SOME ASPECTS OF PROGENY TESTING SOUTHDOWN RAMS

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Chapter 1

INTRODUCTION

Recent changes that have taken place in the preparation and presentation of New Zealand lamb for marketing have been discussed by Barton (1964). Probably the most important of these changes is the increasing amount of lamb that is being displayed and sold as cuts. This is to some extent, the result of, and has definitely contributed to, the growing interest shown by the consumer in meat quality over the last decade. Such interest has been further amplified by increases in the general standard of living of people in many countries, and by the growing consumer aversion to animal fats. Indications of consumer preferences in any particular area may be obtained by surveys, and although these have been carried out extensively for beef, not many have been made concerning lamb. An example however, is that conducted by Marsh (1960), who, by sending questionnaires to members of the middle and working classes of Leeds, showed that the leg was the most popular cut, and that the most favoured quality characteristics in order of popularity were: economy in price and use, leanness, and absence of bone. Results such as these give an indication of the consumers' concept of meat quality, and it is the function of a grading system to integrate this concept with the aims of the lamb producer (Kiehl, 1957; Brayshaw and DeLoach, 1963). These aims will basically be to maximize his profit per unit time, and in order to do this he must produce the greatest possible weight of top grade carcasses in the shortest possible time. Grading of lamb in New Zealand which is carried out subjectively on the whole carcass, is based mainly on conformation and fat cover (Smith-Pilling, 1959), and it has been shown that the carcasses of the top grade contain more fat and less meat

or bone, than those of the lowest grade (Barton, 1960).

If, as it seems, present grading standards are not a true reflection of consumer preferences, then they can offer no real guidance or incentive to farmers who are interested in planning their management and breeding policies, so as to produce the type of lamb that the consumer wants, and for which he is prepared to pay the highest price. For the same reason there would be no real incentive to improve carcass quality through progeny testing. However, considerable interest has been shown in the grading of meat in recent years, both overseas (e.g., Brayshaw and DeLoach, 1963) and in New Zealand, where the Meat Export Grades Investigation Committee of the New Zealand Meat Producers Board is currently investigating the situation. It is assumed (in order to justify the conducting of the experiment reported herein) that the findings of the above Committee will eventually result in consumer preferences being represented more effectively in lamb grading criteria; thereby providing the producer to some extent with the required guidance and incentives.

It has been shown (Morley, 1952) that greater genetic gains can be made through the selection of rams than ewes, and in the case of carcass quality characteristics, where killing of the animal is often necessary for measurement, progeny testing of rams is the obvious selection aid to use.

The preceding comments give an indication of the background for this experiment, which consists basically of a study of some aspects of the progeny testing of sires of export lambs. Southdown rams were crossed with Romney Marsh ewes to produce Southdown-Romney cross lambs which, numerically, are the most important of New Zealand's export lambs. Stevens (1963) gives a general account of the history and development of the New Zealand export lamb industry, with particular emphasis on the

Southdown breed.

Objectives of this study may be summarized as follows:-

(1) Measurement of certain carcass quality characteristics of Southdown-Romney cross lambs, and analysis of the data obtained in order to detect sire differences. Characteristics measured can be classified as:-

    (a) Growth rates.

    (b) Carcass chemical composition.

    (c) Carcass measurements and weights of non-carcass components.

    (d) Tenderness of the cooked meat.

(2) Investigation of the repeatability of sire performance between seasons, with regard to the above characteristics.

(3) Investigation of the repeatability of sire performance when its progeny are selected for slaughter in different ways.

(4) Investigation of the use of sample cuts, and multiple regression prediction equations, to estimate carcass composition.

Chapter 2

REVIEW OF LITERATURE

2.1. Progeny Testing as an Aid to Selection

2.1.1. Introduction

Turner (1964), in discussing the role of genetics in animal production, identified five stages of development as follows:-

1. The unconscious use of genetics in the selection of the best animals for domestic use.
2. The attempted application of simple mendelian genetics to animal improvement and the introduction of the concept of an 'ideal' animal at which to aim.
3. The recognition that the expression of productive characteristics is dependent in most cases on the actions and interactions of a large number of genes. Hence the change from an emphasis on the genetics of the individual to population genetics, and from aiming at an ideal animal to an ideal population.
4. Collaboration between geneticists and physiologists in the hope that selection for some physiological factor, on which the productive characteristic is dependent, will be easier, and/or more effective than direct selection for the character. This aspect has also been discussed by Cockrem (1962).
5. Control of gene action at the cellular level. This is dependent on a complete knowledge of gene function and is still very much in the theoretical stage.

At the present time practical animal breeding is concerned with the third and fourth stages and so is dependent on population genetics, general

accounts of which are given by Falconer (1960b), and Lerner (1958). Aspects of this field that are relevant to progeny testing are reviewed below.

Selection of individuals for productive characteristics may be based on information concerning their own productive performance, that of their relatives, or a combination of the two; i.e., mass selection, family selection, or combination selection (Lush, 1947; Young, 1961).

Family selection in turn may be based on information from ancestors, collateral relatives, or progeny. The most accurate information however, is likely to be that from the progeny, due to the fact that they have half their genes in common with the individual under test and that many of them may be raised at the same time and under the same conditions.

Because males can beget a larger number of progeny, they can be much more effectively progeny tested than females but, in any such test, the population of females and the population of progeny used must be unselected, or selected at random.

Selection within any population will be based on some kind of an evaluation of the individuals, but before an evaluation of their productive performance can be made, the appropriate data must be collected and analysed. Evaluation on pedigree information enables selection of an individual before birth. Evaluation on individual merit, or on the performance of collateral relatives, involves the analysis of a usually small amount of data which becomes available as soon as the individual or his relatives start producing. Evaluation on progeny performance however, involves the analysis of larger quantities of data, which are not available until the progeny begin to produce.

This increase in age at which selection takes place will increase the average age of the population, thereby increasing the generation interval

and decreasing the rate of genetic gain. Such a disadvantage will, in many instances, outweigh the advantage of increased accuracy, and will lead to selection on individual merit or pedigree being as good as, or better than, progeny testing in terms of rate of genetic gain. This is shown by the following conclusions reached by workers who have analysed specific progeny testing situations.

Dickerson and Hazel (1944), in the consideration of progeny testing in a closed herd of 120 cows, concluded that genetic improvement in butterfat production will actually be faster without progeny testing.

After investigating the use of progeny testing in the improvement of both wool and meat production of the Romney, Rae (1948) stated that: "Progeny testing is not the panacea of all the ills besetting the sheep breeder," and that "...the undue optimism as to the startling improvement which it would produce, that characterized earlier thinking about progeny testing, must certainly now give place to a more sober and considered attitude."

Morley (1952) compared the theoretical consequences of the use of progeny testing, sib testing, and mass selection, in a flock of 1,000 ewes producing 700 progeny of breeding age each year. He concluded that, "The literature on progeny testing and other aids to selection has tended to emphasize the increased accuracy of selection rather than the annual improvement that might be expected in relation to the cost incurred", and that, "Optimum use of progeny-tested sires is unlikely to increase rate of improvement as compared with mass selection by more than 10 to 20%, if the heritability is of the order of 0.3, and may result in a decrease where heritability is higher."

2.1.2. Situations Favourable to the Application of Progeny Testing

There are situations in which progeny testing does have an advantage over other aids to selection and the most important of these are considered below.

(a) Due to its greater accuracy, progeny testing is most effective relative to other aids to selection when heritabilities are low. However, as Lush (1945) points out, although a large number of offspring will decrease the random environmental errors, any systematic errors will remain. A theoretical study comparing individual merit, and family merit (which includes progeny testing) as aids to selection, with r, t, and n as variables*, has been made by Lush (1947). The main result is that relative to selection on individual merit, that based on family information becomes increasingly effective as r increases, t decreases, and n increases.

Analysis of the progeny testing situation in Romneys by Rae (1952b) led him to the conclusion that where heritability was about 0.4, there is no advantage in progeny testing over individual merit, but with heritability equal to 0.1 and 70 per cent of the flock used in testing, there was about 10 to 15 per cent increase in the efficiency of genetic gain.

(b) When artificial insemination is being used, a greater number of offspring per sire is possible and this means greater accuracy. Rae (1964) points out that progeny testing is almost essential with any artificial

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* r = Intra class correlation between the breeding values of members of the same family.

t = Intra class correlation between the phenotypes of members of the same family.

n = Number of individuals in a family.

breeding scheme in order to avoid the extensive use of genetically inferior sires. Robertson and Rendel (1950), in a sequel to the paper of Dickerson and Hazel (1944), considered the use of artificial insemination and concluded that, in a unit of 2,000 cows, the use of progeny testing is an effective means of improvement.

(c) When the generation interval can be kept short, and the progeny can be assessed early in their life, the main disadvantages of progeny testing are largely overcome. Sulimov (1964) compared the semen quality of rams at 7-7½ months old with that from rams 19-20 months old. Although the quality was lower in the younger rams, it exceeded minimum Russian standards, and conception rates together with the subsequent performance of the lambs, did not differ significantly between the groups. This means that, in the case of export lamb sires, they can be assessed on the basis of performance of their progeny at the age of 15 months; only one year after information required for assessment on individual merit becomes available.

(d) When it is desired to improve the genetic make-up of a population by selection of the males, but the characteristic concerned is only displayed by the females, then progeny testing, or some other form of family selection, is necessary. Prolificacy and milk production are examples of such characters. Its application in the dairy industry is discussed by Cunningham (1965).

(e) Finally, progeny testing has a particular advantage when it is required that sires be tested on their cross-bred offspring, as in the case of rams used for the production of cross-bred export lambs. Results of selection, based on individual merit or on information from pure-bred members of the same family, will only produce the same results as those

based on the cross-bred lambs if the genetic variance is completely additive. Lerner (1958) points out that when only additive variance has to be considered, the aim in any selection scheme is to increase the frequency of desirable alleles at the expense of the undesirable alleles. However, when non-additive genetic variance becomes important, due to intra- and inter-allelic interactions between genes, this aim must be modified, as the desirability of any particular gene varies according to which other genes are present. He continues to discuss a number of mating schemes which allow the expression of non-additive effects. The most relevant of these to the progeny testing of export lamb sires is that in which intra population selection is practised in the selected population, based on the results of its crosses with a genetically constant test population, i.e., recurrent selection.

The main sources of non-additive genetic variance are interactions between non-allelic genes or epistatic effects, and interactions between allelic genes or dominance effects.

2.1.3. The Significance of Overdominance to Cross-breeding

Probably the most important of the above interactions is that of overdominance which may be defined as the superiority in terms of selective advantage, of the heterozygote over either homozygote at a particular locus. Such a situation may arise in a number of different ways, some of which are given below.

(a) When the heterozygote is superior to both homozygotes on both the absolute and the desirability scales.

(b) When the heterozygote is intermediate on an absolute scale, but has a selective advantage due to the character having an intermediate absolute value as optimum on the desirability scale.

(c) When two characters are negatively correlated on a desirability scale due to pleiotropic or linkage effects, then the best combination of the two may be when both are at an intermediate value. If they show no dominance individually, then they will both show overdominance when considered together. This is referred to as pseudo-overdominance (Lerner, 1958).

Maximum heterozygosity is obviously necessary for full exploitation of overdominance effects, and the only way to increase heterozygosity above 50 per cent is to cross homozygous, or inbred lines. As characters become increasingly important as components of fitness, their proportion of additive genetic variance decreases (Robertson, 1955), which means that use of recurrent selection should be particularly appropriate (Bowman, 1959). This may not be the case however, because importance as a fitness component is also associated with susceptibility to inbreeding depression (Morley, 1954; Falconer, 1960b). Selection within lines in an attempt to reduce inbreeding depression has been tried by several workers with mixed success, and Bowman (1959), after reviewing the work that has been done in this area, points out that in the cases where inbreeding depression has been avoided, it is probably through selection for heterozygosity; thus opposing the exploitation of overdominance. This means that, although recurrent selection will improve the cross-breeding performance of a population, when overdominance is important it tends to disregard intrapopulation performance. In the case of the New Zealand export lamb industry, the Romney population can be considered as the test flock with a relatively constant gene pool, while the meat breeds will be those being improved. Even when the tester flock is not homozygous, recurrent selection in the presence of overdominance will result in increased homozygosity in the selected population. This increased homozygosity will

be for the allele which displays overdominance when in combination with the allele of highest frequency in the test flock and, as such, is likely to be for the inferior allele.

It is on the basis of this difference between cross-bred and pure-bred performance that Bowman (1960) has suggested a method for detecting the presence of overdominance. This method is an adaption of the constant parent regression technique that has been developed by Hull (1945), Hayman (1954), and others. The test is based on either of the following two relationships:-

1. The covariance between, and regression of, a sire's test cross progeny mean performance and his full sister's mean performance.
2. The covariance between, and regression of, a sire's test cross progeny mean performance and his pure strain progeny mean performance.

The second test is more easily applied, but the former is important in the case of characters that can only be measured in the female. Assuming diallele loci with diploid mendelian segregation, and with no epistatic effects, Bowman derives formulae based on a single locus, for the above relationships. If the regression is negative then overdominance is likely to be important while, if it is positive, it may or may not be important. He notes the danger of extrapolating theoretical results calculated on the basis of a single locus to quantitative characters, and concludes by giving the results of two cases where this test has been applied. These experiments on mouse litter size, and Drosophila chaetae number produced a very low negative pooled regression, and a positive pooled regression, respectively. However, they both involved the analysis of only a few cycles and so may not be very reliable.

Experimental evidence concerning overdominance, and the correlation between inbred line performance and cross-bred performance of the same lines, has been reviewed by Bowman (1959), who states that the data collected so far on the larger animals are rather inadequate to reach any firm conclusion. Other evidence of overdominance in the literature is scarce and mainly indirect. For example, Broadbent and Bowman (1964) progeny tested six Suffolk rams on three maternal breeds, and the difference of the ranking of breeds, as regards lamb growth, within each sire group suggests the presence of some specific combining ability, probably in the form of overdominance.

It seems then, that although the importance of overdominance generally has been fairly well shown, its importance in specific cases is still far from clear. If it is important in a particular case, then selection schemes such as that suggested by Dickerson and Hazel (1944), in which performance testing and progeny testing are used sequentially, may become invalid in situations where the former test is based on pure-bred performance while the latter is based on cross-bred performance. Bichard and Yalcin (1964), in an experiment in which they progeny tested 26 Suffolk rams on their cross-bred offspring, concluded that any real differences between the rams were probably associated with additive genetic variance. They then extended the scheme put forward by Dickerson and Hazel, and evaluated it under a range of situations with the main variables being heritability, and the number of progeny per sire. Even if it was shown that overdominance was important in some traits being selected for, it may still be possible to combine performance and progeny testing, but non-sequentially, by employing an independent culling level (Bogart, 1959) scheme so that any trait that displayed overdominance was selected for by progeny test only.

2.1.4. The Application of Progeny Testing

A review of the early applications of progeny testing, particularly in the case of domestic animals, is made by Rae (1947). Since that time a large number of reports of progeny testing schemes have been put forward, but only the most important of these that deal with progeny testing of sheep sires for meat production will be considered here. They may be subdivided into those schemes that are comparing sires of different breeds (Rae, 1952a), and those that are comparing sires of the same breed.

Only the progeny testing of sires within a breed is pertinent to the present study, and schemes doing this may be subdivided into those that have been purely experimental and those that have been run on a commercial scale. The former are usually concerned with finding out if there are differences present between sires for a particular characteristic, while the latter are concerned with finding if a characteristic, which is known to vary between sires, does differ in the sires under test. A number of relevant papers in the former category are summarized in Table 2.1. In all cases the progeny were slaughtered and evaluated as lambs.

The number of progeny per sire was not mentioned in many cases and was very low in some, e.g., Fox and McArthur (1963) used only three progeny to evaluate each sire but noted in their summary that more than three should be used.

Examples of the use of progeny testing for the improvement of meat-type sheep on a commercial scale are its application by the Corriedale Sheep Society (Inc.) (Stevens, 1957), and by the University of California (Spurlock et al., 1964).

TABLE 2.1.

Some experiments involving progeny testing of sires of meat producing sheep breeds

Reference	Breed of Sire	Basis of Selection of Sire	Measurements made	Differences shown
Barton et al. (1949)	Southdown	Conformation	Carcass measurements Age at killing (const. wt.)	Definite Definite
Bichard & Yalcin (1964)	Suffolk	Different flocks	Five wts. up to 15 weeks Skeletal measurements	Significant Significant
Broadbent (1963)	Suffolk	Growth rate to 110 days	Growth rate	Some
Broadbent & Bowman (1964)	Suffolk	Different flocks	Growth rates Yield in pence/lb. Subjective assessment of tenderness and flavour	10% difference Non-significant Non-significant
Burgkart (1962)	Merino	?	Growth rate	Marked but not significant
Busch et al. (1962)	Suffolk	Inbred lines	Body measurements Conformation scores	Definite Definite
Cramer (1962)	?	?	Fat iodine number Fat melting point	Definite Definite
Cramer (1964)	Columbia	?	Fat composition	None
Fox and McArthur (1963)	Hampshire	Weaning wt.	Subjective palatability ratings Adjusted retail value	Non-significant Non-significant

Cont.....

Table 2.1. (Cont.)

Reference	Breed of Sire	Basis of Selection of Sire	Measurements made	Differences shown
Fox et al. (1964)	Hampshire	?	Subjective palatability ratings	Non-significant
McLean (1948)	Southdown	Breed standards	Birth wt. Growth rates Length of cannon bone	Non-significant Non-significant Non-significant
Field et al. (1963b)	Southdown	Growth rate	Growth rate Chemical composition of carcass	Significant Significant
Ray (1964)	?	?	Heart wt. Wt. of endocrine glands Slaughter wt. Wt. of high priced cuts Shear force Loin eye area	Non-significant Non-significant Non-significant Non-significant Non-significant Non-significant
Rowe et al. (1965)	Hampshire (8) Suffolk (2)	?	Retail carcass value	Compares ranking of sires over two years
Clarke (1965)	Suffolk) Clun) Dorset Down) Southdown)	Growth rate birth to 4 months	Growth rate	Negligible

Note: Only those differences termed significant or non-significant were statistically analysed.

2.2. Important Productive Characters in a Meat-Type Sheep

2.2.1. Introduction

Growth rate and carcass quality are the two productive characters that are most important in meat-type lamb sires (Donald, 1958; Morris et al., 1963; Broadbent and Bowman, 1964; Bichard and Yalcin, 1964). However, although growth rate is easily defined objectively, quality of meat is a most difficult concept to define in measurable terms, since in the long run it is the summation of the subjective assessments of a large number of consumers (Pomeroy, 1958). The concept of meat quality also varies between countries, as well as between markets within a country, and within a market from time to time (Palsson, 1955). Because of these difficulties the claim by Howard (1963b), that there are probably almost as many definitions of meat quality as there are workers in the field, is understandable. These range from the superficial observation of Hammond and Mansfield (1936), that high quality meat is "...that which members of the public like, and which butchers can sell best", to the more technical definition of Pearson (1960), that meat quality is "...that combination of physical, structural, and chemical characteristics of meat which results in maximum desirability from the standpoint of appearance and eatability."

Carcass quality, which is largely determined by meat quality, can however, be divided fairly objectively into the three components of carcass composition, carcass conformation, and palatability characteristics. It is the assessment of these components, and the relative importance attached to each that makes it a difficult concept. As carcass composition is determined by the growth of the animal, and as tenderness is the most important of the palatability characteristics (Weir, 1960; Brayshaw et al., 1965), then carcass quality can be discussed under the headings of carcass conformation, animal growth, and tenderness.

2.2.2. Carcass Conformation

Kirton (1964a), taking conformation as being equivalent to shape, proceeds to develop a thesis showing that conformation is of minor importance in meat-type sheep. The following facts support this thesis:-

(1) Conformation has been shown to be of minor economic importance in the case of the Romney (Rae, 1964), a breed used extensively for meat production.

(2) Conformation does not appear to be of very high heritability (Rae, 1956). Barton et al. (1949) however, did show definite differences in certain carcass measurements of lambs sired by Southdown rams of different conformation.

(3) Poor conformation in some breeds may be important to their general fitness and ability to produce in unfavourable environments.

(4) Low-grade carcasses often command as high a price as those in the top grades.

(5) Longer bones have been shown to be associated with greater amounts of muscular tissue than shorter bones (Russel, 1961). This is supported by further data showing that carcasses of poor conformation contain more protein and water, but less fat, than those of good conformation.

(6) Variations of up to three inches in the distance from the crutch to the end of the tibia on legs of the same weight have been shown to have no effect on cooking yield, relative muscle proportions, or connective tissue content of the meat (Boccard and Radomska, 1963).

(7) It has been shown in cattle that the ratio of high-priced cuts to low-priced cuts remains fairly constant over a wide range of conformation (Butterfield, 1963). Similarly in sheep Kirton showed that legs

varying in length may still make up the same proportion of the total carcass.

This proportion of the weights of various cuts to the total carcass weight is an important aspect of conformation as it has been shown by several workers that, in the case of the leg, it is highly correlated with the total retail value of the carcass. Oliver et al. (1963) showed that the yield of primal leg is an important determinant of total retail value per 100 lb. of carcass, Carpenter et al. (1964) estimated a correlation coefficient of +0.63 between retail leg per cent and carcass value per 100 lb., and Smith (1964) estimated a correlation coefficient of +0.93 between the total retail value and the untrimmed leg value. The superiority of the leg over other joints as an indicator of total carcass value is probably due to the fact that:-

(1) it is the most valuable part of the carcass,

(2) it can be accurately removed from the carcass with a small cut area relative to other cuts,

and (3) it is the cut that is least likely to have an excess of subcutaneous fat.

Oliver et al. (1963) state that the retail value of a lamb carcass is determined by its quality (or palatability) and its cutability. 'Cutability' they define as "...the proportion of the carcass weight sold as retail cuts and the distribution of the weight among the cuts."

Robinson et al. (1955), in an attempt to obtain an objective measurement of carcass conformation, made a number of measurements on the intact carcass and correlated each with the results of normal commercial grading. They gave an equation that will give a conformation score based on the four most effective measurements, which were: length of leg, depth

of the thorax, thickness of the loin through the eye muscle to the bone, and length of the carcass. A conformation score such as this however, will only be as meaningful as the grading system involved. Thwaites et al. (1964) point out that previous methods that have been used in the appraisal of sheep carcasses have relied mainly on subjective assessments, and/or have required that the carcass be cut (e.g., McMeekan, 1939; Starke and Joubert, 1961). They criticize the scheme of Robinson et al. (1955), on the basis that it does not specifically penalize overfatness, and is restricted to lamb carcasses. The method they outline is an extension of the concept of a 'fleshing index' developed by Yeates (1952) for beef carcasses. Their 'gross fleshing index' is based on the average weight-length relationship of a large number of lamb and mutton carcasses representative of a wide range of weights and degrees of finish. It is numerically equal to the number of pounds by which a given carcass is heavier, or lighter, than the average carcass of its length. The 'net fleshing index' is derived from this by deducting objectively computed penalty points for fatness. Using the measurements suggested by Palsson (1939), the ratio of B:C at a point $^{F}/_{10}$ from the mid back, and over the first lumbar transverse process was estimated. It was decided that any value of B:C below seven should be penalized and, by trimming the fat from a number of carcasses with a range in their B:C ratio from seven to one, they formed a graph of this ratio against the whole carcass excess, or trimmed, fat weight. This weight can then be estimated from the B:C ratio for any carcass, using the graph, and then subtracted from the 'gross fleshing index' to give the 'net fleshing index' for that carcass.

