year of the study. Year 1 implies that data were recorded in 1978 from steers that were born in 1975. Year 2 includes the data from steers born in 1976 and slaughtered in 1979. Criteria used in classifying the data are those defined in sub-model (3) and sub-model (4) in Chapter 3. Figures in parentheses in the tables show the numbers of steers in the respective sub-classes.

APPENDIX TABLE A2.1: SUB-CLASS MEANS OF CARCASS WEIGHT (KG)

Slaughter lot	Maturity category	Pre-slaughter fasting group				Overall slaughter lot means	
		1		2			
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
1	1	240 ± 26.1 (3)	232 ± 19.6 (9)	228 ± 42.7 (3)	223 ± 31.6 (4)	242 ± 20.9 (23)	243 ± 29.0 (28)
	2	246 ± 16.7 (8)	273 ± 23.8 (4)	244 ± 15.2 (9)	247 ± 29.1 (11)		
2	1	279 ± 7.1 (2)	242 ± 19.0 (3)	270 (1)	229 ± 20.4 (6)	251 ± 22.5 (20)	248 ± 20.7 (26)
	2	255 ± 22.7 (8)	252 ± 19.9 (11)	238 ± 17.7 (9)	252 ± 16.9 (6)		
Overall fasting group means		252 ± 21.4 (21)	248 ± 23.6 (27)	241 ± 21.3 (22)	241 ± 26.6 (27)		

Note:

Maturity category overall means (omitted from the table to avoid confusion) were:

Maturity category 1: 248 ± 33.3 (9) and 231 ± 21.3 (22), for year 1 and year 2

Maturity category 2: 246 ± 18.4 (34) and 253 ± 23.8 (32) for year 1 and year 2, respectively.

APPENDIX TABLE A2.2: SUB-CLASS MEANS OF FAT DEPTH MEASUREMENTS (MM) OVER THE EYE MUSCLE

<table>
<tr><th rowspan="3">Slaughter lot</th><th rowspan="3">Maturity category</th><th colspan="4">Pre-slaughter fasting group</th><th colspan="2" rowspan="2">Overall slaughter lot means</th></tr>
<tr><th colspan="2">1</th><th colspan="2">2</th></tr>
<tr><th>Year 1</th><th>Year 2</th><th>Year 1</th><th>Year 2</th><th>Year 1</th><th>Year 2</th></tr>
<tr><td rowspan="2">1</td><td>1</td><td>9.3 ± 3.1 (3)</td><td>7.1 ± 3.4 (9)</td><td>8.0 ± 1.0 (3)</td><td>4.0 ± 2.7 (4)</td><td rowspan="2">9.3 ± 2.4 (23)</td><td rowspan="2">7.5 ± 3.5 (28)</td></tr>
<tr><td>2</td><td>9.6 ± 2.9 (8)</td><td>10.3 ± 2.6 (4)</td><td>9.4 ± 2.3 (9)</td><td>8.1 ± 3.2 (11)</td></tr>
<tr><td rowspan="2">2</td><td>1</td><td>8.5 ± 2.1 (2)</td><td>4.7 ± 1.5 (3)</td><td>7.0 (1)</td><td>5.7 ± 3.1 (6)</td><td rowspan="2">8.8 ± 2.1 (20)</td><td rowspan="2">6.6 ± 2.7 (26)</td></tr>
<tr><td>2</td><td>9.1 ± 2.5 (8)</td><td>7.4 ± 2.7 (11)</td><td>8.7 ± 2.1 (9)</td><td>7.2 ± 2.2 (6)</td></tr>
<tr><td colspan="2">Overall fasting group means</td><td>9.3 ± 2.5 (21)</td><td>7.5 ± 3.2 (27)</td><td>8.8 ± 2.1 (22)</td><td>6.7 ± 3.1 (27)</td><td></td><td></td></tr>
</table>

Note:

Maturity category overall means (omitted from the table to avoid confusion) were:

Maturity category 1: 8.4 ± 1.9 (9) and 5.8 ± 3.2 (22), for year 1 and year 2

Maturity category 2: 9.2 ± 2.4 (34) and 7.9 ± 2.9 (32), for year 1 and year 2, respectively.