This seems to some extent to be comparable to cutability, in that it is a measure of both carcass composition, and conformation. The work of Kirton (1964a) however, suggests that the emphasis placed on the weight-

length relationship may be unjustified. The main advantage of such an index is that it can be calculated while the carcass is still intact, and it would be interesting to see how closely it is correlated to retail value.

2.2.3. Growth

2.2.3.1. Introduction. Taking the definition of growth as a change in size, then it is clear that this is a most important characteristic of meat animals, particularly from the points of view of rate of growth, efficiency of growth, and composition of growth. The first two of these are straightforward as far as measurement is concerned and, as a high correlation between them has been demonstrated in sheep (Botkin, 1955, $r = 0.80$; Broadbent and Bowman, 1964, $r = 0.89$), then the aim in this species should be simply to maximize them both.

In the case of composition of growth (in terms of different tissues, and different body parts) the problems of measurement and of setting down objectives at which to aim are much greater. This is partly due to a lack of understanding of underlying mechanisms involved. A discussion of growth theories or hypotheses that have been suggested for domestic animals must include also a consideration of methods of estimating carcass composition, ways in which composition data may be analysed and interpreted, and some of the factors which have been shown to affect the composition of growth.

2.2.3.2. Measurement of body composition. The most satisfactory classification of methods of estimating body composition seems to be into those methods used *in vitro* and those methods used *in vivo*. Pearson (1963b), and Harrington (1958) have reviewed these two approaches.

A. In vitro methods

These may be divided into direct and indirect methods which, in turn,

may be subdivided into chemical and anatomical (physical) methods.

(a) Direct chemical methods. These involve the chemical analysis of the whole body or carcass and, although the number of components estimated may vary, the most common ones are fat, water, protein, and ash. Morris and Muir (1963) review some of the methods that have been used and note that most techniques involve the taking of supposedly representative samples of the whole carcass or body. The following methods provide examples of the many that have been used, most of them differing only in detail. The AOAC (1960) method involves the taking of small samples which are analysed separately for fat (ether extract), water, ash, and protein. In the method of Barton and Kirton (1956), larger samples are analysed individually for fat and water, but the dried fat-free material is bulked within experimental groups for ash analysis, and the removal of the last of the fat. Protein can then be estimated by difference. Kemp and Barton (1965), in comparing the AOAC and the Barton and Kirton (1956) methods of analysis, found highly significant correlations between the fat, water, and protein estimates but not between the ash values. A method comparable to that of Barton and Kirton has been suggested by Morris and Muir (1963). Like Barton and Kirton, they used larger samples than the AOAC method, but they differed by making individual estimations of ash and protein, thus making it a much more time-consuming, but probably more accurate, method. The main problem with all the above-mentioned methods, when applied to whole carcasses or whole bodies, is to get a representative sample.

Kirton et al. (1962), and Morris and Muir (1963), discuss the errors associated with their respective sampling procedures. A method that aims at speed and efficiency, even at the expense of some accuracy, is outlined by Everson et al. (1955). They showed that their analyses for fat and water gave results within 3% of those obtained by the standard AOAC

methods.

(b) Direct anatomical methods. These involve the separation by dissection of muscle, bone, and fat in a carcass. Two main approaches have been made with domestic animals. First dissection at Cambridge (Hammond, 1932; McMeekan, 1940a, b, c, 1941; Wallace, 1948; Palsson and Verges, 1952) has involved the jointing of the carcass into its anatomical regions and then dissection of each joint into its component tissues. Secondly, a method which involves the dissection of the carcass muscle by muscle has been described and used in cattle (Walker, 1961; Butterfield, 1963) and sheep (Fourie, 1963).

(c) Indirect methods. Important ways in which carcass composition may be estimated indirectly include the use of specific gravity to estimate fat or protein content, the use of sample joints or cuts, the use of carcass weight, and the use of carcass linear and area measurements. Estimation from sample cuts, which is probably the most common of these methods, involves the estimation of the composition (either chemical or anatomical) of a particular cut, and then by the use of an appropriate regression equation, the composition of the whole side or carcass is predicted. The accuracy of this procedure will be largely dependent on the source of the data on which the prediction equation is based.

Correlations between carcass measurements and carcass composition have been frequently calculated, but as Tulloh (1963) points out, the relationship between these measures of area and length, and carcass composition, which is a volume, cannot be expected to be linear. Hence curvilinear regressions should be fitted, or at least tested for.

Timon and Bichard (1965a, b, c) evaluate the usefulness of sample cuts, specific gravity, and linear carcass measurements, as indices of carcass composition of Clun Forest lambs which varied in carcass weight

from 29 to 42 pounds. They estimated the predictive efficiency of these three methods and expressed it as the number of animals required to detect differences between groups when each method was used, compared with the number required when complete dissection was carried out. The magnitude of the detectable differences considered was expressed in standard deviation units. Their results showed that the use of sample cuts, especially the loin, was the most efficient predictive method, and that for detection of differences of approximately one standard deviation, only small increases in the number of animals (approximately 10%) were necessary.

Some results of indirect, in vitro, methods are shown in Table 2.2. The methods can generally be classified according to their accuracy, sensitivity, simplicity, and economy. Their relative strength in these four attributes will determine their usefulness for a particular purpose. For example, accuracy and sensitivity, relative to economy and simplicity, will be more important in a physiological experiment than in a commercial progeny testing scheme. In the latter case, relative values are often more important than absolute values, making accuracy of lesser importance, and the use of sample cuts, either with or without prediction equations, probably the best method.

B. In vivo methods

All in vivo methods of carcass composition estimation must necessarily be indirect. Methods that have been tried have been reviewed by Pearson (1963b), Panaretto (1963), and Kirton (1964b).

Kirton (1964b) concludes his review by stating that: "Experimental results to date suggest that at present there is no completely satisfactory method of estimating the composition of live animals, although several methods look promising." The development of an accurate, sensitive, and

cheap way of estimating live animal composition would be particularly useful in growth studies, as it would enable serial analyses to be made on the same animal, as done by Wood (1964). This would avoid the necessity to use average growth curves, which may be misleading (Medawar, 1945).

TABLE 2.2.

References to some experiments investigating indirect methods of *in vitro* carcass composition estimation in sheep

Reference	Independent Variable(s)	Dependent Variable	Correlation Coefficient	Standard Error
Palsson (1939)	T	Bone content	See ref.	-
	L/10 + A + B	Muscle content	See ref.	-
	L/10 x (C + J + Y)	Fat content	See ref.	-
Walker & McMeekan (1944)	T + G	Muscle	0.894	-
Kirton & Barton (1962)	Chemical components of joints (%) Carcass ($^{c}/_{c}$) wt. (lb.)	Chemical components of $^{c}/_{c}$ (%)	See ref.	See ref.
Field *et al.* (1963a)	Physical components of cuts (lb.)	Physical components of $^{c}/_{c}$ (%)	See ref.	See ref.
	Area rib eye (sq.in.) Fat depth at 12th rib (in.) % kidney + kidney fat % leg	$^{c}/_{c}$ lean %	0.75	-
	Specific gravity of $^{c}/_{c}$	$^{c}/_{c}$ lean %	0.47	-
	Specific gravity of 7 rib-cut	$^{c}/_{c}$ lean %	0.62	-
Judge & Martin (1963)	Fat thickness between 12th & 13th rib (in.) Kidney fat (lb.) Chilled $^{c}/_{c}$ wt. (lb.)	% edible portion	0.77	2.83%
Barton & Kirton (1958)	Muscle, fat, and bone wts. of joints (g.) $^{c}/_{c}$ wt. (g.)	Wt. of same tissue in $^{c}/_{c}$ (g.)	See ref.	See ref.
		Dissectable fat, muscle, and bone wt. (g.)	See ref.	See ref.

Cont.....

Table 2.2. (Cont.)

Reference	Independent Variable(s)	Dependent Variable	Correlation Coefficient	Standard Error
Carpenter et al. (1964)	Various combinations of carcass traits, e.g. $^{c}/_{c}$ wt. Retail cuts wts. (lb.) Fat trim wt. (lb.) Av. fat thickness (in., in./cwt.) Loin eye area (sq.in., sq.in./cwt.)	$^{c}/_{c}$ value/cwt.	See ref.	-
Kirton & Barton (1958b)	$^{c}/_{c}$ specific gravity	% chemical fat % water	- -	3.25% 2.59%
Russel (1961)	Bone characteristics $^{c}/_{c}$ wt.	Muscle tissue (lb.)	See ref.	See ref.
Kirton (1962)	K^{40} content of cuts	Muscle tissue (lb.)	See ref.	See ref.
Meyer (1962)	Specific gravity of $^{c}/_{c}$ Specific gravity of $^{c}/_{c}$) $^{c}/_{c}$ wt.)	$^{c}/_{c}$ chemical fat % $^{c}/_{c}$ chemical fat %	-0.84 0.96	2.64% 1.40%
Timon & Bichard (1965a)	Fat, muscle, and bone % of English commercial joints and of combinations of these joints in multiple regressions.	$^{c}/_{c}$ fat, muscle, and bone %s.	See ref.	See ref.
Timon & Bichard (1965b)	Specific gravity of the whole $^{c}/_{c}$ and of its parts.	$^{c}/_{c}$ fat, muscle, and bone %s.	See ref.	See ref.
Timon & Bichard (1965c)	Carcass measurements and wts. of non-carcass body components in different combinations.	$^{c}/_{c}$ fat, muscle, and bone %s.	See ref.	See ref.

The ways in which carcass composition data can be analysed in order to produce the most meaningful and valid results have been discussed by Brody (1945), Reeve and Huxley (1945), Bertalanffy (1960), Harrington (1963), Millar (1963), Tulloh (1963), Dinkel and Wilson (1965), and Cockrem (1965). It seems that regression type equations, such as the allometry equation (Reeve and Huxley, 1945), are the most satisfactory.

2.2.3.3. Theories of growth. Theories that have been put forward to explain the growth and development of domestic animals, or animals in general, may be based on general biological rules and laws, or on physiological and genetic considerations (Huxley and DeBeer, 1963). The former type (e.g., Bertalanffy, 1960; Taylor, 1965) are generally concerned with quantitative, and not qualitative changes in size, making them of limited use for growth studies concerning meat animals.

Examples of theories of the latter type include that developed by workers at Cambridge under the late Sir John Hammond (e.g., Palsson, 1955), which theory is based on the relative changes in the metabolic rates, or natural growth intensities of body tissues and parts; and that of Dickinson (1960) which is based on the statement that: "As a morphological character approaches maturity it becomes progressively more independent of the environment and more dependent on genetic control." A number of aspects of the former theory have been criticized however (cf. Luitingh, 1962; Butterfield, 1963; Elsley, 1963; McCance, 1964).

The above two theories, or hypotheses, on growth in mammals do not offer any physiological or biochemical explanation for differences in patterns of growth, beyond attributing them to differences in 'growth intensities', or differences in 'juvenile growth potentials' (Dickinson, 1960). McCance and Widdowson (1962) also include the 'impetus to grow' as one of their four major forces controlling how an animal will develop. The

other three they consider are plane of nutrition, size of animal, and age of animal. They do, however, enlarge on the concept of growth impetus, pointing out that in early life it is a property of every cell, but that later in development it appears to be produced by hormones, mainly from the anterior pituitary gland. Lamond (1963) discusses more fully the endocrine basis of growth with particular emphasis on growth hormone which, together with nutrient supplies, appears to be the main factor controlling growth rates. Interactions between this and other hormones, however, especially sex hormones, are also important. In a review on the endocrine causes of growth, Nalbandov (1963) quotes evidence suggesting that selection for increased growth in animals is in fact selection for the genes that control growth hormone production. He points out that the quantity of growth hormone produced per unit weight of the animal decreases as size and age increase, until finally all the hormone produced appears to be used for maintenance. One of the main effects of growth hormone is to increase protein synthesis through increased amino acid uptake into cells (Knobil and Hotchkiss, 1964). Of the nutrients that enter a developing animal, those that are not excreted or used in maintenance must be largely used in fat and protein synthesis (Clausen, 1965). This gives rise to a situation comparable to that discussed by Rendel (1963) concerning Drosophila bristles. In this case, whether or not selection for increased protein synthesis will result in a correlated increased or decreased fat synthesis will depend on the relative emphasis on selection for (1) an increase in total nutrients being diverted to synthesis generally, and (2) an increase in the proportion of that used for total synthesis being diverted to protein synthesis. If the aim is to increase protein synthesis alone, then selection should be for (2) only. This may not be possible directly, but may be possible indirectly by selection for some other factor

such as growth hormone. This is supported indirectly by a highly significant correlation demonstrated by Ray (1964), between pituitary gland weight and area of the loin eye muscle when both of these had been adjusted for age of dam, sire, sex, birthrank, and slaughter weight. Processes between initial gene actions and their final effect on body composition are far from clear. These however, are likely to be especially useful in the genetic improvement of meat animals as, in general, the nearer to the initial gene action a character can be measured, the higher will be the heritability (Cockrem, 1962).

2.2.3.4. Factors affecting mammalian growth. Although the genetic material of an individual is constant, its expression is considerably affected, directly by the internal, and indirectly by the external environment of the animal's body. Growth constitutes changes in the internal environment and, as such, is controlled at any particular instance by the age and size of the animal, the external environment, the genotype of the animal, and its previous growth. With meat-type lambs, although all these factors, and especially the nutritional environment, will affect their growth and composition (cf. Elsley et al., 1964; Fomen and Owen, 1964; Duckworth, 1965), as far as progeny testing is concerned the main requirement is the separation of the genetic effects, from the effects of ths other factors. This is usually achieved by standardization of the environment, and/or the use of appropriate statistical procedures.

Success in selecting for changes in both the rate and the composition of growth, experimentally and commercially (see Bogart, 1959) indicates that the genotype is an important source of variability in these two characteristics. Response to selection in terms of body composition, when selection is on the basis of body weight alone however, may vary. This appears to be due to interaction effects between the particular genotype,

and the factors that affect growth as outlined above, so that any complete growth experiment will involve very large numbers of treatments (Lamond, 1963). Three examples of factors that have been shown to interact with genotypes in terms of body composition, are given below.

(a) The initial genotype. Fowler (1958) selected within two different strains of mice, for increased, and for decreased body weight at six weeks. He demonstrated that in one strain practically all the difference between high and low lines could be attributed to the laying down of fat, while in the other strain the fat to protein ratio did not vary between selected lines. This suggests that in the former case selection was for an increased proportion of the nutrients being diverted to fat production while, in the second, it was for an increase in the total nutrients utilized for the synthesis of protein and fat.

(b) The environment. In an experiment which involved (amongst other things) selection for increased body weight at six weeks of age in mice, Falconer (1960a) showed that those selected after being raised on a high plane of nutrition had a higher fat content. He offered this as a partial explanation for their poor performance when transferred to a low plane of nutrition, relative to those that had been selected after being raised on this plane. Fowler and Ensminger (1960) demonstrated a similar genotype environment interaction in pigs. They concluded that selection on the two planes was in fact for different characters.

(c) Age at selection. Selection of mice for increased body weight at 3, $4\frac{1}{2}$, and 6 weeks of age by Hull (1960), produced quite different responses in terms of which tissues constituted the increase in size. Selection at 3 weeks resulted in considerable increase in the proportion of fat when the animals were killed at six weeks, while selection at $4\frac{1}{2}$ and

6 weeks resulted in the fat proportion remaining static or falling. This suggests that selection at these different times is for different genes. Statistical analysis of the results showed that the genetic correlations between the weights at the three ages were very high, and that the 3-week weight had the highest heritability, and was the most closely correlated to abdominal fat per cent.

Detailed analysis of the genetic control of growth processes has not been made in mammals. However, some miscellaneous effects have been shown. For example, Fenton (1956) demonstrated that obesity in mice was genetically controlled, and Liebelt (1963), in reviewing the genetic, hormonal, and neurogenic factors affecting adipose tissue, demonstrated that a single gene controls obesity. Induction of obesity by the administration of gold thio glucose has been shown to be through its effect on this gene.

2.2.4. Tenderness

2.2.4.1. Introduction. "The sensation of tenderness is a complicated physical process, since chewing involves not only cutting and grinding, but also includes squeezing, shearing, and tearing." (Pearson, 1963a). This means that tenderness, as a physical property of meat, is likely to be complicated also, and judging by the number of physiological parameters that have been suggested as being directly associated with tenderness, this is the case. Palmer (1963b) makes a distinction between factors which influence or affect tenderness and those which are associated with tenderness. In the former case it is usually an indirect, and therefore an unpredictable relationship, while in the latter case, it is more direct, such as the relationship suggested between tenderness and the marbling of meat. Before any valid assessment of an association between tenderness and any other character can be made, those factors that may affect tenderness must all be either removed, or kept constant (Blumer, 1963).

A number of papers have reviewed the literature concerning these factors (Weir, 1960; Wilson, 1960; Hill, 1961; Briskey, 1963), but most of them have dealt mainly with beef. In the present review, emphasis will be on results from experiments involving lamb.

2.2.4.2. Ante-mortem factors affecting tenderness.

(a) Genotype. Variation in the tenderness of lamb attributable to sires or breeds does not seem to be very great. For example, Fox et al. (1964) investigated differences between the crossbred progeny groups of eight Hampshire rams. A trained panel of eight judges was used in scoring each of five quality factors including tenderness, and although there were no significant differences between sires in any of the quality factors, tenderness and juiciness showed the greatest variation between groups, and the authors note that significant differences may have been obtained if all progeny from each sire had been evaluated. King and Bland (1960) evaluated tenderness in 31 finewool, and 17 crossbred lambs from 16 sires. Although the crossbred lambs were more tender, this difference was not significant and no sire differences were shown. Use of a four-man taste panel to subjectively assess the tenderness and flavour of the progeny groups of six Suffolk rams was reported by Broadbent and Bowman (1964). Three maternal breeds were involved and, although no significant sire differences were demonstrated, the Suffolk x Welsh lambs were more tender than the others. None of these experiments however, have been very extensive, or very intensive as far as tenderness evaluation was concerned. Experiments involving cattle, where tenderness is recognized as a greater problem, have been more numerous and significant differences between breeds, or between sires within breeds, have been demonstrated (Cartwright et al., 1957; Christians et al., 1961; Palmer, 1963a, b).

(b) Age. Weller et al. (1962), in an experiment involving 26 twin wether Columbia lambs that had been divided into three groups killed at 150, 200, and 245 days, measured tenderness by shear values and chew counts. They concluded that tenderness was unrelated to age or live weight in this case. The tenderness of various samples from the leg and rib-loin cuts of lambs was measured by Batcher et al. (1962) by panel methods and by obtaining shear values. The age range from 4 to 14 months was greater than that in the trial of Weller's, and they showed that meat from the rib-loin, but not from the leg, was less tender in the older lambs. Paul et al. (1964) however, showed increased tenderness scores for lambs 11 to 12 months old, over those five and a half months old. They attributed this to an increase in marbling.

It seems unlikely that the age of lambs will greatly affect the tenderness of their meat, as they are by definition of a limited age.

(c) Sex. This does not appear to be an important factor prior to puberty. Usborne et al. (1961) found no significant sex effect on tenderness, which was subjectively assessed for crossbred lambs killed at 90 to 110 days of age. In the experiment reported by Broadbent and Bowman (1964), the male lambs were less tender than the females, but this difference was not analysed for significance.

(d) Nutrition. Nutrition can affect tenderness through its effect on the age at which an animal reaches killing weight, or by varying the percentage of the main tissues, but as Palmer (1963b) points out: "At the present time not a single nutrient known has been demonstrated to have any consistent and pronounced effect on beef or pork tenderness. Accepted feed additives such as antibiotics, hormones, and tranquillizers, have not been shown to markedly influence tenderness. Neither borderline

deficiencies nor nutrient fortification have exerted any strong influence on beef or pork tenderness."

The few attempts that have been made to correlate the tenderness of the meat from lambs with their nutritional history are not conclusive. Usborne et al. (1961), for example, could show no significant tenderness differences between groups of lambs fed on regular and high oil corn to market age, while Jacobson et al. (1962) indicated that tenderness was influenced, although not significantly, by a fish meal ration consumed by lambs for a period of 90 days prior to slaughter.

(e) Physical exercise. It was shown by Hiner and Hankins (1951) that the variation in tenderness of muscles within a carcass was correlated with the amount that they were used. This will be a possible source of variation between individuals also, but is not likely to be of importance in meat-type lambs.

(f) Ante-mortem stress. This may be nutritional, hormonal, or physical, and as such could include the effects of nutrition and physical exercise as discussed previously. However, discussion of this factor is usually confined to the acute application of stress immediately prior to slaughter, as opposed to the chronic effects of long term nutrition and physical exercise. Hedrick (1965) has reviewed the influences of ante-mortem stress on meat palatability and concludes that: "The evidence is not clear whether stress immediately pre-slaughter has any marked effect on palatability characteristics of beef and lamb muscle."

Bramblett et al. (1963) applied stress in the form of epinephrine injections, and electric shocks to lambs at regular intervals over 93 days prior to slaughter, and showed that such chronic application of stress tended to reduce the overall tenderness. However, unlike some other

studies, the samples with a high pH were the least tender, and they suggest that chronic application of stress may cause a variation in the proportion of the tissues, rather than intra-muscular changes only.

The physiological basis of ante-mortem stress has been studied extensively, particularly in pigs, and is discussed by Briskey (1963) and Bendal (1963).

2.2.4.3. Post-mortem factors affecting tenderness. In a paper on meat quality and rigor mortis, Marsh (1963) concluded that "...slight variations in treatment during the important few hours following slaughter may produce vast changes in the acceptability of the meat." He pointed out that the muscular tissue is not static in composition and configuration over this period, and that handling at this stage is probably at least as important to tenderness, as are ante-mortem factors.

The two important post-mortem factors that should be kept constant in any experiment involving tenderness assessment are: (a) conditions during the aging period when time, and temperature are the main variables [although the effect of time is negligible below 0°C. (Wilson, 1960)], and (b) conditions during cooking when the main variables are time, temperature, and moisture content of the atmosphere. Paul (1963) reviews recent advances in this area.

Variation in tenderness may also result from inconsistent sampling of the meat. Hiner and Hankins (1951) classified beef muscles into four groups based on differences in tenderness, and Christians et al. (1961) showed that the Longissimus dorsi muscle at the 12th rib was more tender than at the 8th and 9th ribs. Weir (1960) reviews other evidence showing variations within and between muscles of cattle. Comparable information on lambs is scarce. However, Batcher et al. (1962), in an experiment involving sheep ranging in age from 4 to 14 months, showed that with

either raw or cooked cuts the part of the L. dorsi muscle at the ribs was more tender (lower shear values) than that at the loin. Although both these parts of the raw L. dorsi muscle were more tender than any of the leg muscles, in cooked cuts the Semitendinosus was as tender as the rib sample of the L. dorsi, and the Biceps femoris was as tender as the loin end, indicating an interaction between cooking and muscle source.

2.2.4.4. Factors associated with tenderness. Investigation of any suspected association between tenderness and some other factor means that all the factors previously discussed must be taken into account and their effects allowed for if necessary. As has been pointed out by Palmer (1963b), associations of factors with tenderness may be of a physiological nature, in which case they should be permanent, or they may be due to the pleiotropic and/or linkage effects of genes, which may not be permanent (Cockrem, 1959). Some factors that have been suggested as being associated directly with tenderness are discussed below.

(a) Muscle fibre diameter. This is not now recognized as a very close association, although muscles with a low fibre diameter are generally more tender (Joubert, 1956; Tuma et al., 1962). Hiner et al. (1953) reported a curvilinear relationship between fibre diameter and tenderness, and a correlation coefficient of 0.83. More recently Paul (1962) showed that the cross-sectional areas of raw muscle fibres varied significantly among animals, and among sections from different parts of the same muscle within each animal. All correlations were small between fibre areas and tenderness score, number of chews, and shear force, indicating that fibre area was not a good indication of tenderness in this study.

(b) Connective tissue to muscle ratio. An indication of the importance that has been attached to this association is given by the

number of methods that have been devised to measure tenderness through the estimation of connective tissue. After reviewing some of these, Pearson (1963a) points out, with special reference to the hydroxyproline method, that "...the relationship would hold true only if connective tissues were largely responsible for tenderness, which seems doubtful, and if hydroxyproline or hydroxylysine were responsible for a constant proportion of the connective tissue protein."

Wierbicki and Deatherage (1954) noted in animals of uniform age and size that connective tissue had little relation to differences in tenderness at 15 days post mortem.

It seems from these reports that although the ratio of connective tissue to muscle can affect tenderness, this is not a consistent association, probably because of the variability of the tenderness of the muscle tissue per se.

(c) Marbling. The association between marbling and beef quality has been discussed and reviewed by Blumer (1963), and Walter et al. (1965).

Carpenter et al. (1964) estimated a correlation of -0.03 between a marbling score and tenderness in lambs. They compared this result with those of other workers but did not draw any conclusions.

In his review, Blumer (1963) concludes that the value of the association between marbling and tenderness in beef is about 5%. Such a low value suggests that it is not a very close association, and various ways in which marbling could indirectly affect tenderness do exist. Blumer, for example, suggests that the high heat carrying capacity of fat may result in greater breakdown of the collagen during cooking. Alternatively marbling may only affect juiciness, which has been shown to be highly correlated with tenderness (Cover et al., 1962b).

(d) Water holding capacity (W.H.C.). The association between water holding capacity and tenderness seems to be the most basic of the associations that have been extensively studied, and because of this it should be one of the closest. However, W.H.C. only considers the muscle tissue of meat, and will not explain differences in tenderness due to the amount of connective tissue and marbling fat. Hamm (1960) reviews the biochemistry of meat hydration and, in considering the above association, he makes the following points:-

- Processes causing a loosening of protein structure of muscle cause an increase in the W.H.C. and also an increase in tenderness.
- The greater the level of hydration of proteins the greater is the distance between the peptide chains, and the more soft and tender is the meat.
- During post-mortem changes the minimum of muscle hydration (rigor mortis) corresponds with the minimum of tenderness.
- Increased tenderness with aging coincides with an increased W.H.C.
- Tenderizing enzymes raise the level of hydration of meat.
- The iso-electric point of muscle represents the pH minimum of meat hydration and also the pH minimum of tenderness of cooked meat.

He also points out that significant correlations have been shown only when the range of W.H.C. is wide, suggesting that it is not the only factor affecting tenderness. Water holding capacity in turn is dependent largely on the protein/ion/water relationships and hence on the pH of meat.

The chemical and physical changes taking place in meat from immediately prior to slaughter until after it is cooked, have been extensively studied, and reviews of work done in this area have been made

by Hill (1961), Sayre (1962), Briskey (1963, 1964), Deatherage (1963), Howard (1963a), and Hedrick (1965). As far as tenderness is concerned, it appears as though it can be dependent on any of the tissues of meat (i.e., muscle, connective tissue, or fat), and under standardized conditions its association with any one of them in a series of samples, will depend on that tissue's proportions relative to the others, and/or on its variability relative to the others, either in total quantity, or in certain intrinsic properties, such as the W.H.C. of muscle.

Associations between tenderness and other physiological or biochemical parameters have been suggested but in general have not been very widely tested. For example, Hill (1962) showed that the ratio of myofibrillar to sarcoplasmic nitrogen was greater in the Semitendinosus muscle than in the more tender Longissimus dorsi, and also that it was greater in beef than in pork or mutton. On the basis of this, he suggests that there may be a useful relationship between this ratio and tenderness. A correlation between blood phosphatase and tenderness has been demonstrated by Johnston (1963), who measured blood acid and alkaline phosphatase levels in lambs between the ages of 10 and 110 days of age. The lambs which had the most tender meat had both significantly higher levels of alkaline phosphatase, and higher alkaline to acid phosphatase ratio, from 50 days to the slaughter age.

2.2.4.5. Measurement of tenderness. None of the above associations appear to be close enough, and consistent enough to serve as accurate and reliable methods of assessing tenderness. This can probably be attributed to the complexity of tenderness as a physiological characteristic. Methods that have been used to measure tenderness have been reviewed by Doty (1960), Hill (1961), Cook (1963), and Pearson (1963a). A general classification of these methods will be discussed here, together with some

of their advantages and disadvantages.

(a) Panel methods. These may involve many untrained people in a 'consumer panel' or a few trained people in a 'specialized' or 'laboratory panel'. Although they must always provide the yardstick against which all other methods are compared, panel methods have the major disadvantage of being subjective, thereby necessitating repetition, and increasing the sampling problem. Attempts have been made to maximize the objectivity of panel methods in various ways. For example, Cover et al. (1962a, b, c, d) have divided tenderness into six components each of which is scored individually, while other workers (e.g., Paul, 1962) have counted the number of chews made by each member of a panel.

(b) Chemical and histological methods. Most of these have been based on an estimation of the connective tissue content of meat, or on the measurement of muscle fibre diameter. Pearson, after reviewing these methods, states that: "In spite of the efforts expended on chemical methods, to date, none of the methods appear to be satisfactory measures of tenderness under practical conditions."

(c) Mechanical methods. Because of their objectivity, and the fact that they use only a small sample, many machines have been devised for measuring tenderness. Any such machine however, is only as good as the correlation between its results, and those of a trained taste panel. The classification of tenderometers can be carried out on the basis of the way in which they produce results, as follows:-

(i) Those that measure the energy input; as in the case of mincers when electrical input is measured.

(ii) Those that measure a maximum force. This is usually the force required to shear a sample as with the Warner-Bratzler device,

but may be some other force such as that required to press or squeeze a sample through a hole (Sperring et al., 1959).

(iii) Those that produce a graph of force versus distance through the sample; with the force being increased at a constant rate so that the force axis of the graph may equally well represent time (e.g., Winkler, 1939). Graphs of this sort may be compared by estimating their areas, or by estimating the force required per unit distance.

(iv) Those that produce a graph of force versus distance with the rate of movement through the sample being constant, so that the distance axis of the graph may equally well represent time. The machine described by Volodkevich (1938) produces such a graph, and the Kramer shear press may be modified to do so as well. Comparison of graphs of this type may be by comparing areas, or by estimating the maximum force.

It is difficult to know in which form the results are most meaningful, and which machine gives the best measure of a particular type of result. Some isolated comparisons have been made; for example, Sharra et al. (1965) and also Burrill et al. (1962) showed that the Warner-Bratzler device was more highly correlated with scores of tenderness than was the Kramer shear press. Another comparison was made by Hurwicz and Tischer (1954), who compared maximum shear force with the slope of the force versus time curve as measures of tenderness. They used homogenous samples of bees wax and parawax, and concluded that the latter measure was better due to greater sensitivity, and a lower pooled coefficient of variation for the results.

In the choice of a method to measure tenderness it would seem to be best to use a trained taste panel if this is practical or, failing this, to

use a mechanical tenderometer that has been shown to produce results that are highly correlated with taste panel results, for the type of meat being tested.

Chapter 3

MATERIALS and METHODS

3.1. Design of Experiment

In 1963 four Southdown ram lambs (approximately seven months of age) were mated to 108, 4 to 6-year-old, Romney ewes. In 1964 the same four rams, as two-tooths (approximately 19 months of age) were mated to a further 184, 4 to 6-year-old, ewes. The two sections of the experiment in 1963 and 1964 will be referred to as Trial 1, and Trial 2, respectively. In both trials mating commenced in the third week of March and general flock management followed normal practice for the district.

3.2. Experimental Material

The four rams used were selected from 115 ram lambs produced in the Massey University stud Southdown flock in 1962, so as to represent a range of growth rates from birth to weaning. The selected rams were all born and reared as singles.

TABLE 3.1.

Data concerning the selected rams

Ram No.	Sire	Age of dam (Yr.)	Date of birth	Age at weaning 13 Dec. (days)	Weaning wt. (lb.)	Wt. gain/day (lb.)
1	K51/55	3	23 Aug	112	74	0.66
2	N420/58	3	26 Aug	109	72	0.66
3	M237/60	4	6 Sept	98	59	0.60
4	P112/60	3	6 Sept	98	55	0.56

Table 3.1. gives some data referring to these rams and it can be seen from this that:-

(a) Rams 1 and 2 represent 'fast gainers', 3 a 'medium gainer', and 4 a 'slow gainer'.

(b) The age of the dams was three years in all cases except for ram 3.

(c) Each ram had a different sire.

(d) The ages at weaning of the two fastest gainers (1 and 2) were greater than for the other two.

The Romney ewes in the experiment, which were all at least four years old, were from the Massey University flock, and had survived the usual commercial culling practices based on bad feet, teeth, wool, udder, or general lambing record. The ewes were identified by the use of numbered brass ear tags.

3.3. Pre-Slaughter Experimental Procedure

Some pertinent data relating to the pre-slaughter experimental period are shown in Table 3.2.

3.3.1. Mating Procedure

(a) Trial 1. The aim in 1963 was to condense the mating as much as possible so as to minimize the range of birth dates and, by so doing, avoid the need to correct for age at slaughter. In order to achieve this low range a flock of 160 ewes was available, but only those that were on heat were brought to the rams. A service crate was used, and due to the disparity in size between the mature ewes and the ram lambs, it was set into an earth floor so that the ewe was at a lower level than the ram.

Ewes on heat, as indicated by harnessed teaser rams, were brought into the yards twice a day and randomly allocated to the rams. This technique of hand mating, together with a ration of concentrates (2 parts whole oats, 2 parts meal, and 1 part moose nuts) at the rate of 2 lb. per ram per day, from nine days before mating to the end of mating, was used to maximize the effectiveness of the ram lambs.

(b) Trial 2. In this case paddock mating was used, due to the larger number of ewes per ram, and the greater maturity of the rams. The rams were fitted with standard harnesses, and were with the ewes for 36 days, or the length of approximately two oestrous cycles. Different coloured crayons were used after the first 17 days.

TABLE 3.2.

Data concerning mating and lambing

Sire No.	1		2		3		4	
Trial	1	2	1	2	1	2	1	2
Mating commenced	21 Mar	16 Mar	21 Mar	16 Mar	21 Mar	16 Mar	21 Mar	16 Mar
No. ewes/ram	27	46	27	46	27	46	27	46
Mating ceased	30 Mar	22 Apr	30 Mar	22 Apr	30 Mar	22 Apr	30 Mar	22 Apr
Lambing commenced	12 Aug	13 Aug	14 Aug	14 Aug	14 Aug	14 Aug	16 Aug	12 Aug
Lambing completed	25 Aug	11 Sept	22 Aug	13 Sept	25 Aug	15 Sept	24 Aug	19 Sept
Range of birth dates of selected lambs	12 Aug to 25 Aug	23 Aug to 9 Sept	14 Aug to 22 Aug	21 Aug to 13 Sept	14 Aug to 25 Aug	22 Aug to 10 Sept	16 Aug to 24 Aug	17 Aug to 11 Sept
Range (days)	13	17	8	23	11	19	8	25

3.3.2. Management from Mating to Lambing

Immediately after mating in both trials the ewes from the four sire groups were run as one mob, and their management over the winter and up to lambing followed routine procedures.

3.3.3. Management and Records taken at Lambing

Lambing management also followed routine procedures and was the same for both trials. Records obtained at lambing were kept in a lambing book, the layout of which is shown in Table 3.3.

TABLE 3.3.

Lambing book layout and sample entries

Ewe No.	Ram No.	Lamb No.		Birth date	Birth wt.		Remarks
		Ram	Ewe		Ram	Ewe	
1/58 Meat	1	- -	20 -	16 Aug	- -	10.5 -	Assisted
42/58 Meat	4	21 22	- -	17 Aug	10 11	- -	

Birth weight was obtained with a spring balance weighing to an accuracy of 0.5 lb. Conditions during lambing in both years were generally considered to be fairly normal with some cold and/or wet days; except for a period of several days at the beginning of September in 1964 when a particularly cold and wet spell was experienced.

3.3.4. Management from Lambing to Selection for Slaughter

Over this period in Trial 1, as in Trial 2, the sheep were set stocked in one or more paddocks, any division being made on the basis of lambing dates or at random. The lambs were dagged each year during November.

Seasonal conditions from lambing to selection for slaughter were

better in 1963 as indicated by the carcass weights of the lambs. This difference was attributed largely to a particularly dry November in 1964 (1.9 inches of rain as opposed to 5.2 inches in 1963) which resulted in feed becoming relatively scarce, and possibly less palatable. The cold spell at the beginning of September 1964 may also have had an effect on final lamb weights.

3.4. Experimental Procedure from Selection of Lambs for Slaughter to Freezing of their Carcasses

3.4.1. Selection of Lambs for Slaughter

(a) Trial 1. In this trial selection of lambs for slaughter was based on their age. The average live weight of the lambs, when they were weighed in the paddock on 25th November 1963, was 64.3 lb. Details of the times and dates of slaughter are given in Table 3.4., but the general procedure, which took place on three consecutive days, was to wean the lambs in the late afternoon, leave them in a shed overnight to empty out, and then slaughter them the following afternoon.

(b) Trial 2. The greater number of lambs available enabled half to be slaughtered at a constant age, and half at a constant date. A total of 210 lambs were available in 1964 and it was decided that 120 of these would be used in the progeny test. Selection of these 120 from the 210 involved the following steps:-

(i) Removal of all triplets.

(ii) Removal of all lambs with a birth date outside a 20-day range from 22 August 1964 to 11 September 1964.

(iii) From within this range two groups of 15 were picked at random from each sire group, making a total of 30 per sire and 120 overall.

(iv) A check was made to ensure that each sex and birthrank classification was represented in each slaughter group of each sire. Where this was not the case, a suitable replacement was made, if possible from within the range of birth dates, but in some cases previously discarded lambs had to be used.

(v) Some lambs had to be replaced by a similar procedure due to lost ear tags and missing animals.

TABLE 3.4.

Slaughter details

Group	Date of slaughter	No. of lambs	Time of weaning	Time of killing	Time of entry to freezer	Av. time from weaning to killing (hr.)	Av. time from killing to freezing (hr.)
				TRIAL 1			
1	28 Nov	25	4.00 p.m. 27 Nov	3.30-7.30 p.m.	12.00 a.m. 29 Nov	25	19
2	29 Nov	25	4.00 p.m. 28 Nov	1.30-6.00 p.m.	9.30 a.m. 30 Nov	24	17
3	30 Nov	18	4.00 p.m. 29 Nov	1.30-5.30 p.m.	9.30 a.m. 1 Dec	24	17
				TRIAL 2			
1	2 Dec	17	3.00 p.m. 1 Dec	8.00-9.30 a.m.	7.00 a.m. 3 Dec	18	22
2	8 Dec	60	3.30 p.m. 7 Dec	8.30 a.m. - 2.00 p.m.	7.00 a.m. 9 Dec	20	20
3	9 Dec	31	3.30 p.m. 8 Dec	8.30-11.30 a.m.	7.00 a.m. 10 Dec	19	21
4	15 Dec	5	3.30 p.m. 14 Dec	7.30-8.00 a.m.	6.30 a.m. 16 Dec	17	23
5	17 Dec	7	3.30 p.m. 16 Dec	7.30-8.30 a.m.	6.30 a.m. 18 Dec	17	23

This resulted in two killing groups of 60, each containing 15 lambs from each sire, and each lot of 15 containing at least two (except in two cases when there was only one) representatives of the following four categories: twin wether, single wether, twin ewe, and single ewe.

The times and dates of slaughter of the lambs in Trial 2 are also shown in Table 3.4. The procedure in this trial differed slightly, due to a different place of slaughter. The ewes and lambs were brought into the yards on the day prior to slaughter, when the appropriate lambs were picked out, weaned, weighed, and transported by truck to the city abattoir, where they were slaughtered the following morning.

Slaughter of the 120 lambs was in five lots, four of these at a constant age, and one at a constant date, independent of individual ages. All killing dates in Trial 2 were completely independent of the weight of the lambs, but were entirely dependent on the average age of the lambs, which was equal to that of Trial 1 lambs, i.e., 102.9 days. Table 3.5. shows how closely this average was maintained within the groups.

TABLE 3.5.

Average slaughter ages, and the range of ages within each sire group

Trial / Sire No.		1	2	3	4	Total
1	Av.	103.8	102.7	102.0	102.6	102.9
	Range	100-109	98-107	98-108	99-105	99-109
2A	Av.	102.7	102.2	103.4	102.5	102.7
	Range	100-106	98-106	100-106	98-106	98-106
2B	Av.	100.9	104.1	101.1	103.5	102.4
	Range	91-108	94-110	90-109	97-114	90-114

3.4.2. Slaughter Procedure

(a) Trial 1. The slaughter and the dressing of the lambs was carried out at the University abattoir by a professional butcher. After being weighed, the lambs' throats were cut and they were dressed following normal commercial practice, with removal of the head and the lower limbs (metatarsals and metacarpals). The thyroid gland, plus the kidneys without the perirenal fat, were also removed. Preparation and weighing of the organs and parts, and the recording of the following data, involved a team of six people.

(1) Live wt.
(2) Feet wt. (four shanks).
(3) Pelt + wool wt.
(4) Head + tongue wt.
(5) Hot carcass wt.
(6) Cold carcass wt.
(7) Left fore cannon bone wt.
(8) Stomach + oesophagus wt., full.
(9) Stomach + oesophagus wt., empty.
(10) Stomach + oesophagus wt., contents.
(11) Small + large intestine wt., full.
(12) Small + large intestine wt., empty.
(13) Small + large intestine wt., contents.
(14) Total digestive tract contents wt.
(15) Heart wt.
(16) Lungs + trachea + diaphragm wt.
(17) Spleen wt.
(18) Liver wt.
(19) Kidneys wt.

(20) Thyroid wt.

(21) Omental fat wt.

(22) Mesenteric fat wt.

(23) Genital tract + bladder wt.

(24) Pancreas wt.

The carcasses were hung on gambrels of standard width, and stored in the abattoir chiller until the morning after slaughter, when they were weighed again, and the following linear measurements made, using steel calipers and a wooden metre rule.

(1) Leg length (F).

(2) Gigot width (G).

(3) Maximum rib width (WR).

(4) Maximum width of forequarters (WF).

(5) Minimum width behind scapulae (Wth).

(6) Depth of thorax (Th), (Trial 2 only).

(7) Length of tibia + tarsus (T).

(8) Length of radius-ulna (R).

(9) Length of body; tail head to base of neck (K).

These measurements and the associated letters are those described by Palsson (1939).

The carcasses were then transferred to the freezers of a local freezing works, for storage until they could be dealt with in the meat laboratory.

(b) Trial 2. The procedure in 1964 was basically the same as outlined above but it differed in the following ways: (1) slaughter took place at the local city abattoirs, (2) carcass measurements were not made on the carcasses before they were taken to the freezer, and (3) the number of organs weighed at slaughter was reduced because of the lack of facilities

at the abattoir. The weights that were taken are as follows:-

(1) Live wt.

(2) Feet wt.

(3) Heat + tongue wt.

(4) Hot carcass wt.

(5) Stomach + oesophagus wt., full.

(6) Stomach + oesophagus wt., empty.

(7) Stomach + oesophagus wt., contents.

(8) Heart wt.

(9) Lungs + trachea + diaphragm wt.

(10) Spleen wt.

(11) Liver wt.

(12) Kidneys wt.

(13) Omental fat wt.

3.5. Post-Slaughter Experimental Procedure

3.5.1. Meat Laboratory and Chemical Methods

Three carcasses in Trial 1, and 12 in Trial 2, were brought from the freezer each week day. The greater number handled per day in the second trial was due to: (1) modification of the chemical procedure, as outlined later, and (2) the fact that during the first year some hogget carcasses were being dealt with concurrently. After being weighed, the carcasses were divided down the centre of the vertebral column with a meat bandsaw, and then each side was weighed individually.

The left side of the carcass had the loin removed by cutting with the bandsaw between the fifth and sixth ribs, and between the second to last and last lumbar vertebrae at right-angles to the back. This cut was then trimmed to a width of seven inches and was used for tenderness evaluations.

The remainder of the left side was not used in the experiment.

In Trial 2, linear carcass measurements outlined previously were made prior to the splitting of the carcass, and in both trials measurements taken after splitting were made on the right side. These were as follows (Palsson, 1939):-

(1) Length of body; pubic symphysis to first rib (L).

(2) Pubic symphysis to last rib (H).

(3) Pubic symphysis to tarsals (P).

The right side was cut into four joints, viz., leg, loin, 9-10-11 rib-cut, and rest. Jointing was done as described by Kirton et al. (1962) and involved bandsaw cuts between the eleventh and twelfth ribs; between the eighth and ninth ribs; between the last thoracic and the first lumbar vertebrae perpendicular to the back; and between the last lumbar and the first sacral vertebrae perpendicular to the back.

The following measurements were made on the face of the twelfth rib, i.e., on the loin cut (Palsson, 1939):-

(1) Length of eye muscle (A).

(2) Depth of eye muscle (B).

(3) Depth of fat over B (C).

(4) Depth of fat over the spinal process (D).

(5) Depth of subcutaneous fat over the rib (J).

(6) Depth of muscle over the lower rib (X).

(7) Depth of subcutaneous fat over X (Y).

(8) Area of the eye muscle (Trial 2 only).

The frozen joints, after weighing, were cut into $\frac{1}{8}$-$\frac{1}{4}$ inch thick slices using the bandsaw, and these slices were ground in a Hobart 1 h.p. mincer using a plate with 1.0 cm. holes for the first two mincings, and one with

0.60 cm. diameter holes for the final mincing.

Sampling for chemical analysis, using the method of Kirton and Barton (1958a), involves the taking of two samples, each of approximately 50 g., from the mince of each joint. If all chemical analyses were started immediately following mincing and sampling, the number of carcasses that could be handled per day in the meat laboratory would be dependent on the rate at which these analyses were carried out. To overcome this bottle-neck in Trial 2, 12 carcasses per day were handled and mince samples that could not be analysed immediately were frozen. This was done by taking 400 g. samples from each lot of mince concerned, and storing them in one pint, air-tight glass jars at approximately -10°C. When required, these jars were taken out of the freezer, allowed to thaw at room temperature for five to six hours, and then two 50 g. samples were weighed out for analysis.