APPENDIX TABLE A2.3: SUB-CLASS MEANS OF EYE MUSCLE AREA (SQ. IN.) RECORDED IN YEAR 2

Slaughter lot	Maturity category	Pre-slaughter fasting group 1	Pre-slaughter fasting group 2	Overall slaughter lot means
1	1	9.5 ± 0.8 (9)	10.2 ± 1.2 (4)	10.4 ± 1.1 (28)
	2	11.1 ± 1.2 (4)	11.0 ± 0.7 (11)	
2	1	9.7 ± 0.5 (3)	10.3 ± 1.0 (6)	10.3 ± 0.9 (26)
	2	10.5 ± 0.7 (11)	10.3 ± 1.1 (6)	
Overall fasting group means		10.1 ± 0.9 (27)	10.6 ± 0.9 (27)	

Note:

Eye muscle area was not recorded in year 1. Overall means by maturity category (omitted from the above table to avoid confusion) were 9.9 ± 0.9 (22) and 10.7 ± 0.9 (32) for categories 1 and 2, respectively.

APPENDIX TABLE A2.4: SUB-CLASS MEANS OF INTRA-MUSCULAR (CHEMICAL) FAT PERCENTAGE

Slaughter lot	Maturity category	Pre-slaughter fasting group				Overall slaughter lot means	
		1		2			
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
1	1	3.9 ± 2.1 (3)	3.7 ± 1.2 (4)	2.7 ± 1.4 (3)	2.3 ± 0.6 (4)	3.8 ± 1.2 (23)	3.7 ± 1.3 (28)
	2	3.9 ± 1.1 (8)	5.0 ± 2.0 (4)	4.1 ± 1.0 (9)	3.8 ± 0.9 (11)		
2	1	4.0 ± 0.5 (2)	4.2 ± 1.5 (3)	3.9 (1)	4.4 ± 1.5 (6)	4.3 ± 1.5 (20)	4.1 ± 1.4 (26)
	2	3.9 ± 1.5 (8)	4.0 ± 1.4 (11)	4.7 ± 1.7 (9)	4.0 ± 1.4 (6)		
Overall fasting group means		3.9 ± 1.3 (21)	4.1 ± 1.4 (27)	4.2 ± 1.4 (22)	3.8 ± 1.3 (27)		

Note:

Maturity category overall means, omitted from the table to avoid confusion, were:

Maturity category 1: 3.5 ± 1.4 (9) and 3.7 ± 1.4 (22), for year 1 and year 2

Maturity category 2: 4.2 ± 1.3 (34) and 4.1 ± 1.3 (32), for year 1 and year 2, respectively.

APPENDIX TABLE A2.5: SUB-CLASS MEANS OF FAT TRIM PERCENTAGE[1] FROM YEAR 2 DATA

Slaughter lot	Maturity category	Pre-slaughter fasting group 1	Pre-slaughter fasting group 2	Overall slaughter lot means
1	1	7.6 ± 2.2 (9)	6.7 ± 1.9 (4)	8.4 ± 2.1 (28)
	2	9.9 ± 1.7 (4)	9.0 ± 1.8 (11)	
2	1	8.2 ± 0.9 (3)	9.3 ± 2.1 (6)	9.2 ± 1.8 (26)
	2	9.1 ± 1.8 (11)	10.0 ± 1.9 (6)	
Overall fasting group means		8.6 ± 1.9 (27)	9.0 ± 2.1 (27)	

Notes:

[1] Fat trimmed from the right side of the carcass was related to the side to obtain percentage by weight.

Maturity category overall means which were omitted from the table to avoid confusion were as follows:

Maturity category 1: 8.0 ± 2.1 (22)

Maturity category 2: 9.3 ± 1.7 (32)

APPENDIX TABLE A2.6: SUB-CLASS MEANS OF LEAN PERCENTAGE[1] FROM YEAR 2 DATA

Slaughter lot	Maturity category	Pre-slaughter fasting group		Overall slaughter lot means
		1	2	
1	1	66.4 ± 1.4 (9)	67.1 ± 0.9 (4)	66.4 ± 1.2 (28)
	2	66.1 ± 0.7 (4)	66.3 ± 1.2 (11)	
2	1	65.4 ± 0.3 (3)	63.8 ± 1.7 (6)	64.8 ± 1.5 (26)
	2	65.0 ± 1.7 (11)	65.2 ± 1.0 (6)	
Overall fasting group means		65.7 ± 1.5 (27)	65.6 ± 1.7 (27)	

Notes:

[1] Lean % was obtained by relating weight of trimmed boneless meat from the right side of the carcass to the side weight

Maturity category overall means which were omitted from the table to avoid confusion were as follows:

Maturity category 1: 65.7 ± 1.8 (27)

Maturity category 2: 65.6 ± 1.3 (32)

APPENDIX TABLE A2.7: SUB-CLASS MEANS OF MEAT TENDERNESS[1,2] (WARNER-BRATZLER SHEAR FORCE IN KG) VALUES

Slaughter lot	Maturity category	Pre-slaughter fasting group 1		Pre-slaughter fasting group 2		Overall slaughter lot means	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
1	1	16.9 ± 3.7 (3)	13.5 ± 4.6 (9)	20.0 ± 0.1 (3)	13.6 ± 5.3 (4)	18.1 ± 3.7 (23)	12.2 ± 4.1 (28)
	2	18.3 ± 2.7 (8)	11.9 ± 4.7 (4)	17.7 ± 5.0 (9)	10.8 ± 3.0 (11)		
2	1	21.0 ± 0.3 (2)	10.9 ± 3.4 (3)	19.9 (1)	9.1 ± 2.9 (6)	17.9 ± 3.7 (20)	9.6 ± 2.8 (26)
	2	17.7 ± 3.2 (8)	10.5 ± 2.6 (11)	17.2 ± 4.4 (9)	8.0 ± 2.4 (6)		
Overall fasting group means		18.1 ± 2.9 (21)	11.8 ± 3.8 (27)	17.9 ± 4.2 (22)	10.2 ± 3.6 (27)		

Notes:

[1] Assessment of tenderness carried out on samples stored under refrigeration temperatures (0°C in year 1 and 2° to 4°C in year 2) before cooking in a constant-temperature water bath at 70°C for 90 min.

[2] Higher values imply that the meat was tougher or "less tender".

Overall means by maturity category were omitted from the above table to avoid confusion. For maturity category 1 they were 19.2 ± 2.5 (9) and 12.0 ± 4.4 (22); and for maturity category 2 they were 17.7 ± 3.8 (34) and 10.3 ± 3.1 (32), for year 1 and year 2, respectively.

APPENDIX B: ANALYSIS OF VARIANCE - AN ILLUSTRATIVE EXAMPLE OF PROCEDURES FOR OBTAINING SUMS OF SQUARES

This example illustrates some of the principal mathematical details of procedures adopted to obtain sums of squares that were partitioned to draw inferences on the influence of factors included in the model. A summary of the details is presented for the preliminary analysis of weaning weight (pooled over the two years of study) carried out using desk facilities. These procedures can be employed in all the situations represented by the sub-models defined in Chapter 3 and may be generalized for data that can be suitably described by a fixed-effects model with interactions and covariates. Equations which appeared in the text as well as in this example have been numbered as in Chapter 3. Matrix notation used in this example follows that of Searle (1971) closely.

1. The Linear Model

Data were described by a general model of the form:

$$\underset{\sim}{y} = \underset{\sim}{X}\underset{\sim}{a} + \underset{\sim}{Z}\underset{\sim}{b} + \underset{\sim}{e}, \quad \ldots (3.3) \text{ (as in Chapter 3)},$$

where

$\underset{\sim}{y}$ is the vector of observations;

$\underset{\sim}{X}$ and $\underset{\sim}{Z}$ are known incidence matrices of order 117 x 23, composed of "dummy variables" (1's and 0's indicating occurrence and non-occurrence of data) and covariate observations, respectively;

$\underset{\sim}{a}$ is a vector of unknown fixed-effects (comprising a general mean, main factor levels and interaction);

$\underset{\sim}{b}$ is a vector of regression coefficients to be estimated;

and $\underset{\sim}{e}$ is a vector of unknown residual error effects, such that

$E(\underset{\sim}{e}) = 0$, $var(e_i) = \sigma^2$, $cov(e_i e_j) = 0$ for $i \neq j$; and, for purposes of testing hypotheses, the elements of $\underset{\sim}{e}$ were further assumed to have a multi-variate normal distribution.