In order to find if this freezing-thawing procedure had any effect on the water content of the mince, a series of samples was taken so that one of a pair was from the external layers of the material in the jar, and the second was from the interior which was usually still frozen. The internal samples of 23 pairs averaged 0.2% more water than the external samples and this was not considered important.

Chemical analyses of the samples for fat (petroleum ether extract), water, protein, and ash were carried out using the method of Kirton and Barton (1958a). Attributes of this method of analysis, making it suitable for this type of work, are discussed by Hight (1961), and Kemp and Barton (1965). The dried fat-free residues resulting from the removal of water and most of the fat were bulked within joints and within sire groups, thus producing 16 lots to be analysed for ash content, and remaining fat content. In view of the findings of Kemp and Barton (1965), the components of the carcass were reduced to chemical fat, water, and residue, for purposes of

statistical analysis, i.e., inclusion of ash and protein as a residue. Ash determinations were carried out however, and the ash:protein ratios were estimated for the 16 lots, i.e., the four joints from the four sire groups.

3.5.2. Tenderness Evaluation Techniques

Tenderness tests were carried out, using a tenderometer, on samples of cooked Longissimus dorsi muscle taken from the loin of the left side of each carcass. Removal of the loin from the side has been described previously. Preparation of this loin for cooking involved the removal of the Psoas muscle and the trimming of the fat to an even thickness.

The prepared loins were placed in thermostatically controlled 'Neeco' ovens, which had been heated to, and were set at, 163°C. When an internal temperature of 80°C. was reached, the roasts were removed from the ovens, left for $\frac{3}{4}$ hour, and then the L. dorsi muscle was removed, wrapped in aluminium foil, and stored in a refrigerator at 5°C. until the following day when samples were taken. The internal temperature was measured by means of thermocouples which were inserted into the centre of the L. dorsi muscle. Two were placed in each loin and a third measured oven temperature, so that with four ovens there were 12 thermocouples. Readings from each of these were made on the same galvonometer by the use of a 12-way switch.

The samples taken from the L. dorsi muscle were approximately 30 mm. x 15 mm. x 6 mm. with the muscle fibres running parallel to the 30 mm. edges. They were taken after removing the outer layer of connective tissue from one side of the muscle, and extended forward from a point approximately 45 mm. from the posterior end of the loins.

The tenderness of the samples was evaluated by the use of a tenderometer of local manufacture, which is basically the same design as that described by Winkler (1938), and that referred to by Marsh (1963) in

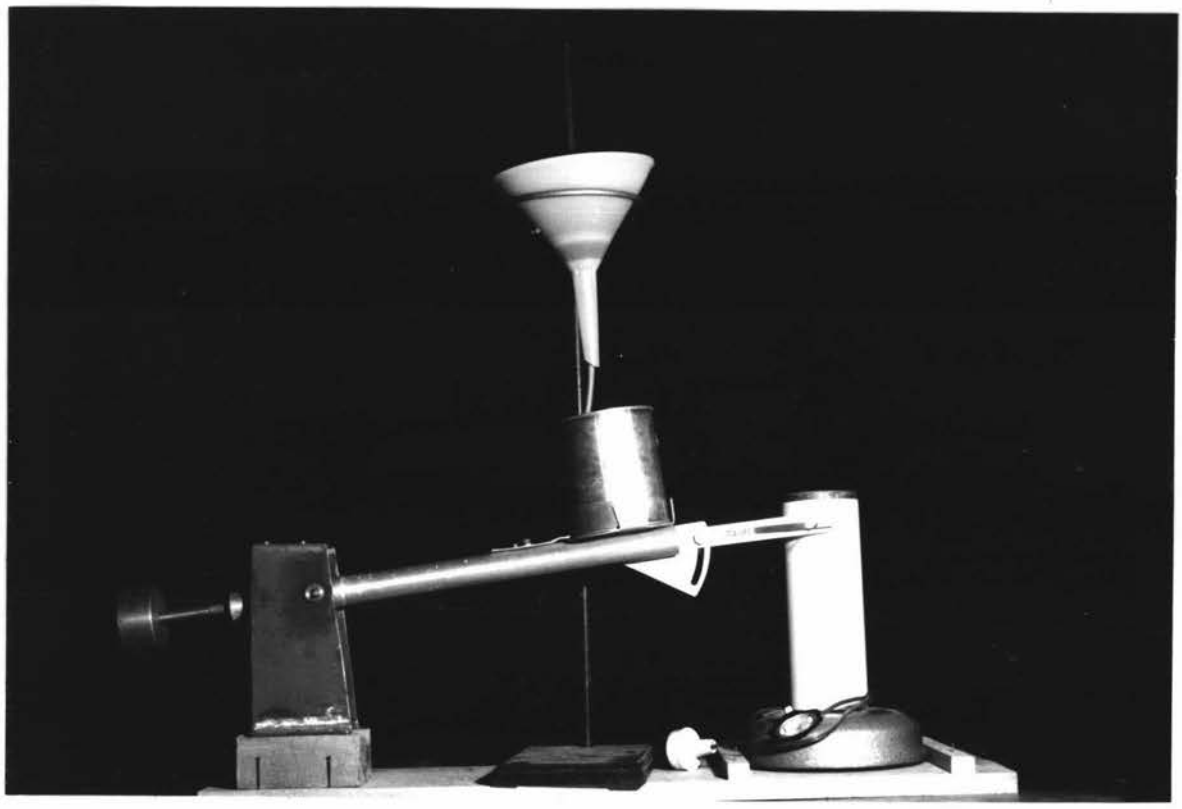


Fig. 3.1. Two aspects of the tenderometer

his discussion concerning the correlations between taste panel and objective assessment. The device which is shown in Figure 3.1. measures the force required to shear the sample between two blunt wedges, when this force is increasing at a constant rate. The sample is held between two 13 x 30 mm. brass plates, 15 mm. apart. The smaller wedge, which is approximately 2 mm. deep, is between these two plates and at right-angles to them. The larger wedge is stationary and is positioned so that the tip of both wedges is equidistant from the pivot of the arm. Initially the sample is placed between the brass plates on the smaller wedge, and the adjustable weight on the arm is set so that the large wedge is just touching the sample. The force is produced by the flow of lead shot through a funnel into a container which is attached to the arm on the opposite side of its pivot to the wedge. When the flow of lead shot into this container is constant, the graph that is produced on the revolving drum is of 'distance through the sample' along the y axis, versus 'force' or 'time' along the x axis. Two such graphs were produced for each sample.

3.6. Statistical Methods

Information available for each lamb from the experiments may be summarized as follows:

(a) Age, birth weight, live weight at slaughter, carcass weight, and weights of non-carcass components.

(b) Linear carcass measurements and loin eye area.

(c) The chemical composition of the whole right side and of four joints making up that side.

(d) Tenderness graphs.

The most obvious possible sources of variation between the lambs

involved were:-

(a) Due to year differences. Trial 1 was run in 1963 while Trials 2A and 2B were run in 1964.

(b) Due to age differences. In Trial 1 and 2A lambs were slaughtered at a constant age, but in Trial 2B they were slaughtered at a constant date, and therefore varied in age.

(c) Due to weight differences.

(d) Due to sire differences. The same four sires were used in all trials.

(e) Due to birthrank differences. Singles and twins only were considered; those twins that were raised as singles were regarded as singles.

(f) Due to sex differences.

Some requirements of a method of analysis that could be applied to such data are that it should:-

(a) Enable corrections to be made for a number of discrete and continuous variables.

(b) Enable analysis of lots of data with unequal subclass numbers.

(c) Enable estimation of the significance of the sources of variation considered.

(d) Enable estimation of the significance of interactions between the variables.

The method used in this case involved the fitting of constants by least squares as described by Kempthorne (1952), and Harvey (1960).

Several models, all of which were additive, were used to analyse

different sections of the data, as shown in Table 3.6. An example of a model, which was not actually used but which incorporates all the constants and regressions that were fitted in any of the models, is as follows:-

$$y_{ijklm} = \mu + s_i + a_j + b_k + t_l + (st)_{il} + d\,(Z_{ijklm} - \bar{z}) + c\,(X_{ijklm} - \bar{x}) + e_{ijklm}$$

where y_{ijklm} = the m^{th} observation in the i^{th} sire class,
in the j^{th} birthrank class,
in the k^{th} sex class,
and in the l^{th} year.

μ = overall mean for all the observations when subclass numbers are equal.

s_i = effect of the i^{th} sire expressed as a deviation from μ.
$i = 1$ to 4.

a_j = effect of the j^{th} birthrank expressed as a deviation from μ.
a_1 = single, a_2 = twin.

b_k = effect of the k^{th} sex expressed as a deviation from μ.
b_1 = ewe, b_2 = wether.

t_l = effect of the l^{th} year expressed as a deviation from μ.
t_1 = 1963, t_2 = 1964.

$(st)_{il}$ = effect of the il^{th} subclass after the average effects of sire and year have been removed, i.e., an individual sire/year interaction effect expressed as a deviation from μ.

d = coefficient of partial regression of the dependent variable y on the age of the individual which is the independent variable.

Z_{ijklm} = the value of the independent variable (age) corresponding to y_{ijklm}.

TABLE 3.6.

Constants included in the least squares models used in the statistical analysis of data concerning different characteristics

Group	Characteristics	Constants fitted									
		μ	s_i	a_j	b_k	t_l	$(st)_{il}$	c			d
								c/c	Leg	Side	
Trial 1 or Trial 2A	Growth rate, Live wt., Carcass (c/c) wt., Birth wt.	*	*	*	*						
	Tenderness, Wts. of non-carcass body parts, Carcass measurements.	*	*	*	*			*			
	Side chemical components wts., Wts. of joints.	*	*	*	*					*	
	Leg chemical components wts.	*	*	*	*				*		
Trial 2B	Growth rate, Live wt., Carcass wt., Birth wt.)	*	*	*	*						*
	Tenderness, Wts. of non-carcass body parts, Carcass measurements.	*	*	*	*			*			*
	Side chemical components wts., Wts. of joints.	*	*	*	*					*	*
	Leg chemical components wts.	*	*	*	*				*		
Trials 1 plus 2A	Side chemical components wts., Wts. of joints.	*	*	*	*	*	*			*	
	Tenderness, Wts. of non-carcass body parts, Carcass measurements.	*	*	*	*	*	*	*			

$\bar{z}$ = the mean age of the individuals.

c = coefficient of partial regression of y on X where X is either side weight, carcass weight, or leg weight.

X_{ijklm} = the value of the independent variable (e.g., side wt.) corresponding to y_{ijklm}.

$\bar{x}$ = mean weight of the individuals.

e_{ijklm} = a random error term.

For least squares methods of estimation, and of testing significance to be valid, the error term must have a mean of zero, a constant variance, and be normally and independently distributed. Validity of the model is also dependent on the homogeneity of the regression coefficients between the classes, and this was tested for using covariance techniques (Snedecor, 1956).

The analysis of data using any of the models shown in Table 3.6. started with the formation of a set of normal equations, one for each constant being fitted, and one for each regression. The coefficients of the constants in these equations were equal to the appropriate numbers in the classes or subclasses, and those of the regression coefficients were expressed as the deviations of the independent variable from its overall mean (Kempthorne, 1952).

The availability of an IBM 1620 model II electronic computer after some of the data had been analysed, resulted in certain changes being made in the methods used to reduce the normal equations to a set of independent simultaneous equations, and in the computation of sums of squares for the different classifications. The steps followed in the two procedures will be briefly outlined separately.

(A) The steps taken using a desk calculator are those set out in detail by Kempthorne (1952).

(1) Absorption of the mean (μ) into the main classification (s_i) to form four ($\mu + s_i$) equations.

(2) Rearrangement of the ($\mu + s_i$) equations so that the ($\mu + s_i$) are expressed in terms of the other constants, the partial regression coefficients, and the right hand side (RHS), or y term.

(3) Substitution of these expressions for the ($\mu + s_i$) in the other equations, thus reducing the total number of equations by four.

(4) All other classifications (except in the case of the interaction model which was not analysed in this way) contained only two constants, so that by equating one of these to zero, the estimate of the other became a measure of the difference between the two, e.g., if a_2 is equated to zero then the a_2 column and row are removed from the matrix of coefficients and a_1 will be estimated as $(a_1 - a_2)$.

(5) Application of these restrictions resulted in a set of independent simultaneous equations. These were solved by inverting the variance-covariance matrix formed from the coefficients of the constants and regression coefficients, and post-multiplying this by the column vector formed by the right hand sides.

(6) The estimates from this procedure were then substituted in the original ($\mu + s_i$) equations in order to estimate the ($\mu + s_i$).

(7) The reduction in sums of squares due to the fitting of all

constants and regressions $[R(\mu,s_i,a_j,b_k,t_l,(st)_{il},d,c)$ in model shown previously$]$ was calculated as the sum of the products of the estimates and the right hand sides. The error sums of squares is equal to the difference between this total reduction, and the total uncorrected sums of squares of y.

(8) The sums of squares due to various constants were calculated as the difference between the reduction in sums of squares when all constants are fitted, and that when all but the constant being tested are fitted. This gives the analysis of variance in Table 3.7. for the model:-

$$y_{ijkl} = \mu + s_i + a_j + b_k + c\ (X_{ijkl} + \bar{x}) + e_{ijkl}$$

where $\bar{x}$ = mean carcass weight.

TABLE 3.7.

Analysis of variance

Source of variation	S.S.	d.f.	M.S.	F
Birthrank	$R(\mu,s_i,a_j,b_k,c) - R(\mu,s_i,b_k,c)$ $= SSa$	j-1	$\frac{SSa}{j-1} = MSa$	$\frac{MSa}{EMS}$
Sex	$R(\mu,s_i,a_j,b_k,c) - R(\mu,s_i,a_j,c)$ $= SSb$	k-1	$\frac{SSb}{k-1} = MSb$	$\frac{MSb}{EMS}$
Sire	$R(\mu,s_i,a_j,b_k,c) - R(\mu,a_j,b_k,c)$ $= SSs$	i-1	$\frac{SSs}{i-1} = MSs$	$\frac{MSs}{EMS}$
Carcass wt.	$R(\mu,s_i,a_j,b_k,c) - R(\mu,s_i,a_j,b_k)$ $= SSc$	1	$\frac{SSc}{1} = MSc$	$\frac{MSc}{EMS}$
All constants	$R(\mu,s_i,a_j,b_k,c)$	j+k+i-2		
Error	$\Sigma\Sigma\Sigma\Sigma_{ijkl}\ y^2_{ijkl} - R(\mu,s_i,a_j,b_k,c)$ $= SSe$	n-(j+k+i-2)	$\frac{SSe}{n-j-k-i+2} = EMS$	
Total	$\Sigma\Sigma\Sigma\Sigma_{ijkl}\ y^2_{ijkl}$	n		

(B) With the use of an electronic computer the following steps were taken as they were more easily programmed.

(1) The restriction that the members within a classification sum to zero was applied so that by subtracting the last member of each classification from every other member, and removing the appropriate rows and columns from the variance-covariance matrix, a set of independent simultaneous equations was produced.

(2) These were solved as in (A) above by matrix inversion and multiplication.

(3) Total reduction of the sums of squares due to fitting all constants was calculated as above by vector multiplication.

(4) The sum of squares due to each separate classification was calculated directly using the following formulae:-

$$\text{Sum of squares} = B' \, Z^{-1} \, B$$

where B' = the transpose of the column vector made up of the estimates of the constants within a particular classification, e.g., in the s_i classification it will be the estimates of s_1, s_2, and s_3. (S_4 is removed due to (1) above.)

Z^{-1} = the inverse of the segment of the inverse of the variance-covariance matrix, corresponding by row and by column, to the set of constants whose estimates make up B.

B = the column vector of the estimates of the constants within a particular classification.

Calculation of the sum of squares is then, by pre-multiplication

of Z^{-1} by B' to produce a row vector, and post-multiplication of this by B to give the estimate.

(5) Analysis of variance is as shown in Table 3.7., except in the calculation of the sums of squares.

The estimates that are obtained by solving the normal equations by the two procedures (A) and (B) outlined differ in the following ways:-

(a) In procedure (A) the mean sire effects are estimated as absolute values ($\mu + s_i$) while in procedure (B) they are estimated as deviations from the mean (s_i).

(b) In procedure (A) the means are not calculated separately, but the sire effects ($\mu + s_i$) are corrected to a base of the mean twin wether. In procedure (B) however, the means (μ) are corrected to a base of the individual whose sex is equivalent to (mean wether + mean ewe)/2, whose birthrank is equivalent to (mean single + mean twin)/2, and who belongs to a sire group equivalent to (sum of the means of the four sire groups)/4.

(c) The difference in (b) is a result of the different restrictions imposed on the normal equations so that in procedure (A), a_1 (for example) is estimated as $(a_1 - a_2)$ while in procedure (B) a_1 is estimated as a deviation from the mean, and $a_2 = -a_1$, i.e., $a_1(A) = 2a_1(B)$.

(d) Valid comparison of the ($\mu + s_i$) calculated in the two procedures will necessitate the addition of a_2 and b_2 (and e_2 where appropriate) to the μ if procedure (B) was followed.

Variance components corresponding to the effects corrected for in a particular least squares model were calculated in a number of cases.

Table 3.8. shows the expected mean squares in terms of variance components for a model which includes corrections for sire, birthrank, sex and side weight effects.

TABLE 3.8.

Expected mean squares expressed as variance components

Source of variation	E(MS)
Sire	$\sigma_e^2 + k_4\sigma_s^2$
Birthrank	$\sigma_e^2 + k_3\sigma_a^2$
Sex	$\sigma_e^2 + k_2\sigma_b^2$
Side wt.	$\sigma_e^2 + k_1\sigma_c^2$
Error	σ_e^2

The k's shown in Table 3.8. were calculated by the 'direct' method of Harvey (1960), which involved the use of the following general equation:-

$$k = \frac{1}{m}\left(\Sigma_i Z^{ii} - \frac{1}{d.f.}\Sigma\Sigma_{ij} Z^{ij}\right)$$

m = number of members in the classification concerned.

z = the inverse of the symetrical square segment from the variance-covariance inverse matrix, corresponding by row and by column to the classification.

d.f. = degrees of freedom.

$\Sigma_i Z^{ii}$ = the sum of the elements on the main diagonal of the z matrix.

$\Sigma\Sigma_{ij} Z^{ij}$ = the sum of all the off-diagonal elements of the z matrix.

From the k's and σ^2_e, which is known, all other components were calculated and each was expressed as a percentage of the total.

A programme was written for the computer enabling calculation of the means, the standard deviations, and all correlations between a set of 12 variables. Data on carcass linear measurements and weights of body parts were analysed in this way within trials, within sexes, within birthranks, and within sires. In some cases the homogeneity of a set of such correlations was tested by applying a transformation and following the procedure outlined by Snedecor (1956).

The chemical composition data of the whole sides, and of the four cuts making up that side, were also used to form multiple regression equations. The dependent variable being the weight of a particular component in the whole side, and the independent variables being the weight of that same component in one of the cuts, plus the side weight. The partial regression coefficients, the multiple correlation coefficient, the sum of squares of deviations from the regression, and the standard error of the estimate were calculated as described by Snedecor (1940). Homogeneity of the partial regression coefficients between trials, between sexes, and between sires, in Trials 2A and B, was tested by covariance techniques (Snedecor, 1956). Fortran computer programmes were written for multiple regression and covariance analyses such that part of the output of the first programme was in the form of punched cards which served as input for the second programme.

Chapter 4

RESULTS

4.1. Homogeneity of Regression Coefficients

Analysis of data using a least squares model which includes a covariance or regression term, is only valid if the regression coefficients based on data from the classes and subclasses are homogenous. Table 4.1. gives the results of a number of covariance analyses carried out on a sample of characteristics. Regression equations within each sire group are given, together with the standard errors both as absolute values, and as a percentage of the mean of the dependent variable ($\overline{Y}$). The heterogeneity column gives the results of the covariance tests. In the case of those regressions with side or carcass weight as the independent variable, a non-significant result from Trial 1 data was taken to be representative of all data. The only significant result obtained in the sets tested was for carcass length (L), in which case a further covariance analysis was conducted using data from Trial 2A. This resulted in the most homogenous set of regression coefficients of those tested, and on the basis of this the relationship between carcass length, which was taken as a typical carcass linear measurement, and carcass weight was treated as constant between sire groups.

Only analysis of Trial 2B data involved a regression of the characters on age, as well as on carcass or side weight. Covariance analyses on a sample of such characteristics all showed non-significant heterogeneity, despite quite large variations in the regression coefficients. This appears to have been due to particularly large within group sums of squares of the deviations, which reflects the low proportion of the characteristics' variability that can be attributed to age. This in turn is probably due to

TABLE 4.1.

Regression equations within each sire group, standard errors, and measurements of the significance of the heterogeneity of regression coefficients between sire groups, for a selection of characteristics

Dependent variable (Y)	Sire group	Regression equation	Standard error		Heterogeneity
			Absolute	% of $\bar{Y}$	
		X = Side wt. (kgm)			
Side fat wt. (kgm) Trial 1	1	Y = 0.486X - 1.16	0.16	7.44	
	2	Y = 0.439X - 0.97	0.21	10.88	
	3	Y = 0.474X - 1.23	0.29	11.64	
	4	Y = 0.571X - 1.73	0.28	12.14	N.S.
Side protein wt. (kgm) Trial 1	1	Y = 0.316 + 0.106X	0.07	6.93	
	2	Y = 0.141 + 0.132X	0.07	7.21	
	3	Y = 0.438 + 0.095X	0.09	7.52	
	4	Y = 0.506 + 0.072X	0.07	6.14	N.S.
		X = Carcass wt. (kgm)			
Heart wt. (kgm) Trial 1	1	Y = 0.0486 + 0.00631X	0.009	7.04	
	2	Y = 0.0361 + 0.00787X	0.013	9.75	
	3	Y = 0.1079 + 0.00305X	0.008	5.37	
	4	Y = 0.0705 + 0.00479X	0.008	5.62	N.S.
Carcass length L (cm) Trial 1	1	Y = 48.69 + 0.0970X	2.87	5.53	
	2	Y = 36.49 + 0.4625X	1.25	2.50	
	3	Y = 49.10 + 0.0519X	1.05	2.06	
	4	Y = 43.56 + 0.2081X	1.08	2.16	*
Carcass length L (cm) Trial 2A	1	Y = 40.55 + 0.3855X	1.74	3.36	
	2	Y = 39.87 + 0.3751X	0.94	1.82	
	3	Y = 41.33 + 0.3557X	1.54	3.00	
	4	Y = 40.29 + 0.3747X	3.90	7.00	N.S.
Depth of fat at C (mm) Trial 1	1	Y = 0.6521X - 3.726	1.90	35.16	
	2	Y = 0.6639X - 7.350	1.39	30.39	
	3	Y = 1.0460X - 10.427	1.64	26.90	
	4	Y = 0.6789X - 4.872	0.98	20.81	N.S.
Tenderness Trial 1	1	Y = 0.2146 + 0.0844X	0.42	30.13	
	2	Y = 0.6748 + 0.0331X	0.31	27.52	
	3	Y = 0.0248 + 0.0751X	0.39	31.93	
	4	Y = 0.7024 + 0.0158X	0.29	32.10	N.S.