2. Normal (Least Squares) Equations and their Solution

The normal equations corresponding to the model (3.3) were (see Chapter 3) as shown in equations (3.4).

$$\begin{bmatrix} \underset{\sim}{X}'\underset{\sim}{X} & \underset{\sim}{X}'\underset{\sim}{Z} \\ \underset{\sim}{Z}'\underset{\sim}{X} & \underset{\sim}{Z}'\underset{\sim}{Z} \end{bmatrix} \begin{bmatrix} \underset{\sim}{a}^o \\ \hat{\underset{\sim}{b}} \end{bmatrix} = \begin{bmatrix} \underset{\sim}{X}'\underset{\sim}{y} \\ \underset{\sim}{Z}'\underset{\sim}{y} \end{bmatrix}, \quad \ldots \quad (3.4)$$

In terms of the data used in the study the matrices and vectors in the normal equations were obtained as follows:

$\underset{\sim}{X}'\underset{\sim}{X}$ was an 18 x 18 matrix composed of numbers of data by respective sub-classes, as shown below:[1]

μ	117	24	22	17	23	21	10	41	48	28	60	57	36	5	19	29	5	23
α_1	24	24	0	0	0	0	0	11	11	2	16	8	11	0	5	6	0	2
α_2	22	0	22	0	0	0	0	7	14	1	12	10	6	1	5	9	1	0
α_3	17	0	0	17	0	0	0	5	12	0	10	7	3	2	7	5	0	0
α_4	23	0	0	0	23	0	0	7	6	10	9	14	5	2	2	4	2	8
α_5	21	0	0	0	0	21	0	4	5	12	5	16	4	0	0	5	1	11
α_6	10	0	0	0	0	0	10	7	0	3	8	2	7	0	0	0	1	2
β_1	41	11	7	5	7	4	7	41	0	0	36	5	36	5	0	0	0	0
β_2	48	11	14	12	6	5	0	0	48	0	19	29	0	0	19	29	0	0
β_3	28	2	1	0	10	12	3	0	0	28	5	23	0	0	0	0	5	23
θ_1	60	16	12	10	9	5	8	36	19	5	60	0	36	0	19	0	5	0
θ_2	57	8	10	7	14	16	2	5	29	23	0	57	0	5	0	29	0	23
$(\beta\theta)_{11}$	36	11	6	3	5	4	7	36	0	0	36	0	36	0	0	0	0	0
$(\beta\theta)_{12}$	5	0	1	2	2	0	0	5	0	0	0	5	0	5	0	0	0	0
$(\beta\theta)_{21}$	19	5	5	7	2	0	0	0	19	0	19	0	0	0	19	0	0	0
$(\beta\theta)_{22}$	29	6	9	5	4	5	0	0	29	0	0	29	0	0	0	29	0	0
$(\beta\theta)_{31}$	5	0	1	0	2	1	1	0	0	5	5	0	0	0	0	0	5	0
$(\beta\theta)_{32}$	23	2	0	0	8	11	2	0	0	23	0	23	0	0	0	0	0	23

Elements in vector $\underset{\sim}{a}$ were the general mean, (μ), 6 herd groups (α_i), 3 age of dam groups (β_j), 2 peri-natal treatments (θ_k), and 6 elements for age-of-dam x treatment interaction, $(\beta\theta)_{jk}$.

[1] Note that there is linear dependence between rows (and between columns) of $\underset{\sim}{X}'\underset{\sim}{X}$. For example, elements of rows 2 to 7 add up to those of row 1 in any column. The matrix is symmetrical.

$X'Z$ was an 18 x 5 matrix composed of totals of covariate data, corresponding to the vector a elements and 5 covariates (birth date, birth weight and 3 estimates of milk consumption), respectively:

$X'Z$ =

27405	3516.9	531.0	581.0	582.0
5316	689.8	102.5	114.5	103.5
5070	638.7	109.0	97.0	101.5
4198	515.9	76.0	83.0	79.5
5127	683.1	97.0	128.5	122.0
5089	658.3	103.5	106.0	114.5
2605	331.1	43.0	52.0	61.0
9667	1198.2	170.0	180.5	180.5
11170	1462.6	233.0	256.0	251.5
6568	856.1	128.0	144.5	150.0
14075	1809.4	263.5	290.0	280.5
13330	1707.5	267.5	291.0	301.5
8483	1060.0	149.0	158.5	155.5
1184	138.2	21.0	22.0	25.0
4420	593.0	91.0	104.5	104.0
6750	869.6	142.0	151.5	147.5
1172	156.4	23.5	27.0	21.0
5396	699.7	104.5	117.5	129.0

Note the linear dependence between the rows of $X'Z$ similar to that explained for $X'X$.

$Z'X$ was the transpose of the matrix shown above and is not presented here as it would be unnecessary repetition.

$Z'Z$ was a 5 x 5 matrix of sums of squares[1] (diagonal elements) and products[2] (off-diagonal) between the covariate data:

$Z'Z$ =

6441489.00	825813.70	124443.00	136109.00	136769.50
825813.80	107284.25	16116.25	17689.75	17673.95
124443.00	16116.25	2510.00	2670.75	2688.50
136109.00	17689.75	2678.75	3124.00	2968.50
136769.50	17673.95	2688.50	2968.50	3218.00

[1,2] Raw sums of squares (underlined) and raw sums of cross-products are shown in the matrix presented.

Elements of $\underset{\sim}{b}$ represented regression coefficients for weaning weight on birth date (b_1), birth weight (b_2) and milk consumption at 25, 45, and 65 d of age (b_3, b_4, b_5), respectively.

In the vector of the right hand side (RHS) of the equation:

$\underset{\sim}{X}'\underset{\sim}{y}$ was made up of totals for weaning weight for steers in the various sub-classes as defined by vector $\underset{\sim}{a}$ (the grand total corresponding to the general mean); and

$\underset{\sim}{Z}'\underset{\sim}{y}$ contained sums of cross-products[1] between weaning weight and respective covariates.

$$\underset{\sim}{X}'\underset{\sim}{y} = \begin{bmatrix} 22089 \\ 6474 \\ 4292 \\ 3233 \\ 4480 \\ 3819 \\ 1591 \\ 7364 \\ 9511 \\ 5214 \\ 11234 \\ 10855 \\ 6434 \\ 930 \\ 3857 \\ 5654 \\ 943 \\ 4271 \end{bmatrix}, \text{ and } \underset{\sim}{Z}'\underset{\sim}{y} = \begin{bmatrix} 5160558.0 \\ 666429.8 \\ 101177.5 \\ 110858.0 \\ 110542.5 \end{bmatrix}$$

There is dependence between elements of vector $\underset{\sim}{X}'\underset{\sim}{y}$, similar to that in $\underset{\sim}{X}'\underset{\sim}{X}$ and $\underset{\sim}{X}'\underset{\sim}{Z}$. For example, the first element is the sum of the 6 that follow it.

[1] Raw sums of cross-products are shown in the matrix presented.

A solution for the normal equations was calculated by first generating a generalized inverse of sub-matrix $(X'X)$; a solution for the model without covariates was then calculated and substituted for in the normal equations to calculate vector $\hat{b}$. The algebra involved is explained below.

From the equations (3.4)

$$X'Xa^{o} + X'Z\hat{b} = X'y \text{ , ... (3.4.1)}$$

and

$$Z'Xa^{o} + Z'Z\hat{b} = Z'y \text{ , ... (3.4.2)}$$

Equation (3.4.1) leads to:

$$\begin{aligned} a^{o} &= (X'X)^{-} (X'y - X'Z\hat{b}) \\ &= (X'X)^{-} X'y - (X'X)^{-} X'Z\hat{b} \text{ ,} \end{aligned}$$

where $(X'X)^{-}$ is a generalized inverse of $(X'X)$ and

$(X'X)^{-} X'y$ is a solution of the normal equations for the model without covariates, call it a^{*}, so that:

$$a^{o} = a^{*} - (X'X)^{-} X'Z\hat{b}$$

Substituting for a^{o} into equation (3.4.2) gives the solution for $\hat{b}$, as follows:

$$Z'X[(X'X)^{-} X'y - (X'X)^{-} X'Z\hat{b}] + Z'Z\hat{b} = Z'y$$

$$\therefore \quad \hat{b} = [Z'Z - Z'X(X'X)^{-} X'Z]^{-1}[Z'y - Z'X(X'X)^{-} X'y], \text{ ... (3.4.3)}$$

Equation (3.4.3) can then be utilized to calculate $\hat{b}$. Incidentally, the algebra simplifies to:

$$\hat{b} = \{Z'[I - X(X'X)^{-} X']Z\}^{-1} Z'[I - X(X'X)^{-} X']y$$

Sub-matrix $(\underset{\sim}{X}'\underset{\sim}{X})$ did not have full rank and a generalized inverse was obtained after applying the constraints:

$$\mu^o = \alpha_6^o = \beta_1^o = \beta_2^o = \beta_3^o = \theta_1^o = \theta_2^o = 0$$