Cont.....

Table 4.1. (Cont.)

Dependent variable (Y)	Sire group	Regression equation	Standard error		Heterogeneity
			Absolute	% of $\bar{Y}$	
		X = Age at slaughter (days)			
Side water (kgm) Trial 2B	1	Y = 4.6653 - 0.0130X	0.50	15.03	
	2	Y = 2.4950 + 0.0117X	0.55	14.90	
	3	Y = 1.8675 + 0.0128X	0.50	16.10	
	4	Y = -2.1205 + 0.0530X	0.39	11.76	N.S.
Width of forequarter (WF) (cm) Trial 2B	1	Y = 20.1937 - 0.0147X	1.97	11.11	
	2	Y = 10.3806 + 0.0833X	1.72	9.01	
	3	Y = 17.1747 - 0.0088X	1.66	9.45	
	4	Y = 0.5593 + 0.1799X	1.99	10.62	N.S.
Measurement B (mm) Trial 2B	1	Y = 50.471 - 0.2109X	3.47	11.87	
	2	Y = 43.435 - 0.1184X	3.49	11.23	
	3	Y = 19.910 + 0.0793X	3.21	11.49	
	4	Y = -4.060 + 0.3208X	4.04	13.92	N.S.
Liver wt. (kgm x 10) Trial 2B	1	Y = -4.9687 - 0.0128X	0.72	14.48	
	2	Y = -0.5897 + 0.0356X	0.53	9.92	
	3	Y = +1.6901 + 0.0512X	0.59	12.88	
	4	Y = +6.2510 + 0.0950X	0.50	10.31	N.S.

* Indicates statistical significance at the 5% level of probability.
** Indicates statistical significance at the 1% level of probability.
N.S. Indicates non-significance at the 5% level of probability.

This notation will be used throughout the thesis.

the small variation in the ages of the lambs (Coefficient of variation = 5.2%).

The regression equations with fat measurements as the dependent variable had negative 'a' values as a result of the fact that fat is a late developing tissue. Standard errors for the regressions on side and carcass weights are all low except in the case of fat thickness (C) over the L. dorsi muscle at the first lumbar vertebra, and tenderness. In the case of C it is probably due to its high variability (Coefficient of variation = 48.1% in Trial 1), which may be either inherent variation, or variation

due to difficulty in taking the measurement. Measurements of C, which had an average value in Trial 1 of approximately 5 mm., were made to an accuracy of only 1 mm. or 20% of the average, suggesting that inaccuracy of measurement would be a major source of variation. In the case of tenderness, high standard errors of regression probably reflect its lack of dependence on carcass weight.

4.2. Live and Carcass Weights

Table 4.2. gives the least squares estimates of the overall mean, the deviations of each sire group from this mean, the least squares differences between singles and twins, and between ewes and wethers, and the partial coefficients of regression on age and carcass weight; for birth weight, live weight at slaughter, and dressing-out per cent. Table 4.3. gives the mean squares from an analysis of variance, for the same characters as are involved in Table 4.2., and for the following sources of variation: sire, birthrank, sex, carcass weight, age, and error. These two forms of tables (Tables 4.2. and 4.3.) will hereinafter be referred to as tables of least squares estimates, and of mean squares, respectively. In all such tables the weight on which any particular characteristic is regressed (e.g., carcass weight in Table 4.2.) will be measured in the same units as the characteristic, unless otherwise specified.

Birth weights were measured to an accuracy of 0.5 lb. within 24 hours of birth. Some sources of variation in this weight that were not included in the statistical model were: whether or not the lamb had had its first drink, the wetness of the lamb, and the accuracy of the actual weighing. Live weights were taken by using a tripod and clockfaced scales accurate to 1 lb. Here again two obvious sources of variation existed that were not considered statistically. First, the weighing of Trial 1 lambs took place immediately before slaughter, after they had been held in yards for almost

TABLE 4.2.

Least squares means and least squares deviations of sire groups from the means, or least squares means of sire groups, least squares differences due to birthrank and sex, and partial regression coefficients, for the characteristics indicated.

Trial	Mean	Deviations from mean, and rankings, of sire groups				Singles minus twins	Ewes minus wethers	Coefficient of regression on	
		1	2	3	4			c/c wt. (kgm)	Age
Birth wt. (lb.)									
1	10.71	-0.08 (3	-0.52 (4	0.65 (1	-0.05 (2	0.92	-1.30		
2A	10.39	-0.37 (3	-0.00 (2	0.85 (1	-0.48 (4	1.73	-1.32		
2B	10.04	-0.18 (4	0.17 (1	-0.01 (3	0.02 (2	1.01	-1.68		0.060
Live wt. at slaughter (lb.)									
1	59.94	0.67 (2	0.00 (3	2.15 (1	-2.82 (4	7.31	-4.42		
2A	65.12	0.43 (2	-1.64 (4	1.69 (1	-0.48 (3	11.36	-5.03		
2B	60.32	-0.12 (2	5.07 (1	-3.63 (4	-1.32 (3	7.37	-8.30		0.393
Dressing-out per cent									
1	52.96	-0.35 (3	-1.13 (4	0.72 (2	0.76 (1	-0.24	0.94	0.775	
2A	44.06	1.29 (1	0.81 (2	-1.61 (4	-0.49 (3	0.44	0.14	0.528	
2B	45.13	0.66 (2	-1.14 (4	-0.53 (3	1.01 (1	0.18	0.82	0.876	-0.023

	Means and rankings of sire groups							
	1	2	3	4				
Cold carcass wt. (kgm)								
1	13.60 (2	13.09 (3	14.39 (1	12.99 (4	2.14	-1.01		
2A	13.02 (1	12.31 (3	12.36 (2	12.25 (4	2.91	-1.06		
2B	12.86 (2	13.67 (1	11.38 (4	12.72 (3	2.15	-1.90		0.071
Carcass gain per day of age (kgm) (CDA)								
1	0.131 (2	0.128 (3	0.140 (1	0.126 (4	0.023	-0.011		
2A	0.128 (1	0.120 (4	0.122 (2	0.121 (3	0.027	-0.012		
2B	0.128 (2	0.134 (1	0.113 (4	0.124 (3	0.019	-0.020		
Average daily gain (kgm) (ADG)								
1	0.213 (3	0.214 (2	0.224 (1	0.199 (4	0.028	-0.017		
2A	0.233 (1	0.223 (4	0.231 (2	0.229 (3	0.041	-0.017		
2B	0.228 (3	0.246 (1	0.212 (4	0.234 (2	0.026	-0.032		

N.B. 30 lb. = approx. 13.6 kgm.

TABLE 4.3.

Mean squares, and levels of significance, from analyses of variance for the characteristics indicated.

Trial	Source of variation					
	Sire	Birthrank	Sex	Carcass wt.	Age	Error
			Degrees of freedom			
1	3	1	1	1		61
2A	3	1	1	1		53
2B	3	1	1	1	1	52
			Birth wt. (lb.)			
1	3.1898	12.1051**	27.4292**			1.5222
2A	5.3912	33.2926**	24.3856**			2.5683
2B	0.2944	39.0353**	12.9479*		5.1026	2.3728
			Live wt. at slaughter (lb.)			
1	43.0375	759.242**	317.748**			32.2492
2A	29.6748	1434.810**	351.271*			68.0848
2B	194.0901*	693.191**	950.120**		220.865	62.5598
			Dressing-out per cent			
1	11.7855*	0.6071	13.0558	97.0481**		3.7751
2A	26.4093*	1.4910	0.2365	58.5075**		6.7928
2B	14.7889	0.3100	7.7894	170.3810**	0.7515	5.8175
			Carcass wt. (kgm)			
1	4.7024	65.1380**	11.4968*			2.6045
2A	1.9039	94.3582**	15.5194			3.8806
2B	12.8667*	58.8361**	49.3525**		7.1904	4.1332
			Carcass gain per day of age (kgm) (CDA)			
1	0.000432	0.007535**	0.002046**			0.000231
2A	0.000192	0.008174**	0.001868			0.000405
2B	0.001111*	0.005050**	0.005550**			0.000396
			Average daily gain (kgm) (ADG)			
1	0.003097	0.011440**	0.004520**			0.000462
2A	0.001137	0.018691**	0.003913			0.001137
2B	0.003236*	0.009338**	0.014620**			0.001074

N.B. Error degrees of freedom will increase if any of the sources of variation shown are not included in the statistical model for a characteristic.

a day, while lambs in Trials 2A and 2B were weighed shortly after leaving the paddocks. This made valid comparisons between years impossible. Secondly, some of the killing groups in Trials 2A and 2B were weighed when the lambs were wet, which could affect the live weights considerably, depending on the amount of wool. This effect should however, affect all classes equally, but is probably responsible for the error mean squares in Trials 2A and 2B being approximately twice that of Trial 1 for liveweight. These sources of variation in liveweight will also be reflected in the dressing-out percentages.

As expected, for both birth weight and liveweight at slaughter, singles were significantly heavier than twins, and wethers (or rams at birth) were significantly heavier than ewes. No significant sire differences were shown in these characters except for liveweight at slaughter in Trial 2B, in which case it was only significant at the 5% level. The repeatability of the ranking of the four sire groups over the three trials is also low and such rankings are probably best considered as being meaningless unless significant differences between sire groups are shown.

No significant birthrank or sex effects were shown on dressing-out per cent, but a significant sire effect at the 5% level was shown in Trials 1 and 2A. The repeatability of the ranking of the sire groups is again low, suggesting a sire-year interaction. This will be considered later. Although in each of these three characteristics in Trial 2B lambs the effect of age was shown to be non-significant, inclusion of it as a source of variation may be the reason for the error mean square (EMS) of Trial 2B being less than that of Trial 2A in each case. Inclusion of age at slaughter as a possible source of variation in birth weight was made with the object of testing for systematic effects of day of birth on birth weights. No significant effect was shown however.

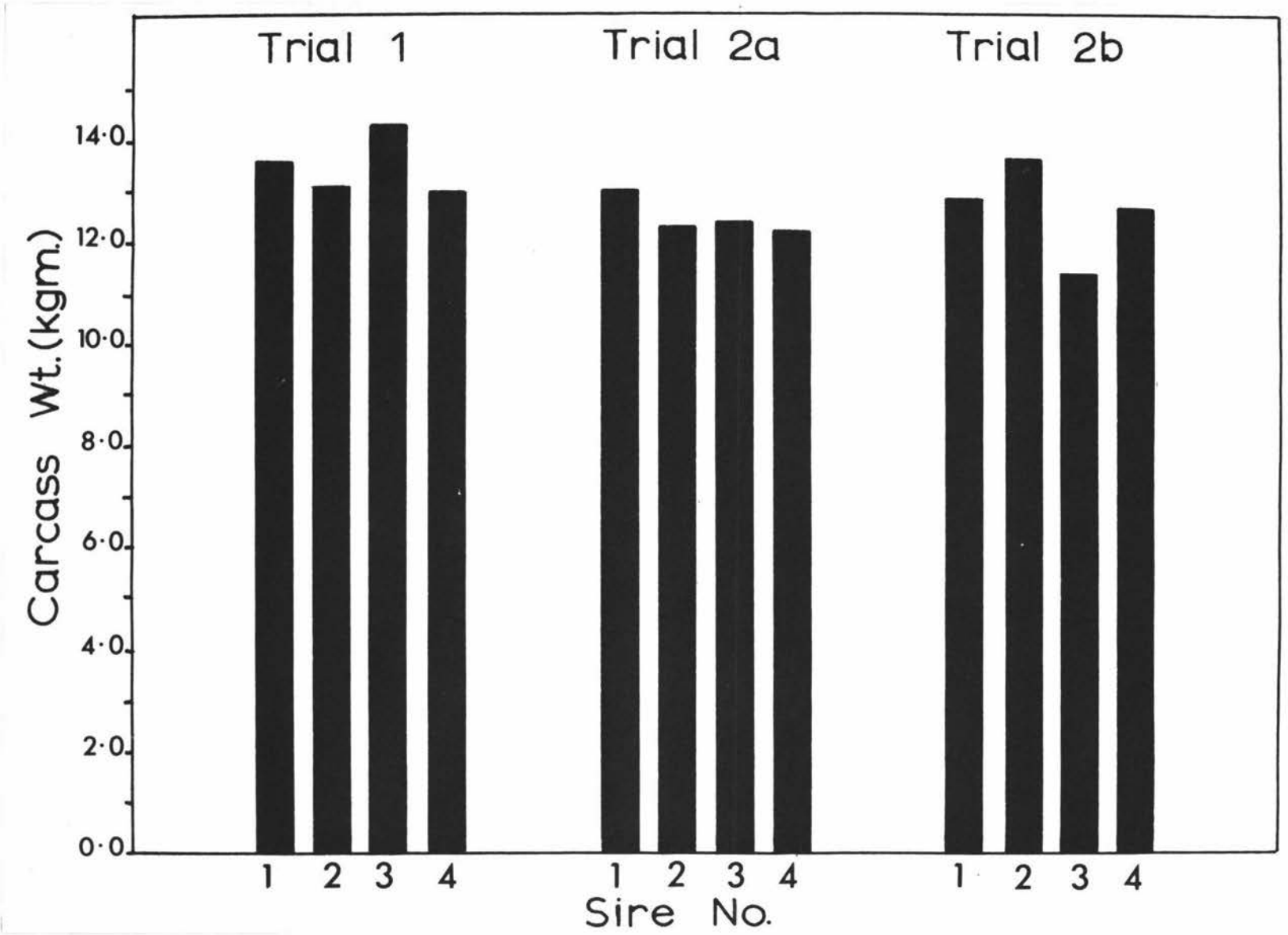
Least squares estimates and mean squares for carcass weight are given in Tables 4.2. and 4.3., respectively. The change in layout half way through Table 4.2. is the result of different procedures being followed in the statistical analysis (see Chapter 3, section 3.6.). These differences result in the sire effects, in one case being expressed as deviations, with the mean separate, as in the top half of Table 4.2., and in the other case with sire effects being as absolute values. Figure 4.1. gives a graphical representation of average corrected carcass weights within trials and within sire groups.

Carcass weight follows closely the pattern of birth weight and liveweight at slaughter with significant sex and birthrank effects (except for sex in Trial 2A), but with no significant sire differences except at the 5% level in Trial 2B. Unlike birth weight and liveweight however, birthrank effects on carcass weight were consistently greater than sex effects. Carcass weight is also one of the few cases where the EMS of Trial 2B is greater than that in Trial 2A.

4.3. Growth Rates

With the data available it was possible to measure growth rate as average daily gain (ADG = $\frac{\text{Live wt. at slaughter - Birth wt.}}{\text{Age at slaughter}}$), liveweight gain per day of age (WDA = $\frac{\text{Live wt. at slaughter}}{\text{Age at slaughter}}$), or carcass gain per day of age (CDA = $\frac{\text{Carcass wt.}}{\text{Age at slaughter}}$). All these values were calculated for each lamb in Trial 1, and Table 4.4. shows the correlation coefficients between the three sets of values within each sire group and for the total. Coefficients of regression of CDA and WDA on ADG are also given, together with their standard errors, both as absolute values and as a percentage of the mean of the dependent variable. These give an indication of the closeness of the relationships and are not influenced by the variability as are correlation coefficients. From these results it appears as though

Fig. 4.1. Mean corrected carcass weights within trials and within sire groups



these three measurements are measuring the same characteristic, especially in the case of WDA and ADG. Because of this only CDA and ADG were further analysed using a least squares model, and the results of these analyses are given in Tables 4.2. and 4.3. These results show that the levels of significance and the rankings of the sires, birthranks, and sexes, are essentially the same for carcass weight as they are for the two measurements of growth rates.

TABLE 4.4.

Correlations between different measurements of growth rates, and regressions of liveweight gain per day of age (WDA), and carcass weight gain per day of age (CDA), on average daily gain (ADG). (Trial 1 data only.)

Sire group	Dependent variable (Y)	Independent variable (X)	Coef. of regression	Coef. of correlation	Standard error of regression	
					Absolute	% of $\bar{Y}$
1	WDA	ADG	1.1492	0.980	8.50	3.23
2	WDA	ADG	1.1133	0.974	6.29	2.43
3	WDA	ADG	1.1066	0.996	2.87	0.97
4	WDA	ADG	1.0515	0.970	8.62	3.32
Total	WDA	ADG	1.1280	0.979	6.43	2.42
1	CDA	ADG	0.7753	0.972	6.75	4.99
2	CDA	ADG	0.6100	0.955	4.60	3.54
3	CDA	ADG	0.7786	0.971	5.67	3.66
4	CDA	ADG	0.7437	0.980	4.93	3.59
Total	CDA	ADG	0.7153	0.953	6.21	4.57
1	WDA	CDA		0.980		
2	WDA	CDA		0.973		
3	WDA	CDA		0.971		
4	WDA	CDA		0.978		
Total	WDA	CDA		0.966		

4.4. Carcass Chemical Components and Cuts

Tables 4.5. and 4.6. give the least squares estimates, and the mean squares for the chemical components of the right sides. Figures 4.2. and 4.3. give graphical representations of average corrected side water and side fat weights within sire groups and within trials. Fat weight appears to be negatively correlated with water weight, and singles and ewes had significantly more fat and less water than twins and wethers in all cases except Trial 2A, where the birthrank effect was not significant. Age and side weight both had a significant effect on fat and water weight. The sire effect was also significant in all cases, but only at the 5% level for fat in Trials 1 and 2A, and for water in Trial 2A. The repeatability of sire rankings is very high, but the most striking aspect is the greater fat weight and the lower water weight of sire groups 1 and 4 relative to groups 2 and 3.

The analysis of ash plus protein weights has not produced nearly so clear a picture. Again the side weight and age effects are highly significant, but the birthrank and sex effects, although significant in some cases, are inconsistent. Sire effects also are inconsistent from the point of view of repeatability of ranking. The more highly significant effects in Trial 2B appear to be mainly a reflection of the smaller EMSs.

The coefficients of regression of any particular component weight on side weight are similar in each trial, suggesting that these are reliable estimates.

Ash estimations were made on a within sire group, and within year basis, while protein estimations were calculated by difference. Ash to protein ratios for these groups are given in Table 4.7. The ratios in Trial 1 (1963) are generally lower than the corresponding ratios in Trials 2A plus 2B (1964), reflecting the higher average carcass weight in Trial 1. Apart

Fig. 4.2. Mean corrected side water weights within trials and within sire groups

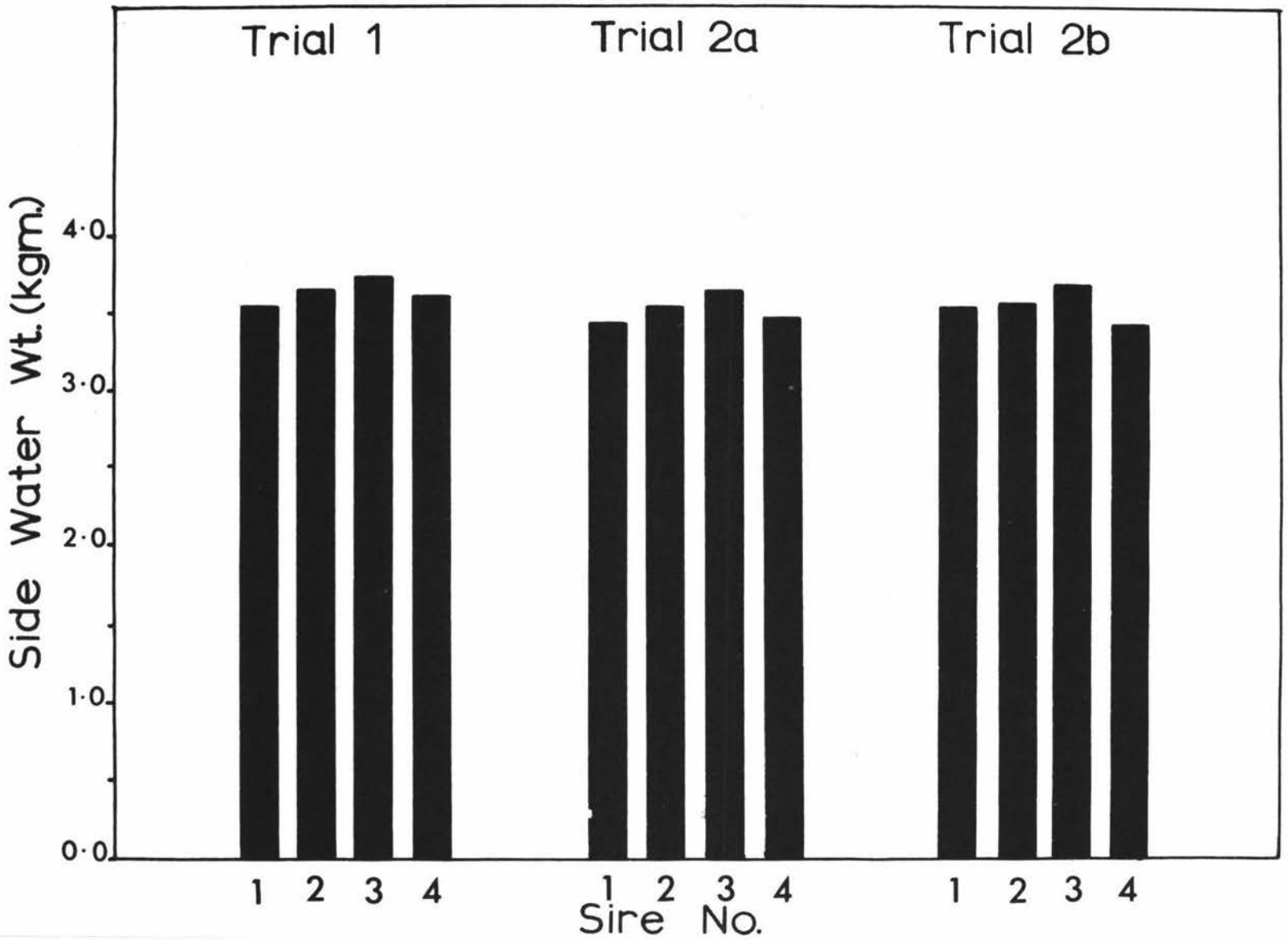


Fig. 4.3. Mean corrected side fat weights within trials and within sire groups

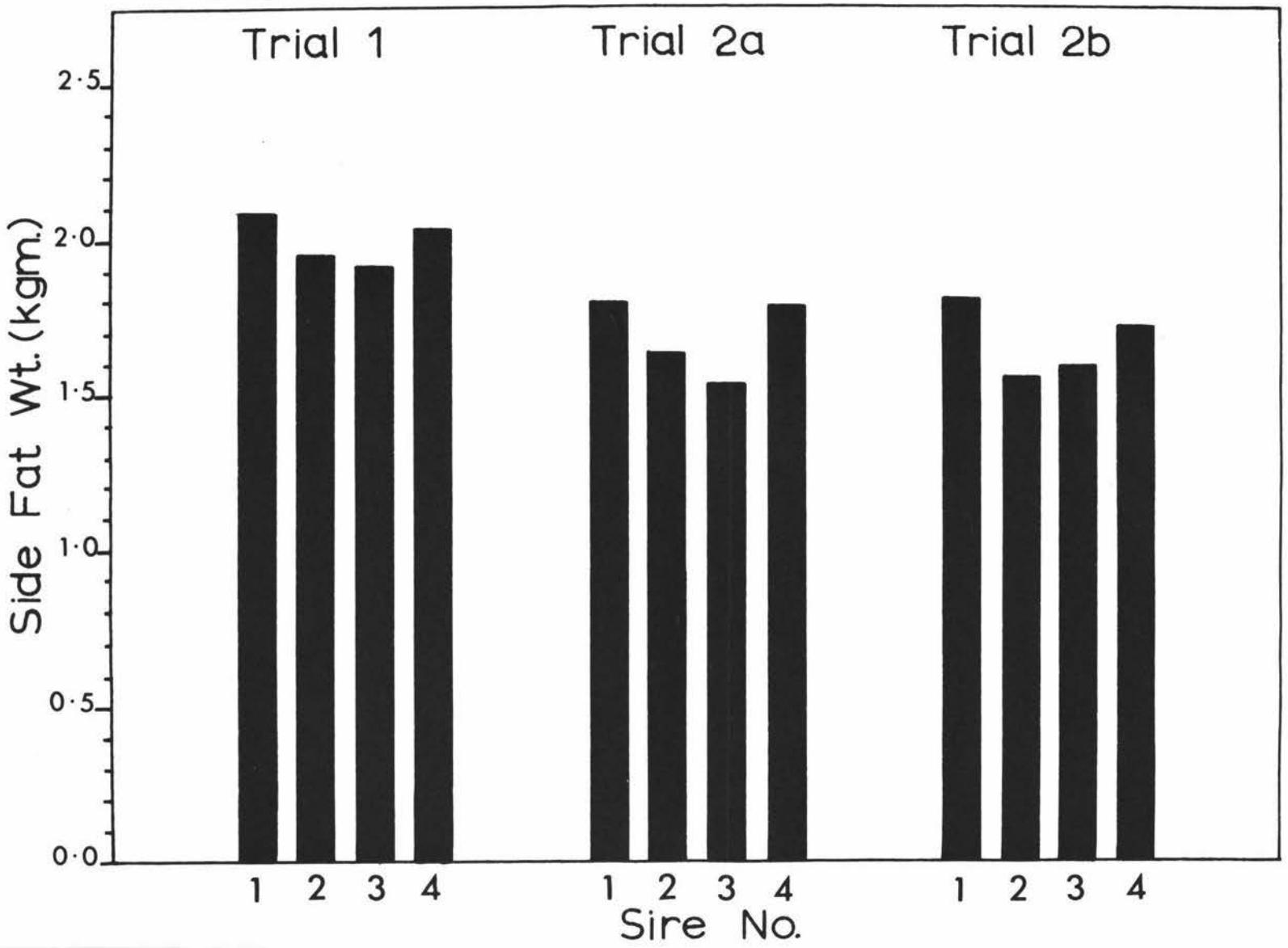


TABLE 4.5.