The resultant "reduced" sub-matrix was of size 11 x 11:

$$\left[\begin{array}{ccccc|cccccc}
24 & 0 & 0 & 0 & 0 & 11 & 0 & 5 & 6 & 0 & 2 \\
0 & 22 & 0 & 0 & 0 & 6 & 1 & 5 & 9 & 1 & 0 \\
0 & 0 & 17 & 0 & 0 & 3 & 2 & 7 & 5 & 0 & 0 \\
0 & 0 & 0 & 23 & 0 & 5 & 2 & 2 & 4 & 2 & 8 \\
0 & 0 & 0 & 0 & 21 & 4 & 0 & 0 & 5 & 1 & 11 \\
\hline
11 & 6 & 3 & 5 & 4 & 36 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 2 & 2 & 0 & 0 & 5 & 0 & 0 & 0 & 0 \\
5 & 5 & 7 & 2 & 0 & 0 & 0 & 19 & 0 & 0 & 0 \\
6 & 9 & 5 & 4 & 5 & 0 & 0 & 0 & 29 & 0 & 0 \\
0 & 1 & 0 & 2 & 1 & 0 & 0 & 0 & 0 & 5 & 0 \\
2 & 0 & 0 & 8 & 11 & 0 & 0 & 0 & 0 & 0 & 23
\end{array}\right]$$

To obtain an inverse, the sub-matrix was partitioned as indicated by the broken lines and the procedure outlined by Searle (1966; pp 210 - 212, procedure *aa*) was followed. A solution pertaining to the normal equations for the model without covariates was then calculated:

$$\underset{\sim}{a}^* = (\underset{\sim}{X}'\underset{\sim}{X})^- \underset{\sim}{X}'\underset{\sim}{y} = \begin{bmatrix} 30.35634317 \\ 28.37779604 \\ 21.48847176 \\ 30.69733358 \\ 18.11637188 \\ 156.6498861 \\ 159.450118 \\ 176.3955439 \\ 168.8154558 \\ 167.0222328 \\ 163.7142842 \end{bmatrix}$$

The estimate of the vector of regression coefficients was calculated from equation (3.4.3):

$$\hat{\underset{\sim}{b}} = \begin{bmatrix} -0.27 \\ 1.86 \\ 4.76 \\ 2.14 \\ 1.88 \end{bmatrix}$$

3. Sums of Squares and Tests for Significance

Reductions in sums of squares were obtained by multiplication of the solution vectors[1] by corresponding parts of the vectors in the right hand side of the equations (3.4) as explained in Chapter 3. For example, to obtain the reduction in sums of squares due to fitting factors (including the interaction) after the general mean, the procedure was as follows:

$$R(a) = \underset{\sim}{a}^{*\prime}\underset{\sim}{X}^{\prime}\underset{\sim}{y} \text{ , where } \underset{\sim}{a} \text{ includes } \mu\text{, main factors and interaction.}$$

$$= [0 \;\; 30.34534317 \;\; 28.37779604 \;\; \ldots \;\; 163.7142842] \begin{bmatrix} 22089 \\ 6474 \\ 4292 \\ \vdots \\ 4271 \end{bmatrix}$$

which worked out to $\underline{\underline{4187605.607}}$

But $R(\mu) = N(\bar{y}...)^2 = (y...)^2/N = (22089)^2/117$ where N = 117 = total number of observations

$R(\mu) = \underline{\underline{4170289.923}}$,

and $R(\text{factors}/\mu) = R(\mu, \text{ factors}) - R(\mu)$

$= 4187605.607 - 4170289.923$

$= \underline{\underline{17315.684}}$, which was rounded to 17316 as presented in Appendix Table B3.2.

Two alternative orders of fitting were used to give rise to two ANOVA tables suitable for testing the significance of factors and covariates (Appendix Table B3.1 and B3.2), respectively).

---

[1] It is best to use the values as calculated, without rounding, otherwise serious errors may result. The elements set to zero by the constraints may be included in the calculation, but they are of no consequence because when multiplied by corresponding figures in the right hand side they do not add anything to the sums of squares calculated.

APPENDIX TABLE B3.1: PRELIMINARY ANALYSIS OF WEANING WEIGHT. TESTING MAIN FACTORS[1] HAVING ADJUSTED FOR COVARIATES

Source of variation	d.f.	Sums of squares	Mean squares	F
General mean	1	4170290	4170290	
Covariates/mean	5	23812	4762	
Factors/mean, covariates	10	6544	654	4.04***
Residual	101	16381	162	
Total	117	4217027	36043	

*** $P<0.001$

APPENDIX TABLE B3.2: PRELIMINARY ANALYSIS OF WEANING WEIGHT. TESTING THE SIGNIFICANCE OF COVARIATES[2]

Source of variation	d.f.	Sums of squares	Mean squares	F
General mean	1	4170290	4170290	
Factors/mean	10	17316	1732	
Covariates/mean, factors	5	13040	2608	16.10***
Residual	101	16381	162	
Total	117	4217027	36043	

*** $P<0.001$

[1,2] Where the term "Factors" appears in Tables B1.1 and B1.2 it refers to all terms in the model excluding the general mean and covariates; "Covariates" refers collectively to all variables on which weaning weight was regressed.

Results from this exercise suggested that factors (collectively) and covariates were significant (P<0.001). They did not indicate which individual factors or covariates were significant. To do this would have required further partitioning of the sums of squares between individual factors and covariates. An attempt to this effect in a model including interaction would not yield sums of squares suitable for testing the factors giving rise to the interaction. This is explained in Chapter 3. Analyses of post-weaning liveweights were carried out to test for significance of the individual covariates and (where feasible) factors. The results are presented in Table B3.3, showing the mean squares involved and levels of significance.

APPENDIX TABLE B3.3: SUMMARY OF PRELIMINARY ANALYSES OF LIVEWEIGHT AT VARIOUS STAGES TO TEST FOR SIGNIFICANCE OF AGE OF DAM x TREATMENT INTERACTION[1] AND INDIVIDUAL COVARIATES USING SUB-MODEL (1)[2]

Source of variation		d.f.	Mean squares for weights recorded at: Weaning (200 d)	1-year old	2-year old	Finish (30 months)
Main factors:						
Herd	5	8	2779 nt	11414 nt	2520 nt	2286 nt
Age of dam	2					
Treatment	1					
Age of dam x treatment		2	48 ns	50 ns	489 ns	42 ns
Covariates:						
Birth date		1	295 ns	549 ns	1086 ns	2086 ns
Birth weight		1	4230 ***	4412 ***	1514 ns	7191 *
Milk consumption at:						
25 d of age		1	1668 **	3222 **	6807 *	1000 ns
65 d of age		1	958 *	724 ns	620 ns	224 ns
Residual		102	169	397	1126	1669

*** P<0.001
** P<0.01
* P<0.05
ns P>0.05
nt not tested

Tests were based on reductions in sums of squares when relevant terms were fitted after all other terms in sub-model (1), so it was only possible to draw inferences on herd, age-of-dam x treatment interaction and the individual covariates. Where herd was fitted after all other terms in the model it was found to be significant for weaning and yearling weights (P<0.001), an aspect not shown in the table.

1 Since age of dam and treatment were the sources of the interaction in the model, inferences could not be drawn on them individually. In fitting sub-models to obtain reductions in sums of squares both factors had to be included when the interaction was included.

2 Sub-model (1) was defined in Chapter 3.

Further analyses aimed at partitioning sums of squares to test for the influence of the main factors (leaving out interaction effects) were carried out using a model that considered herd, age of dam and treatment as fixed-effects factors and dam autumn weight, calf birth weight and milk consumed at 25 d of age as covariates. This was identified as sub-model (2). Results were presented in Chapter 4 (Tables 4.1 and 4.2).