Least squares means of sire groups, least squares differences due to birthrank and sex, and partial regression coefficients, for the characteristics indicated.

Trial	Means and rankings of sire groups				Singles minus twins	Ewes minus wethers	Coef. of reg. on	
	1	2	3	4			Side wt.	Age
				Side fat wt. (kgm)				
1	2.082 (1	1.961 (3	1.930 (4	2.043 (2	0.142	0.193	0.460	
2A	1.799 (1	1.642 (3	1.536 (4	1.776 (2	0.048	0.165	0.484	
2B	1.812 (1	1.558 (4	1.600 (3	1.728 (2	0.107	0.147	0.488	0.022
				Side water wt. (kgm)				
1	3.562 (4	3.683 (2	3.757 (1	3.636 (3	-0.091	-0.145	0.395	
2A	3.462 (4	3.556 (2	3.661 (1	3.499 (3	-0.033	-0.136	0.369	
2B	3.527 (3	3.582 (2	3.700 (1	3.471 (4	-0.210	-0.211	0.373	0.031
				Side protein plus ash wt. (kgm)				
1	1.353 (1	1.340 (3	1.348 (2	1.315 (4	0.046	0.048	0.139	
2A	1.207 (3	1.267 (2	1.269 (1	1.191 (4	-0.016	0.030	0.147	
2B	1.238 (2	1.237 (3	1.280 (1	1.177 (4	-0.053	-0.064	0.150	0.009
				Leg wt. (kgm)				
1	2.171 (4	2.287 (1	2.254 (2	2.172 (3	-0.037	-0.016	0.286	
2A	2.122 (2	2.170 (1	2.095 (3	2.090 (4	0.017	-0.060	0.282	
2B	2.135 (3	2.158 (1	2.145 (2	2.006 (4	-0.033	-0.070	0.285	0.023
				Loin wt. (kgm)				
1	0.976 (4	0.981 (3	1.016 (2	1.030 (1	0.007	0.058	0.166	
2A	0.957 (2	0.913 (4	0.981 (1	0.936 (3	0.021	0.069	0.191	
2B	0.985 (2	0.936 (4	0.993 (1	0.960 (3	-0.074	0.001	0.186	0.008
				Rib-cut wt. (kgm)				
1	0.452 (2	0.438 (3	0.428 (4	0.471 (1	-0.001	0.011	0.068	
2A	0.429 (2	0.408 (3	0.407 (4	0.434 (1	0.006	0.014	0.075	
2B	0.443 (1	0.394 (4	0.425 (3	0.439 (2	-0.006	0.020	0.083	0.004
				Rest wt. (kgm)				
1	3.385 (1	3.273 (4	3.367 (2	3.322 (3	0.056	0.088	0.445	
2A	2.942 (3	2.957 (2	2.898 (4	2.988 (1	0.007	-0.007	0.431	
2B	3.026 (2	2.878 (4	3.042 (1	2.976 (3	0.072	-0.056	0.484	0.027

TABLE 4.6.

Mean squares, and levels of significance, from analyses of variance for the characteristics indicated.

Trial	Source of variation					
	Sire	Birthrank	Sex	Side wt.	Age	Error
			Degrees of freedom			
1	3	1	1	1		61
2A	3	1	1	1		53
2B	3	1	1	1	1	52
			Side fat wt. (kgm)			
1	0.0743*	0.1990**	0.5580**	9.1680**		0.02527
2A	0.2230*	0.0182	0.3546*	14.8820**		0.05122
2B	0.2013**	0.1104*	0.2556**	13.5022**	0.6611**	0.02393
			Side water wt. (kgm)			
1	0.2230**	0.4816**	0.7136**	7.1253**		0.01964
2A	0.1125*	0.0086	0.2388**	7.0822**		0.03301
2B	0.1253**	0.4271**	0.5247**	7.9117**	1.4036**	0.02320
			Side protein plus ash wt. (kgm)			
1	0.00300	0.02134	0.03511*	0.8337**		0.006891
2A	0.02371*	0.00205	0.01164	1.1232**		0.006238
2B	0.02312**	0.02723**	0.04829**	1.2743**	0.1245**	0.002481
			Leg wt. (kgm)			
1	0.06343**	0.012600	0.002801	3.5213**		0.012070
2A	0.01998*	0.002400	0.046130**	4.1354**		0.006142
2B	3.58980*	13.079100**	11.959200**		1.9901	1.069100
			Loin wt. (kgm)			
1	0.00793	0.000712	0.04960	1.1955**		0.01253
2A	0.01241	0.003312	0.06185*	1.8936**		0.01342
2B	0.00768	0.053101*	0.00002	1.9619**	0.09790**	0.01257
			Rib-cut wt. (kgm)			
1	0.003707*	0.000000	0.001850	0.2087**		0.001309
2A	0.002807	0.000304	0.002408	0.2946**		0.001104
2B	0.004026**	0.000371	0.004677**	0.3886**	0.02170**	0.000562
			Rest wt. (kgm)			
1	0.04770	0.02800	0.1125*	8.5361**		0.01732
2A	0.02114	0.00094	0.0015	9.6463**		0.02575
2B	3.58980*	13.07910**	11.9592**		1.9901	1.06910

TABLE 4.7.

Ash to protein ratios for each cut, and for each sire, in each of the two years concerned.

Sire \ Cut	Leg		Loin		9-10-11 Rib-cut		Rest	
	1963	1964	1963	1964	1963	1964	1963	1964
1	0.262	0.238	0.197	0.228	0.190	0.232	0.269	0.273
2	0.237	0.263	0.165	0.214	0.175	0.274	0.253	0.285
3	0.241	0.293	0.202	0.237	0.173	0.249	0.177	0.293
4	0.233	0.263	0.172	0.168	0.198	0.214	0.262	0.263

from this there do not appear to be any systematic differences that are repeated in each year.

Tables 4.5. and 4.6. show the least squares estimates and the mean squares for the four cuts (leg, loin, 9-10-11 rib-cut, and rest) of the right side of each carcass. Figures 4.4. and 4.5. give graphical representations of average corrected leg and rib-cut weights within sire groups and within trials. Least squares analysis of the leg weight, and the rest weight of Trial 2B lambs using a model incorporating corrections for sire, birthrank, sex, side weight, and age, resulted in the estimated reduction in the total sum of squares due to fitting all constants, being greater than the total sum of squares. This gives rise to the impossible situation of having a negative error sum of squares, and was attributed to the particularly high correlations between the weights of these joints and side weight ($\underline{r}$ = 0.99 for rest weight, and 0.95 for leg weight). This means that practically all the variation in the weight of these cuts is accounted for by variation in side weight, and hence analysis of the effects of the other sources of variance on side weight will be virtually the same as analysing the cut weights themselves. In Table 4.6. the mean squares

Fig. 4.4. Mean corrected leg cut weights within trials and within sire groups

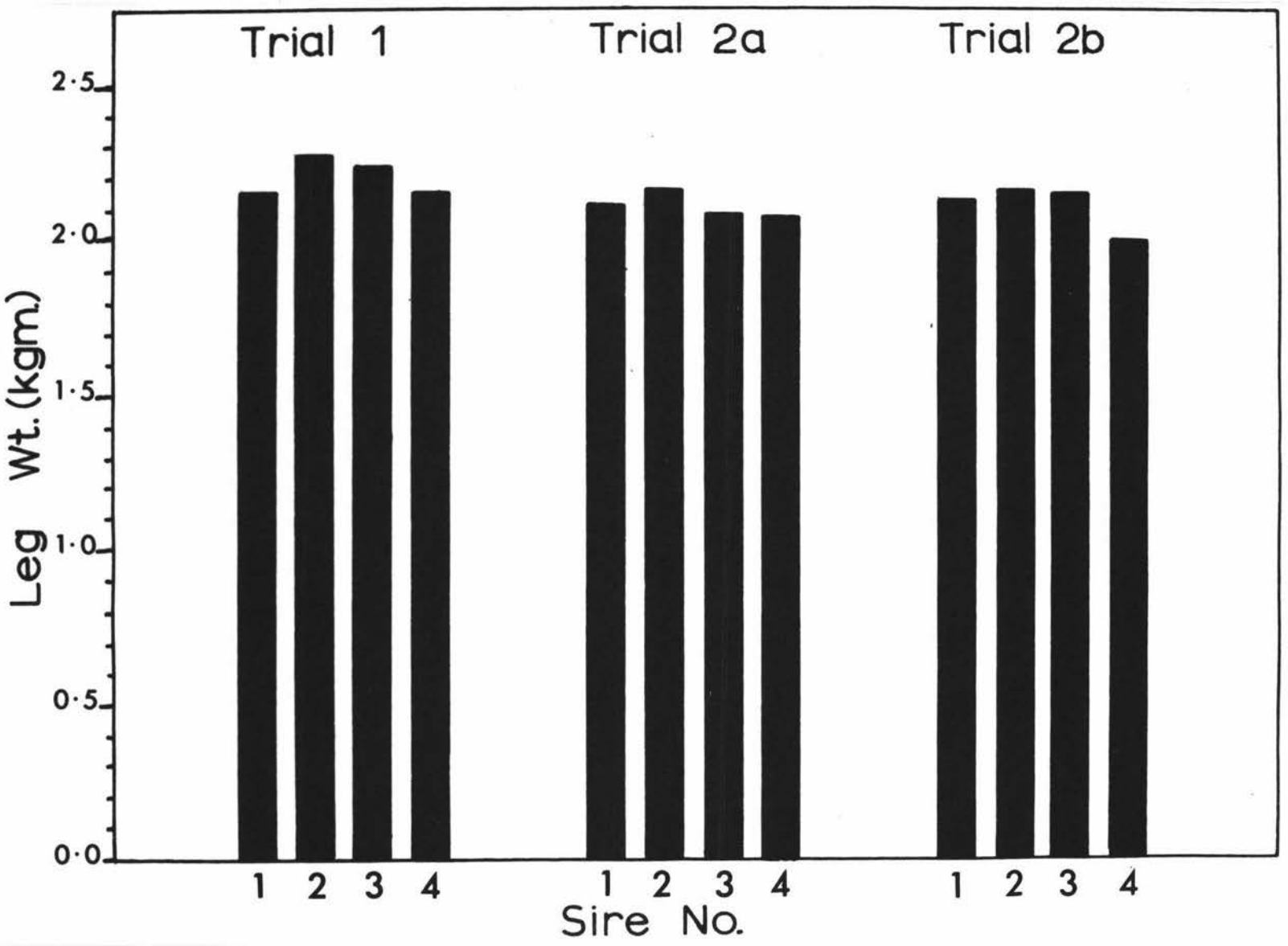
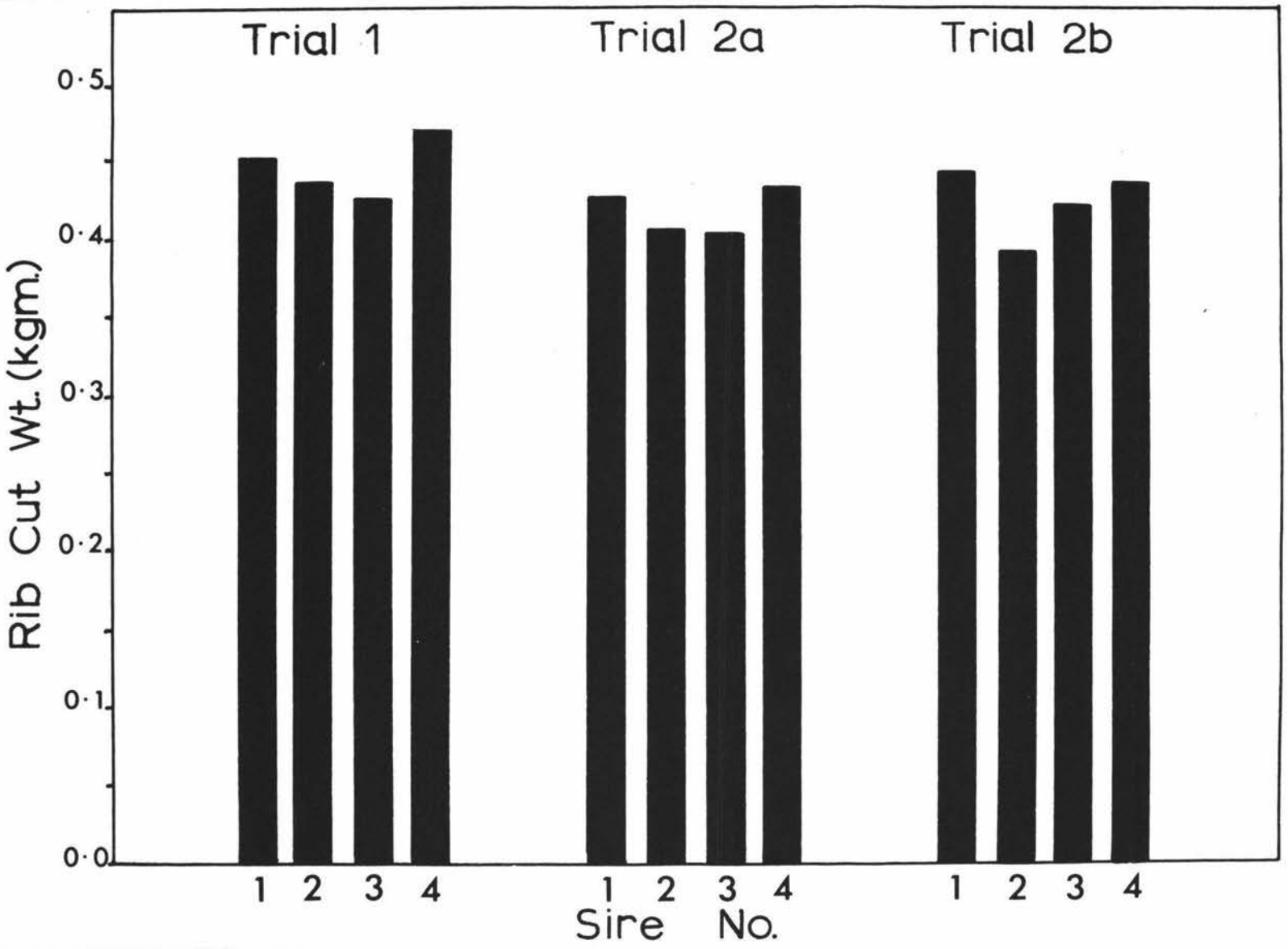


Fig. 4.5. Mean corrected rib-cut weights within trials and within sire groups



for side weight are shown in place of leg weight and rest weight for Trial 2B.

The effects of sex, birthrank, sire, and age on other cuts is also likely to be mainly through their effect on side weight, which has a highly significant effect on the weight of each cut in each trial. However, some significant effects were present after the cut weights had been adjusted to a constant side weight, mainly in the case of sex and sire effects. The latter was significant in the case of leg weight (all trials) and rib-cut weight (Trials 1 and 2B). The rankings of sire groups for leg weight were similar to those for water weight; sire groups 2 and 3 having heavier legs and more water than groups 1 and 4, except in the case of Trial 2A. With rib-cut weight, on the other hand, the ranking of sire groups followed closely that of side fat weight with groups 2 and 3 having less fat and heavier rib-cuts than sire groups 1 and 4. The coefficients of regression of the weights of cuts on side weight are similar between trials.

4.5. Carcass Measurements and Weights of Non-Carcass Parts

Although data collected included a large number of weights of non-carcass components, and carcass linear measurements, not all of these were analysed using the least squares models. A number of the measurements were discarded without any analysis, but for most of them correlations with carcass weight, fat per cent of the right side, and leg cut weight as a percentage of the right side, were estimated. The latter two were taken as indices of carcass quality, and a major criteria in selection of characteristics for further analysis was whether or not they were more highly correlated with leg or fat per cent than was carcass weight. Other characteristics selected for further analysis were those which were considered to be indices of carcass quality *per se*, such as tenderness and measurements of the cross-sectional area of the *L. dorsi* muscle.

Table A.1. in the appendix gives the means and standard deviations of some measurements considered. Correlations between all possible pairings of 12 variables, which always included leg per cent, fat per cent, and carcass weight, were possible in one run of a particular computer programme. These correlations were calculated within sex within trial, within birthrank within trial, within sire within trial, and total within trial, thus giving 27 correlations for any particular pair of variables. A selection of the total within trial correlations is given in Table 4.8. The heterogeneity columns give the probability that the particular set of correlations from groups within a trial are from the same homogenous population. Sets of correlations that were obviously not significantly heterogenous were not tested. Considering the traditional significance levels of 5 and 1%, then of the sets tested only those consisting of correlations between the ratio of G (gigot width) to F (length of leg from crutch) and leg per cent were significantly heterogenous. Usually the sets of correlations involving leg per cent were less homogenous than those involving fat per cent. The generally higher correlations for Trial 2B data are probably the result of the greater variation present, which in turn may be attributed to the greater age range.

Tables 4.9. and 4.10. give the least squares estimates and mean squares for eye muscle area, measurement A (width of eye muscle), and measurement B (depth of eye muscle). There was a significant carcass weight effect in each case but the effects of age, birthrank, sex, and sire were generally non-significant and inconsistent, although eye muscle area was greater in twins and in wethers, and sire group 3 is consistent in having the greatest eye muscle area.

Tables 4.9. and 4.10. also give the least squares estimates and mean squares for some weights and measurements that were chosen for analysis

TABLE 4.8.

Simple correlation coefficients between fat per cent, leg per cent, carcass weight, and other measurements.

Variables	Trial 1	Hetero-geneity	Trial 2A	Hetero-geneity	Trial 2B	Hetero-geneity
WF : Carcass wt.	0.917		0.923	P > 0.10	0.953	P > 0.90
WF : Fat %	0.631	P > 0.05	0.688	P > 0.05	0.802	P > 0.25
WF : Leg %	-0.462		-0.412	P > 0.50	-0.494	
G/F : Carcass wt.	0.577		0.507		0.610	
G/F : Fat %	0.423		0.487	P > 0.50	0.613	
G/F : Leg %	-0.243		-0.213	P > 0.01	-0.495	P > 0.25
C : Carcass wt.	0.702		0.693		0.763	
C : Fat %	0.638		0.821	P > 0.50	0.810	
C : Leg %	-0.304	P > 0.50	-0.536		-0.395	
Caul fat wt. : Carcass wt.	0.709		0.811		0.832	
Caul fat wt. : Fat %	0.727	P > 0.25	0.766		0.831	
Caul fat wt. : Leg %	-0.403	P > 0.10	-0.526		-0.434	
Carcass wt. : Fat %	0.619		0.679		0.772	
Carcass wt. : Leg %	-0.361	P > 0.05	-0.425	P > 0.75	-0.371	P > 0.25
Leg % : Fat %	-0.548		-0.509		-0.562	
A : Eye muscle area			0.709		0.735	
B : Eye muscle area			0.750		0.871	
Eye muscle area : Carcass wt.			0.767		0.861	
Eye muscle area : Fat %			0.400		0.583	
Eye muscle area : Leg %			-0.239		-0.345	

TABLE 4.9.

Least squares means, least squares deviations of sire groups from the means, least squares differences due to birthrank and sex, and partial regression coefficients for the characteristics indicated.