APPENDIX C: SIMPLE CORRELATION COEFFICIENTS[1] BETWEEN THE PRINCIPAL TRAITS UNDER STUDY: CALCULATED FROM THE DATA WITHOUT CONSIDERING THE VARIOUS FACTORS EXPLAINED IN CHAPTER 3.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Birth weight		.32	.48	0	.33	.21	.22	-.12	-.03	-	.17	.14	-.10	.28	-
2 Pre-weaning ADG[2]	-.01		.98	-.11	.76	.32	.31	.12	.06	-	-.14	.14	-.10	.10	-
3 Weaning weight	.18	.98		-.10	.76	.34	.33	.08	.05	-	-.10	.15	-.11	.15	-
4 Post-weaning ADG	.20	-.13	-.10		.12	.90	.83	.42	.34	-	.27	0	.24	-.14	-
5 Yearling weight	.16	.70	.72	.24		.45	.45	.28	.12	-	-.01	.16	-.04	0	-
6 Finish (30 mth) weight	.26	.32	.37	.89	.55		.93	.43	.35	-	.21	.07	.17	-.07	-
7 Carcass weight	.19	.39	.42	.78	.60	.92		.46	.44	-	.21	.04	.12	-.06	-
8 Kidney and channel fat	-.11	.23	.20	.46	.18	.52	.58		.15	-	.27	.10	.13	-.11	-
9 Dressing-out %	-.18	.10	.06	.39	.14	.40	.54	.57		-	-.06	.19	.05	-.02	-
10 Eye muscle area	.03	.33	.34	.23	.41	.37	.53	.36	.40		-	-	-	-	-
11 Fat depth	-.05	.24	.23	.44	.10	.51	.56	.61	.55	.31		.27	.27	-.08	-
12 Intra-muscular fat[3]	.06	.09	.10	.26	.23	.28	.37	.46	.36	.29	.36		.23	-.21	-
13 Sarcomere length	-.18	.28	.24	.20	.24	.29	.42	.40	.40	.37	.41	.33		-.52	-
14 "Meat tenderness"[4]	.12	-.10	-.07	-.24	-.13	-.25	-.32	-.28	-.28	-.36	-.24	-.65	-.65		-
15 Fat trim %	-.18	.28	.24	.34	.20	.43	.54	.68	.42	.37	.65	.56	.42	-.42	
16 Lean %	.07	-.10	-.08	-.04	-.01	-.08	-.10	-.30	.06	.02	-.31	-.32	-.16	.27	-.66

Notes:

[1] Correlation coefficients above the diagonal (from year 1 data) and those below the diagonal (from year 2 data) which are higher than |0.30| and |0.27|, respectively, are significantly different from zero ($P<0.05$).

[2] ADG = Average daily gain.

[3] Intra-muscular fat = % fat in a muscle sample. This was determined by chemical extraction (see Chapter 3 for details).

[4] "Meat tenderness" determined by the amount of force required to shear through a sample core of meat using the Warner-Bratzler shear machine; higher values imply "less tenderness" and *vice versa*. Positive correlation coefficients imply that there is a positive correlation with "toughness" and *vice versa*.

Traits numbered 10, 15 and 16 were not recorded in year 1.
The following correlation coefficients obtained from year 1 data have been rounded to zero:

Correlated traits:	Correlation coefficients:
1 and 4	-0.0017
4 and 12	0.0039
5 and 14	-0.0003

APPENDIX D: COEFFICIENTS OF DETERMINATION ($r^2 \times 100$) BETWEEN THE PRINCIPAL TRAITS[1] UNDER STUDY: CALCULATED FROM CORRELATION COEFFICIENTS PRESENTED IN CHAPTER 4.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Birth weight		5	16	0.2	10	4	4	2	0.4	-	0.3	2	2	8	-
2 Pre-weaning ADG	20		100	0.6	46	20	6	0.2	0	-	9	5	5	1	-
3 Weaning weight	40	100		0.6	52	12	8	0	0	-	7	6	5	3	-
4 Post-weaning ADG	2	0.2	0		1	90	74	12	13	-	5	2	7	4	-
5 Yearling weight	23	34	38	12		16	14	4	0.2	-	1	4	1	0.1	-
6 Finish (30 mth) weight	14	10	14	69	31		85	11	12	-	1	0.1	2	1	-
7 Carcass weight	8	15	17	64	32	85		15	18	-	1	0.1	0.6	0.8	-
8 Kidney and channel fat	0.6	2	1	34	2	34	38		0.8	-	6	0	1	5	-
9 Dressing-out %	7	0.1	0.6	20	0.5	14	26	32		-	2	5	0.5	0.6	-
10 Eye muscle area	1	4	4	7	13	11	24	7	10		-	-	-	-	-
11 Fat depth	0	2	2	26	0.1	27	28	30	28	6		1	6	7	-
12 Intra-muscular fat	3	0	0.1	14	3	13	37	27	32	7	30		7	17	-
13 Sarcomere length	3	6	4	7	4	11	18	14	14	13	14	12		36	-
14 "Meat tenderness"	2	0	0.2	7	0.8	21	8	6	5	9	5	15	44		-
15 Fat trim %	1	2	0.8	20	0.5	20	28	46	14	10	37	46	16	21	
16 Lean %	0.5	1	0.6	0.8	0.3	1	1	18	0.6	0	13	18	3	14	50

Notes:

[1] Figures above the diagonal are from year 1 data and those below from year 2. See explanation given in Appendix D.

Traits numbered 10, 15 and 16 were not recorded in year 1.

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