Trial	Mean	Deviations from mean, and rankings, of sire groups				Singles minus twins	Ewes minus wethers	Coefficient of regression on	
		1	2	3	4			$^{c}/_{c}$ wt. (kgm)	Age
Eye muscle area (sq.in. x 10)									
2A	17.53	-0.85 (4	0.21 (3	0.36 (1	0.28 (2	-0.01	-0.58	0.813	
2B	17.23	-0.32 (4	0.23 (2	0.35 (1	-0.26 (3	-1.14	-0.12	1.036	0.067
A (mm)									
1	50.61	1.21 (1	0.89 (3	1.12 (2	-3.22 (4	0.67	-1.05	0.963	
2A	51.08	-1.30 (4	0.44 (2	0.52 (1	0.34 (3	-0.41	-2.15	0.631	
2B	50.54	0.22 (2	0.13 (3	1.26 (1	-1.61 (4	-1.82	-1.53	0.817	0.126
B (mm)									
1	30.89	-0.53 (3	0.47 (2	1.25 (1	-1.19 (4	-0.58	0.40	0.711	
2A	29.61	-1.25 (4	0.60 (1	0.23 (3	0.42 (2	-0.78	0.05	1.037	
2B	29.19	-0.38 (4	-0.06 (2	0.73 (1	-0.29 (3	-1.13	-0.36	1.303	0.089
WF (cm)									
1	18.28	-0.11 (3	-0.19 (4	0.10 (2	0.20 (1	0.20	0.17	0.526	
2A	18.74	-0.24 (4	0.05 (2	-0.03 (3	0.22 (1	0.15	0.04	0.571	
2B	18.51	0.07 (3	-0.61 (4	0.28 (1	0.26 (2	-0.11	0.23	0.762	0.074
C (mm)									
1	4.92	0.55 (1	0.20 (2	-0.17 (3	-0.58 (4	0.74	0.56	0.680	
2A	3.58	0.22 (1	-0.21 (4	-0.12 (3	0.11 (2	0.41	0.66	0.487	
2B	3.50	0.36 (2	-0.34 (3	-0.41 (4	0.39 (1	0.82	0.38	0.415	0.004
$^{G}/_{F}$ ratio x 10									
1	10.08	-0.11 (4	-0.10 (3	0.27 (1	-0.06 (2	-0.27	0.23	0.187	
2A	10.14	-0.14 (4	0.03 (3	0.04 (2	0.07 (1	-0.19	0.25	0.157	
2B	10.11	-0.11 (3	-0.15 (4	0.18 (1	0.08 (2	0.20	0.13	0.170	-0.008
Omental fat wt. (kgm x 10)									
1	4.27	0.17 (1	0.15 (2	-0.30 (4	-0.02 (3	0.43	0.51	0.409	
2A	3.20	0.07 (2	-0.05 (3	-0.12 (4	0.10 (1	0.04	0.71	0.480	
2B	3.36	-0.01 (3	-0.49 (4	0.10 (2	0.40 (1	-0.26	0.69	0.559	0.077

TABLE 4.10.

Mean squares, and levels of significance from the analyses of variance for the characteristics indicated.

Trial	Source of variation					
	Sire	Birthrank	Sex	Carcass wt. (kgm)	Age	Error
			Degrees of freedom			
1	3	1	1	1		61
2A	3	1	1	1		53
2B	3	1	1	1	1	52
			Eye muscle area (sq.in.)			
2A	0.04747	0.0000	0.04383	1.3840**		0.02394
2B	0.01677	0.1250*	0.00181	2.3852**	0.06379	0.01961
			A (mm)			
1	47.7806	4.5882	16.2680	149.8591*		26.7639
2A	11.0641	0.5207	59.8822**	83.5407**		6.7743
2B	18.7158*	31.7557*	27.5604*	148.4841**	22.2182*	5.0335
			B (mm)			
1	13.1232	3.4218	9.5689	81.6392**		5.7749
2A	10.4349	1.8289	0.0303	225.2123**		5.0945
2B	3.3265	12.2624	1.5729	377.1370**	11.2565	4.0774
			WF (cm)			
1	0.4212	0.4133	0.4464	44.7159**		0.2286
2A	0.5136	0.1775	0.0246	68.4411**		0.3248
2B	2.1960**	0.1077	0.6231*	129.0720**	7.7333**	0.0909
			C (mm)			
1	2.7235	5.4784	4.5744	74.5876**		2.1592
2A	0.5713	1.3051	5.6504	49.6986**		1.4867
2B	2.7376*	6.4710**	1.7338	38.2374**	0.02030	0.8342
			G/F ratio			
1	0.003281	0.007380	0.007532	0.05647**		0.002070
2A	0.001290	0.002880	0.008081	0.05165**		0.002411
2B	0.004864	0.003740	0.001870	0.06422**	0.000900	0.002540
			Omental fat wt. (kgm x 10)			
1	0.4929	1.8591	3.7929*	27.0680**		0.6155
2A	0.1542	0.0101	6.6079**	48.1997**		0.5136
2B	1.8684**	0.6605	5.5688**	69.3190**	8.4375	0.2924

because of their relationships with carcass quality indicators such as side fat per cent. These include WF (maximum width of forequarter), C (depth of fat over eye muscle), the $^{G}/_{F}$ ratio (gigot width/distance from the crutch to hock) and weight of omental fat. The effect of carcass weight was highly significant on all these measurements, but age significantly affected WF only. Sex had a significant effect on omental fat weight, with the ewes having more than the wethers, as was the case with side fat weight. Singles differed significantly from twins in Trial 2B for measurement C. Significant sire effects are present only in Trial 2B and only for WF, C, and omental fat weight. The greater significance of sire effects in Trial 2B is due to both a larger sire mean square and a smaller EMS than in the other trials. Only in the case of C was the ranking of sire groups comparable to that of side fat weight, with groups 2 and 3 having less depth of fat than groups 1 and 4 in Trials 2A and 2B.

Tables 4.11. and 4.12. give the least squares estimates and the mean squares for liver weight, and for the weight of the contents of the stomach and the oesophagus (SOc). Significant carcass weight and age effects were shown in all cases, except for SOc in Trial 1. With liver weight no other significant effects were shown, although in all trials twins and wethers had heavier livers than singles or ewes, respectively. Sire group deviations and rankings are inconsistent between trials but the coefficients of regression of liver on carcass weight vary only a little.

Twins and wethers had greater amounts of SOc than singles or ewes, and in this case the sex effect is significant in all trials. The sire effect is also significant in all trials but the ranking of sires is not consistent.

TABLE 4.11.

Least squares means, least squares deviations of the sire groups from the means, least squares differences due to birthrank and sex, and partial regression coefficients, for the characteristics indicated.

Trial	Mean	Deviations from mean, and rankings, of sire groups				Singles minus twins	Ewes minus wethers	Coefficient of regression on	
		1	2	3	4			$^{c}/_{c}$ wt. (kgm)	Age
Liver wt. (kgm x 10)									
1	5.28	0.15 (2	0.15 (1	-0.17 (4	-0.13 (3	-0.02	-0.24	0.206	
2A	4.94	0.11 (1	-0.11 (4	0.06 (2	-0.06 (3	-0.01	-0.21	0.242	
2B	4.93	0.03 (3	0.07 (1	0.05 (2	-0.15 (4	-0.16	-0.18	0.208	0.055
Stomach + oesophagus contents wt. (kgm x 10) (SOc)									
1	17.40	0.82 (2	1.32 (1	0.47 (3	-2.59 (4	-1.20	-2.58	0.462	
2A	17.80	-0.21 (2	-1.45 (4	2.95 (1	-1.29 (3	-0.84	-2.49	0.787	
2B	16.64	0.64 (3	0.66 (2	1.12 (1	-2.42 (4	-2.17	-2.05	0.710	0.204
Tenderness values x 10									
1	11.48	2.45 (1	-0.01 (2	-0.30 (3	-2.14 (4	-0.23	-0.36	0.517	
2A	7.91	0.48 (2	-0.64 (4	0.61 (1	-0.45 (3	0.50	-0.01	0.115	
2B	10.16	0.92 (1	-0.94 (4	0.82 (2	-0.80 (3	2.11	0.84	-0.079	0.019
								Coefficient of regression on	
								Leg wt.	Age
Leg fat wt. (kgm x 10)									
1	5.44	0.20 (1	-0.04 (3	-0.23 (4	0.07 (2	0.53	0.42	0.312	
2A	4.82	0.44 (1	-0.15 (3	-0.46 (4	0.17 (2	0.35	6.49	0.371	
2B	4.85	0.34 (1	-0.23 (3	-0.30 (4	0.19 (2	0.45	0.22	0.365	0.007
Leg water wt. (kgm x 10)									
1	12.26	-0.29 (4	0.10 (2	0.25 (1	-0.06 (3	-0.37	-0.27	0.515	
2A	12.03	-0.34 (4	0.07 (2	0.34 (1	-0.07 (3	-0.25	-0.42	0.456	
2B	11.65	0.00 (2	-0.02 (3	0.06 (1	-0.04 (4	-0.97	-0.49	0.502	0.013
								Coefficient of regression on	
								Side wt.	Age
Predicted side fat wt. (kgm x 10)									
1	20.35	0.21 (2	0.63 (1	-0.76 (4	-0.08 (3	0.78	1.28	0.440	
Predicted side water wt. (kgm x 10)									
1	35.61	-0.83 (4	0.76 (1	0.62 (2	-0.55 (3	-0.95	-0.67	0.398	

TABLE 4.12.

Mean squares, and levels of significance, from analyses of variance for the characteristics indicated.

Trial	Source of variation					
	Sire	Birthrank	Sex	Carcass wt. (kgm)	Age	Error
			Degrees of freedom			
1	3	1	1	1		61
2A	3	1	1	1		53
2B	3	1	1	1	1	52
			Liver wt. (kgm x 10)			
1	0.3627	0.00370	0.8422	6.8579**		0.2142
2A	0.1480	0.00046	0.5750	12.3126**		0.2616
2B	0.1447	0.24081	0.3864	9.6517**	4.2915**	0.1100
			Stomach + oesophagus contents wt. (kgm x 10) (SOc)			
1	35.4001*	14.5872	97.7394**	34.4851		8.1085
2A	62.5683*	5.4327	80.0621*	129.6890**		16.5569
2B	36.1105*	44.8829	51.7385*	112.1540**	58.3828*	11.3857
			Tenderness values			
1	0.4515*	0.0054	0.019360	0.04310		0.12230
2A	0.0599	0.0192	0.000000	0.02763		0.04826
2B	0.1229	0.4251*	0.083390	0.01390	0.005130	0.06325
				Leg wt.		
			Leg fat wt. (kgm)			
1	0.00414	0.03160**	0.02656**	0.4167**		0.002631
2A	0.02232**	0.00942	0.02966**	0.6150**		0.003681
2B	0.01482**	0.01928**	0.00555	0.6508**	0.06133**	0.002026
			Leg water wt. (kgm)			
1	0.01585**	0.01586**	0.01066**	1.1375**		0.003681
2A	0.01163**	0.00460	0.02141**	0.9296**		0.002203
				Side wt.		
			Predicted side fat wt. (kgm)			
1	0.04175	0.05991	0.2453**	8.2329**		0.02003
			Predicted side water wt. (kgm)			
1	0.1146**	0.07080	0.06720	6.7562**		0.02159

4.6. Tenderness

Tenderness results as produced by the tenderometer were in the form of graphs of distance versus force or time. Two curves were produced for each lamb, and conversion of them to a single numerical value was possible by either dividing the maximum force by the total distance for each curve and averaging these values for each lamb, or by dividing the area under each curve by the total distance and averaging these. In order to assess the relative merits of these two methods, they were both applied to the graphs of Trial 2A lambs. Table 4.13. gives the correlation coefficients between the results of the two methods, as well as the repeatabilities, or intra-class correlations, between the values obtained by using the same method on the two curves of each lamb. These correlation coefficients, together with their significance levels, are given within each sire group and for the total. Because the repeatabilities of the values produced using the former method of conversion were higher, these values were used for further analysis. Figure 4.6. shows two graphs each containing two curves. Data relating to these graphs, which correspond to a pair of twin wether lambs in sire group 2, are given in Table 4.14., where the methods of evaluation outlined above are compared (i.e., area over depth and force over depth).

The values in the $\frac{71 \text{ Mean}}{70 \text{ Mean}}$ column indicate how the different methods of conversion or evaluation of the graphs can give widely differing relative results. From an inspection of the curves it would appear that lamb 70 was less tender, as in each case a greater force was required to shear through a smaller sample. The larger areas under the curves for lamb 71 appears to be due mainly to the fact that the toughest part of the sample was reached after a smaller proportion of the total depth had been sheared, relative to lamb 70. These observations also suggest that force per unit

Fig. 4.6. Graphs as produced by the tenderometer for two samples from lamb numbers 71 and 70

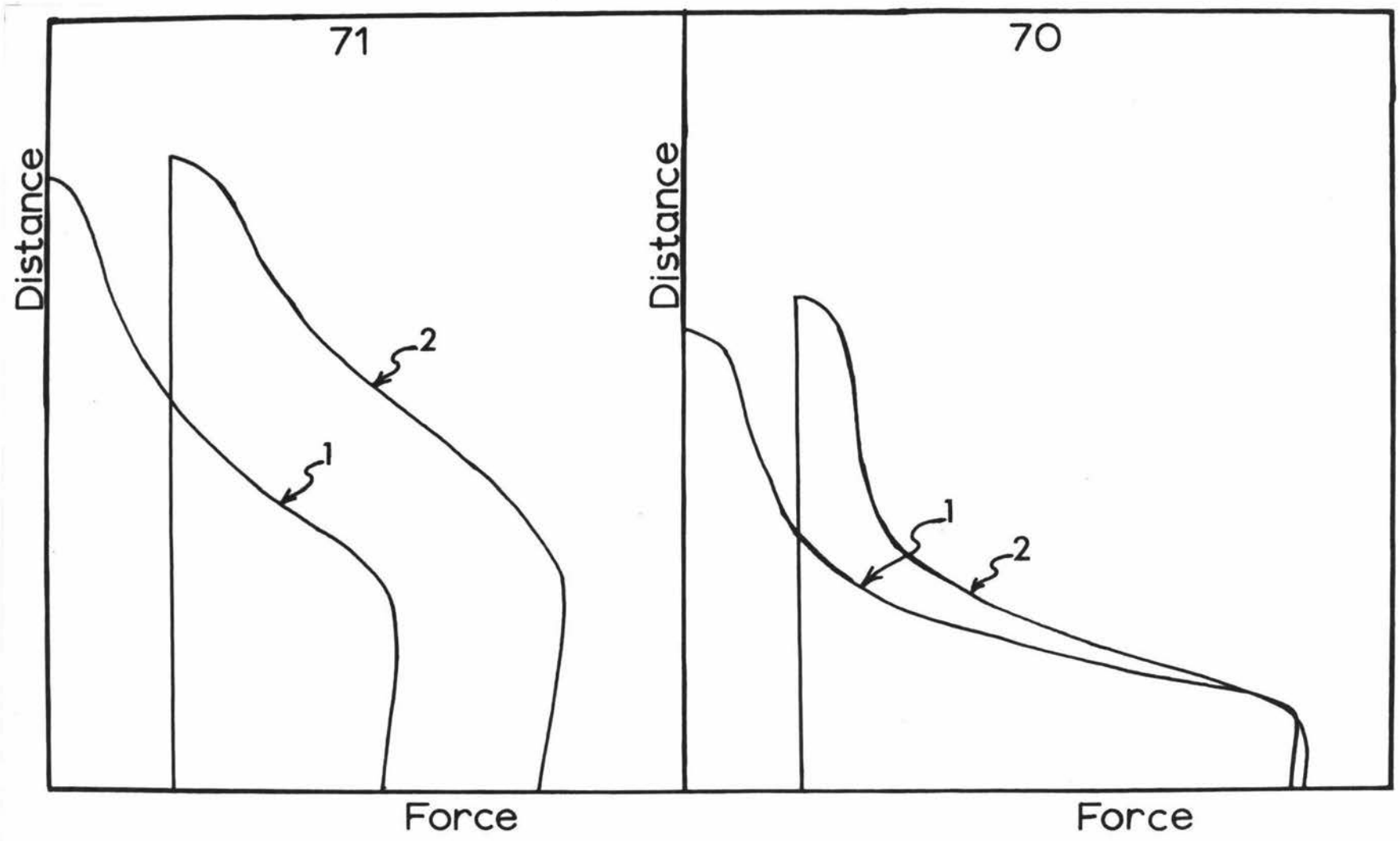


TABLE 4.13.

Correlations between, and repeatabilities within, the two methods of evaluating the tenderness graphs, from lambs of Trial 2A.

Variables \ Sire group	1	2	3	4	Total
A.B.(1) (correlation)	0.3972	0.5256*	0.6659**	0.7058**	0.6151**
A.A. (repeatability)	0.7079**	0.9134**	0.8749**	0.7551**	0.8054**
B.B. (repeatability)	0.7028**	0.3961	0.7801**	0.7344**	0.7467**

(1) $A = \frac{\text{distance along force axis (x)}}{\text{distance along distance axis (y)}}$

$B = \frac{\text{area under curve}}{\text{distance along distance axis (y)}}$

TABLE 4.14.

Comparison of methods of converting tenderness graphs to numerical values

Lamb number	71			70			71 Mean / 70 Mean
Graph number	1	2	Mean	1	2	Mean	
Area/Depth	0.60	0.74	0.67	0.73	0.56	0.65	1.03
Force/Depth	0.54	0.56	0.55	1.32	1.01	1.17	0.47

depth is the more realistic way of evaluation.

Tables 4.11. and 4.12. give the least squares estimates, and mean squares for tenderness values which are equal to force per unit depth of the sample. Figure 4.7. gives a graphical representation of average corrected tenderness values within sire groups and within trials. No significant carcass weight, age, or sex effects were shown and birthrank was significant at the 5% level in Trial 2B only. Sire differences however, although significant only in Trial 1, are of interest in that if sire group 2 was more tender than sire group 3 in Trial 1, then all three trials would have shown sire groups 2 and 4 to be more tender than groups 1 and 3.

4.7. Sire-Year Interactions

By analysing the combined data from Trials 1 and 2A it was possible to calculate least squares estimates of year effects and of year by sire interactions. The analysis of variance table produced by these calculations is shown for side fat weight in Table 4.15. The mean squares for sire, year, and sire-year interactions are given in Table 4.16. together with significance levels.

TABLE 4.15.

Analysis of variance of side fat weight

Source of variation	Sums of squares	d.f.	Mean squares	F ratio
Sires	0.82115	3	0.2737	5.8 **
Birthrank	0.2726	1	0.2726	5.8 *
Sex	0.8293	1	0.8293	17.6 **
Side wt.	18.7921	1	18.7921	398.4 **
Year	0.35344	1	0.3534	7.49 **
Sire-year interaction	0.06849	3	0.0228	0.48 N.S.
All constants	542.22488	10		
Error	5.51822	117	0.0472	
Total	547.74310	127		

Fig. 4.7. Mean corrected tenderness values within trials and within sire groups

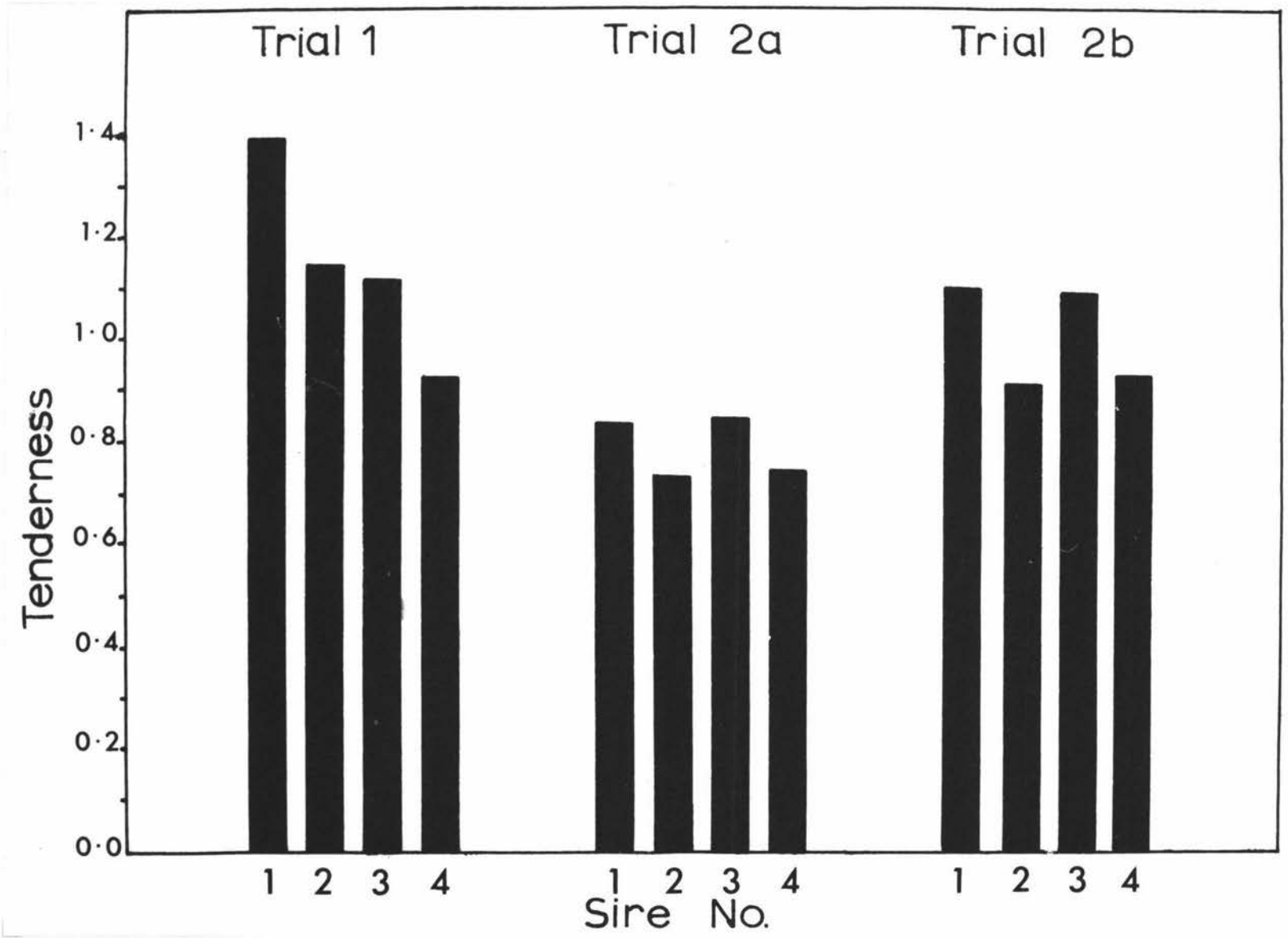


TABLE 4.16.

Some mean squares and significance levels from the analyses of variance which included a sire-year interaction

	Source of variation			
	Sire	Year	Sire/Year	Error
Degrees of freedom	3	1	3	117
Fat wt.	0.2737**	0.3534**	0.0228	0.0472
Water wt.	0.1408**	0.3400**	0.0171	0.0278
Protein + ash wt.	0.0177*	0.0010	0.0112	0.0063
Leg wt.	0.07508**	0.06454**	0.00932	0.008655
Loin wt.	0.00949	0.08032*	0.01465	0.012451
9-10-11 rib-cut wt.	0.00703**	0.00611*	0.00078	0.001159
Rest wt.	0.02052	0.52930**	0.06256*	0.019380
Tenderness	0.3804**	3.0619**	0.1773	0.0887
Stomach + oesophagus) contents wt. (SOc))	57.2132**	20.0454	40.0491*	12.9673
Dressing-out %	8.3190	1945.2868**	49.6000**	6.0737
Cold carcass wt.	4.2314	28.8411**	20.0179**	2.7528

Carcass weight, the weights of the chemical components of the side, and the weights of all four cuts were analysed in this way, but of the other characteristics considered only those that had shown a significant sire effect in Trials 1 or 2A were analysed. These included tenderness, the weight of the contents of the stomach and the oesophagus (SOc), and dressing-out per cent.

Sire effects were essentially the same as when the two trials had been analysed separately, although in some cases the levels of significance increased (e.g., tenderness, rib-cut weight), while in others the effect decreased in significance (e.g., dressing-out per cent). Significant year effects were present in all cases except for protein plus ash weight, and SOc weight. Significant sire-year interactions were shown at the 5% level

for rest weight, and SOc weight, and at the 1% level for dressing-out per cent and cold carcass weight. The highly significant interaction for dressing-out per cent probably explains the loss of significance of sire effects in the interaction model.

4.8. Variance Components

Variance components were estimated for seven characteristics which were considered to be particularly important direct indicators of carcass quality. These were side fat weight, side water weight, leg weight, tenderness, eye muscle area, cold carcass weight, and average daily live weight gain. Estimates of a number of variance components for each of these are given in Table 4.17., where the components for any particular characteristic correspond to the effects that were included in the least squares statistical model concerned. Blank spaces in the table indicate that the effect in that row was not included in the model (e.g., age effect in all but Trial 2B), and dashes indicate that the mean square of the particular effect was less than the EMS so that the variance component would have been negative. The components are expressed as percentages of the total variance, which in turn is the sum of the components, so that within any characteristic and trial they will sum to 100.

Figure 4.8. gives a graphical representation of the proportion of the total variance that is attributable to sire effects, other known effects included in the least squares models, and unknown effects; for carcass weight, leg weight, side fat weight, and tenderness of Trial 1 lambs.

No results are present for eye muscle area in Trial 1 as the measurement was not taken in that trial, and results are not present for leg weight in Trial 2B, for the reason given in section 4.4.

For the first three characteristics in Table 4.17. (Side fat, Side water, and Leg wt.) the statistical models used were quite effective in

TABLE 4.17.

Variance components estimated for the effects included in the least squares statistical models, and expressed as percentages of the total variance.

Source of variation \ Trial	1	2A	2B	1	2A	2B	1	2A
	Side fat weight			Side water weight			Leg weight	
Sire	1.308	3.249	4.608	5.905	2.973	3.605	28.189	1.070
Birthrank	3.329	-	1.542	9.638	-	9.790	0.019	-
Sex	6.770	3.257	3.387	9.504	4.370	9.966	-	1.755
Age			0.156			0.461		
Side wt.	79.060	79.260	82.052	66.888	74.513	65.284	62.425	90.198
Error	9.533	14.234	8.255	8.065	18.144	10.894	9.367	6.977
	Tenderness			Area of eye muscle				
Sire	15.663	1.611	4.843		4.802	-		
Birthrank	-	-	21.711		-	15.409		
Sex	-	-	0.976		3.893	-		
Age			-			0.086		
Carcass wt.	1.298	-	-		19.476	29.732		
Error	83.039	98.389	72.470		71.829	54.773		
	Cold carcass weight			Average daily gain (ADG)				
Sire	2.747	-	7.188	15.623	-	7.371		
Birthrank	44.134	48.622	25.116	33.490	38.946	15.433		
Sex	5.241	5.004	19.228	10.829	4.931	23.450		
Age			0.025					
Error	49.878	46.374	48.443	40.058	56.123	53.746		

accounting for the variance, as in all cases the percentage of variation ascribed to error is less than 20%, and in Trials 1 and 2B is less than 12%. By far the largest proportion of the remainder is ascribed to side weight effects, followed by sex and sire effects.

The tenderness results indicate that at least 70% of the variation in tenderness must be ascribed to effects other than sire, birthrank, sex, age,

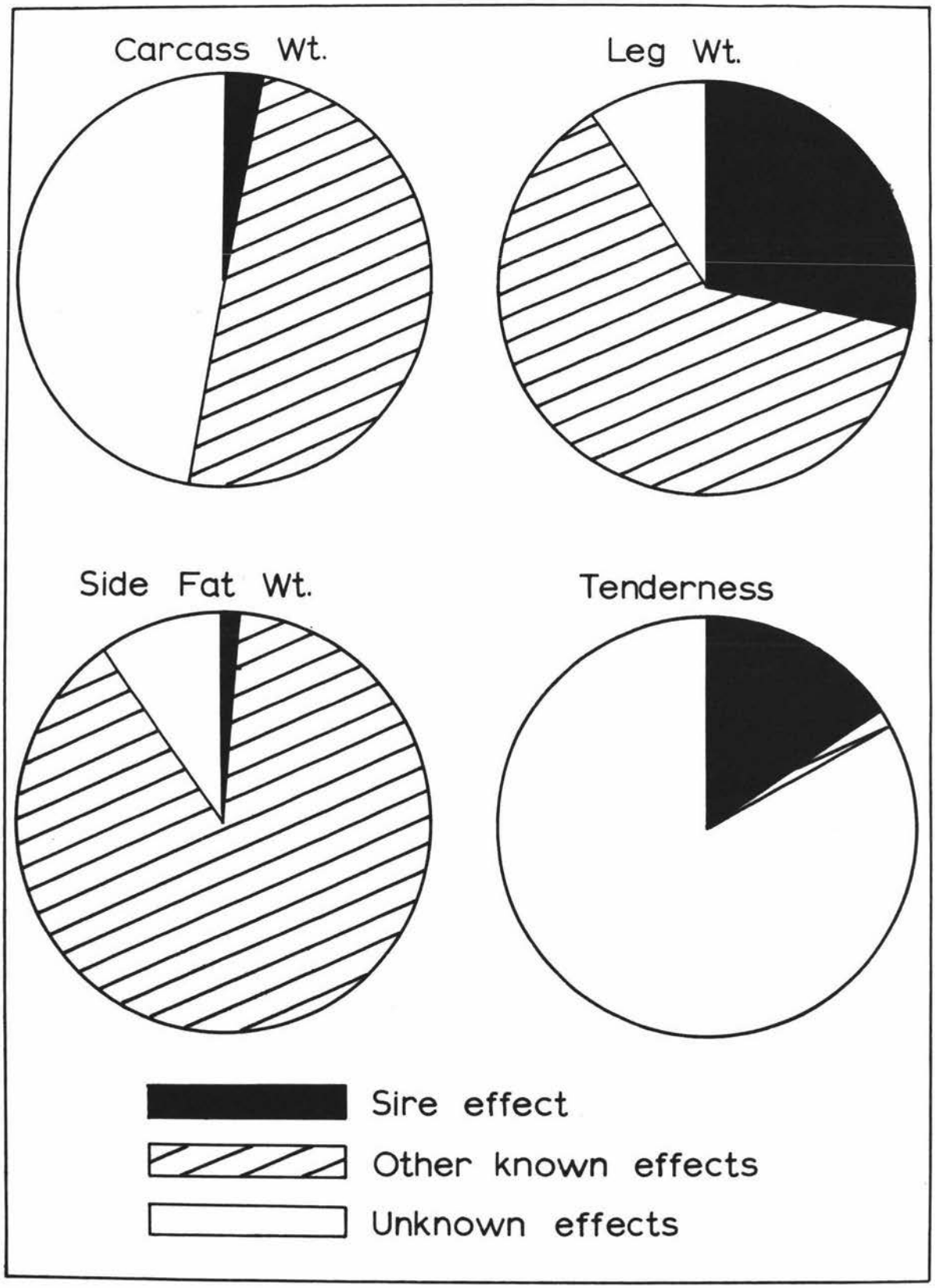


Fig. 4.8. The proportion of total variance that is attributable to sire effects, other known effects included in the least squares models, and unknown effects. Shown for carcass weight, leg weight, side fat weight, and tenderness for Trial 1 only.

and carcass weight, although birthrank did account for 21% of the variance in Trial 2B. The sire effect was the only known effect that accounted for some variation in tenderness in each trial. Over half the variation in eye muscle area also is ascribed to the error category, with the most important demonstrated effect being that of carcass weight, all others being inconsistent.

In the case of cold carcass weight and average daily gain, the relative sizes of the components are very similar, with approximately half the variance being ascribed to error, followed in importance by birthrank effects in all cases except for the average daily gain of lambs in Trial 2B, where a larger percentage is ascribed to sex than to birthrank. Sire effects accounted for none of the variation in either characteristic in Trial 2A but in the other trials they accounted for an appreciable percentage.

4.9. Prediction Equations

Equations that could be used to predict the weight of fat or water in a side from estimates of the weight of fat or water in any of the four cuts, plus the side weight are given in Tables 4.18. and 4.19. for Trial 1. Corresponding equations for the prediction of protein plus ash weight in a side were not produced as it was considered that it could be as accurately estimated by difference from predicted side fat, and water weights, as by prediction equation from the weight of protein plus ash in a sample cut. Multiple correlation coefficients, and standard errors both as absolute values, and as a percentage of the mean of the dependent variable are also given. Two analyses of covariance were made in order to test the homogeneity of the regression coefficients between sire groups. These analyses were carried out when side weight and rib-cut fat weight or water weight were the independent variables. No significant heterogeneity was shown.

TABLE 4.18.

Multiple regression equations enabling prediction of side fat weight from side weight and the weight of fat in a cut.
(Trial 1 data)

Sire group	X_2 (kgm)	Regression equation	Multiple correlation coefficient	Standard error	
				Absolute	as % $\bar{Y}$
		X_1 = Side wt. (kgm)			
1	Leg fat wt.	$Y = 2.24 + 0.3035\ (X_1 - 7.03) + 2.0356\ (X_2 - 0.544)$	0.970	0.1270	5.67
	Loin fat wt.	$Y = 2.24 + 0.3266\ (X_1 - 7.03) + 1.4708\ (X_2 - 0.411)$	0.971	0.1236	5.52
	Rib-cut fat wt.	$Y = 2.24 + 0.3250\ (X_1 - 7.03) + 3.7684\ (X_2 - 0.193)$	0.972	0.1232	5.50
	Rest fat wt.	$Y = 2.24 + 0.1346\ (X_1 - 7.03) + 1.5223\ (X_2 - 1.101)$	0.983	0.0934	4.17
2	Leg fat wt.	$Y = 1.96 + 0.0762\ (X_1 - 6.66) + 3.5216\ (X_2 - 0.521)$	0.933	0.1562	7.97
	Loin fat wt.	$Y = 1.96 + 0.1856\ (X_1 - 6.66) + 2.2296\ (X_2 - 0.353)$	0.952	0.0892	4.55
	Rib-cut fat wt.	$Y = 1.96 + 0.1661\ (X_1 - 6.66) + 6.9864\ (X_2 - 0.160)$	0.950	0.1347	6.87
	Rest fat wt.	$Y = 1.96 + 0.0518\ (X_1 - 6.66) + 2.0067\ (X_2 - 0.927)$	0.972	0.1017	5.19
3	Leg fat wt.	$Y = 2.52 + 0.0153\ (X_1 - 7.90) + 3.7418\ (X_2 - 0.605)$	0.932	0.2523	10.01
	Loin fat wt.	$Y = 2.52 + 0.1637\ (X_1 - 7.90) + 3.0166\ (X_2 - 0.471)$	0.960	0.1048	4.16
	Rib-cut fat wt.	$Y = 2.52 + 0.0889\ (X_1 - 7.90) + 9.4040\ (X_2 - 0.199)$	0.980	0.1300	5.16
	Rest fat wt.	$Y = 2.52 + 0.0667\ (X_1 - 7.90) + 1.8023\ (X_2 - 1.243)$	0.985	0.1235	4.90
4	Leg fat wt.	$Y = 2.30 + 0.0770\ (X_1 - 7.06) + 4.0590\ (X_2 - 0.554)$	0.975	0.1856	8.07
	Loin fat wt.	$Y = 2.30 + 0.2501\ (X_1 - 7.06) + 2.5367\ (X_2 - 0.440)$	0.989	0.1201	5.22
	Rib-cut fat wt.	$Y = 2.30 + 0.1174\ (X_1 - 7.06) + 7.7960\ (X_2 - 0.204)$	0.985	0.1398	6.08
	Rest fat wt.	$Y = 2.30 + 0.2380\ (X_1 - 7.06) + 2.0596\ (X_2 - 1.121)$	0.990	0.0681	2.96

TABLE 4.19.

Multiple regression equations enabling prediction of side water weight from side weight and the weight of water in a cut.
(Trial 1 data)

Sire group	X_2 (kgm)	Regression equation	Multiple correlation coefficient	Standard error	
				Absolute	as % $\bar{Y}$
		X_1 = Side wt. (kgm)			
1	Leg water wt.	$Y = 3.47 + 0.2043 (X_1 - 7.03) + 1.4410 (X_2 - 1.180)$	0.974	0.0888	2.56
	Loin water wt.	$Y = 3.47 + 0.3275 (X_1 - 7.03) + 1.0586 (X_2 - 0.441)$	0.964	0.1055	3.04
	Rib-cut water wt.	$Y = 3.47 + 0.3647 (X_1 - 7.03) + 0.5714 (X_2 - 0.200)$	0.953	0.1194	3.44
	Rest water wt.	$Y = 3.47 + 0.1609 (X_1 - 7.03) + 1.1002 (X_2 - 1.652)$	0.975	0.0868	2.50
2	Leg water wt.	$Y = 3.45 + 0.1343 (X_1 - 6.66) + 3.1000 (X_2 - 1.033)$	0.953	0.1287	3.73
	Loin water wt.	$Y = 3.45 + 0.3809 (X_1 - 6.66) + 0.8263 (X_2 - 0.451)$	0.900	0.1842	5.34
	Rib-cut water wt.	$Y = 3.45 + 0.3233 (X_1 - 6.66) + 4.6791 (X_2 - 0.194)$	0.930	0.1573	4.56
	Rest water wt.	$Y = 3.45 + 0.1484 (X_1 - 6.66) + 1.3741 (X_2 - 1.574)$	0.977	0.0907	2.63
3	Leg water wt.	$Y = 4.03 + 0.0868 (X_1 - 7.90) + 1.8089 (X_2 - 1.380)$	0.976	0.1201	2.98
	Loin water wt.	$Y = 4.03 + 0.2786 (X_1 - 7.90) + 1.4814 (X_2 - 0.521)$	0.920	0.2039	5.06
	Rib-cut water wt.	$Y = 4.03 + 0.2742 (X_1 - 7.90) + 7.2258 (X_2 - 0.217)$	0.940	0.1749	4.34
	Rest water wt.	$Y = 4.03 - 0.0027 (X_1 - 7.90) + 1.9698 (X_2 - 1.873)$	0.970	0.1269	3.15
4	Leg water wt.	$Y = 3.49 + 0.1106 (X_1 - 7.06) + 2.3669 (X_2 - 1.170)$	0.985	0.0876	2.51
	Loin water wt.	$Y = 3.49 + 0.2663 (X_1 - 7.06) + 1.4421 (X_2 - 0.481)$	0.920	0.1825	5.23
	Rib-cut water wt.	$Y = 3.49 + 0.1523 (X_1 - 7.06) + 8.4365 (X_2 - 0.207)$	0.950	0.1501	4.30
	Rest water wt.	$Y = 3.49 + 0.1270 (X_1 - 7.06) + 1.2488 (X_2 - 1.632)$	0.982	0.0921	2.64

With the data from Trials 2A and 2B, a more detailed analysis was made because of the availability of an electronic computer after Trial 1 data had been analysed. For any particular component (e.g., loin fat wt.), which was to be used together with side weight as an independent variable, 16 multiple regression equations were produced, each one within trial, within sire, and within sex. In the case of leg water weight, equations were also calculated for within trial within sire groups; within trial within sex groups; within sire within sex groups; within trial groups; within sire groups; and within sex groups.

This gave a total of 44 multiple regression equations involving leg water weight. Covariance analyses, as outlined in Table 4.20., were then conducted to test for homogeneity of regression coefficients between sexes, between trials, and between sires. The significance of heterogeneity was tested for at the 1, 5, and 20% levels of probability. Covariance tests were carried out at these successive levels of breakdown into classes, in order to find if the sensitivity of the test varied with degree of breakdown. It did not appear to however, and in all other cases (i.e., with independent variables other than leg water weight) only the 20 covariance analyses involving the 16 subclasses (within trial, within sire, within sex) were conducted.

Heterogeneity was significant at the 20% level in several cases for each set of equations, and was significant at the 5% level as well in a few cases. However, these effects appeared in nearly all instances to be the result of particularly small within group deviation sums of squares, rather than large regression sums of squares. Consequently all data from Trials 2A and 2B were bulked together to form single equations for fat and water weights of each cut. These overall equations, together with those within sires, within sexes, and within trials, are shown in the appendix in Tables

A.2. to A.9., while the overall equations alone, in a simplified and more useful form, are shown in Table 4.21.

TABLE 4.20.

Covariance analyses carried out to test for homogeneity of regression coefficients between trials, between sires, and between sexes. (Trials 2A and 2B only)

Groups involved	No. of analyses	No. of groups per analysis
Within trial; Within sire; Between sex.	8	2
Within trial; Within sex; Between sire.	4	4
Within sire; Within sex; Between trial.	8	2
Between all Within sire; Within sex; Within trial; subclasses.	1	16
Within trial; Between sire.	2	4
Within sire; Between trial.	4	2
Between all Within trial; Within sire; subclasses.	1	8
Within trial; Between sex.	2	2
Within sex; Between trial.	2	2
Between all Within trial; Within sex; subclasses.	1	4
Within sire; Between sex.	4	2
Within sex; Between sire.	2	4
Between all Within sire; Within sex; subclasses.	1	8
Between trials	1	2
Between sires	1	4
Between sexes	1	2

Table 4.22. gives some results obtained when the prediction equations in Table 4.21. that involve leg fat and water weights as independent variables, were used with data from Trial 1 to predict side fat and water weights. The predicted values were then correlated with actual values. The resulting correlation coefficients, together with the predicted and actual means, are shown in Table 4.22.

TABLE 4.21.

Prediction equations enabling estimation of side fat and water weights from side weight plus the weight of these components in any cut
(Trial 2A and 2B data)

Independent variables		Regression equation	Multiple correlation coefficient	Standard error	
X_1	X_2			Absolute	as % of $\bar{Y}$
		Estimation of water weight of side			
Side wt.	Leg water wt.	$Y = 0.3788 + 0.1541X_1 + 1.7327X_2$	0.968	0.1276	3.70
Side wt.	Loin water wt.	$Y = 0.9339 + 0.3086X_1 + 1.0950X_2$	0.928	0.1885	5.48
Side wt.	Rib-cut water wt.	$Y = 0.7702 + 0.2657X_1 + 4.6777X_2$	0.936	0.1773	5.15
Side wt.	Rest water wt.	$Y = 0.2959 + 0.1114X_1 + 1.5617X_2$	0.980	0.1005	2.92
		Estimation of fat weight of side			
Side wt.	Leg fat wt.	$Y = -0.5217 + 0.1454X_1 + 2.8748X_2$	0.967	0.1652	9.32
Side wt.	Loin fat wt.	$Y = -0.5071 + 0.2326X_1 + 2.5037X_2$	0.974	0.1490	8.41
Side wt.	Rib-cut fat wt.	$Y = -0.4115 + 0.1909X_1 + 6.5742X_2$	0.979	0.1336	7.54
Side wt.	Rest fat wt.	$Y = -0.1989 + 0.0542X_1 + 1.9373X_2$	0.988	0.0993	5.60

TABLE 4.22.

Comparison of actual side fat and water weights of Trial 1 lambs with that estimated from leg fat and water weights using prediction equations based on Trial 2A plus 2B data.

	Side fat weight		Side water weight	
	Actual	Predicted	Actual	Predicted
Mean (kgm)	2.154	2.058	3.523	3.581
Coefficient of correlation between actual and predicted values.	0.9370		0.9475	

4.10. Chemical Composition of the Leg Cut

The leg and the 9-10-11 rib-cut only, were chosen for further statistical analysis due to the fact that the loin is required for tenderness tests if these are carried out, and the rest or shoulder is the cut which is likely to be most affected by errors in splitting the carcass. Correlations between the fat and water weights of the two cuts, and the fat and water weight of the right side are given within each trial in Table 4.23. These correlations indicate that although the two cuts are very similar with regard to the correlations between cut fat weight and side fat weight, leg water weight is repeatedly more closely correlated with side water weight, than is rib-cut water weight. For this reason only the leg chemical composition was further analysed for sire differences, after corrections had been made for leg weight, birthrank, and sex. Tables 4.11. and 4.12. give least squares estimates and mean squares respectively. Leg fat and leg water of Trial 1 were also analysed as percentages of the leg weights, so that the regression on leg weight could be left out of the linear model. Although the two approaches (using weights or percentages) resulted in very similar significance levels for all effects, the ranking of the sires was different and, because of this, the use of percentages

was discontinued. Apart from some deviations in Trial 2B, the results in Table 4.11. are highly repeatable between trials, and the ranking of sire groups as regards the weight of fat and water in the leg and in the whole side is very close.

TABLE 4.23.

Simple correlation coefficients within trials between the weight of fat and water in the leg cut, and the 9-10-11 rib-cut, and in the right side.

Variables	Trial 1	Trial 2A	Trial 2B
Leg fat wt. : Side fat wt.	0.9250	0.9473	0.9583
Rib-cut fat wt. : Side fat wt.	0.9289	0.9398	0.9625
Leg water wt. : Side water wt.	0.9289	0.9557	0.9418
Rib-cut water wt. : Side water wt.	0.7499	0.8371	0.8750

No mean squares are given for leg water in Trial 2B (Table 4.12.) because the reduction in the sum of squares when all constants were included was greater than the total sum of squares. This was attributed to the high correlation between leg water weight and leg weight ($\underline{r}$ = 0.946).

Tables 4.11. and 4.12. also give the least squares estimates and the mean squares for the side fat and water weights of Trial 1, as predicted from leg composition and side weight, using prediction equations derived from Trials 2A and 2B. These do not follow very closely the results from actual chemical composition data (Tables 4.5. and 4.6.), either as regards significance of the various effects, or the ranking of the sires.

Table 4.24. gives simple regression equations within each sire group, for the regression of side fat weight on side weight, the regression of predicted side fat weight (using the multiple regression prediction equation, Table 4.21.) on side weight, and the regression of leg fat weight on leg weight. Figures 4.9., 4.10., and 4.11. give graphical represent-

ations of these three sets of regression equations respectively, by graphing the independent variable both against the dependent variable (straight lines), and against the fat per cent (curves). It can be seen from these that the leg fat results give a better indication of the side fat weights of sire groups relative to each other, than do the predicted side fat weights. Use of the prediction equation has resulted in there being less difference between sire groups, and also in lower standard errors of regression, than when raw data were used.

TABLE 4.24.

Sets of simple regression equations with standard errors, calculated within sire groups; for Trial 1 data only.

Dependent variable (Y)	Independent variable (X)	Sire group	Regression equation	Standard error	
				Absolute	as % $\bar{Y}$
Side fat wt. (kgm) Trial 1	Side wt. (kgm) Trial 1	1	Y = 0.486X - 1.16	0.1674	7.44
		2	Y = 0.439X - 0.97	0.2122	10.88
		3	Y = 0.474X - 1.23	0.2933	11.64
		4	Y = 0.571X - 1.73	0.2793	12.14
Predicted side fat wt. (kgm) Trial 1	Side wt. (kgm) Trial 1	1	Y = 0.410X - 0.82	0.1387	6.74
		2	Y = 0.414X - 0.82	0.1585	8.17
		3	Y = 0.489X - 1.50	0.1559	6.59
		4	Y = 0.506X - 1.48	0.1265	6.04
Leg fat wt. (kgm)	Leg wt. (kgm)	1	Y = 0.335X - 0.181	0.5434	9.21
		2	Y = 0.287X - 0.102	0.5206	10.91
		3	Y = 0.326X - 0.197	0.6050	12.74
		4	Y = 0.454X - 0.421	0.5540	12.19

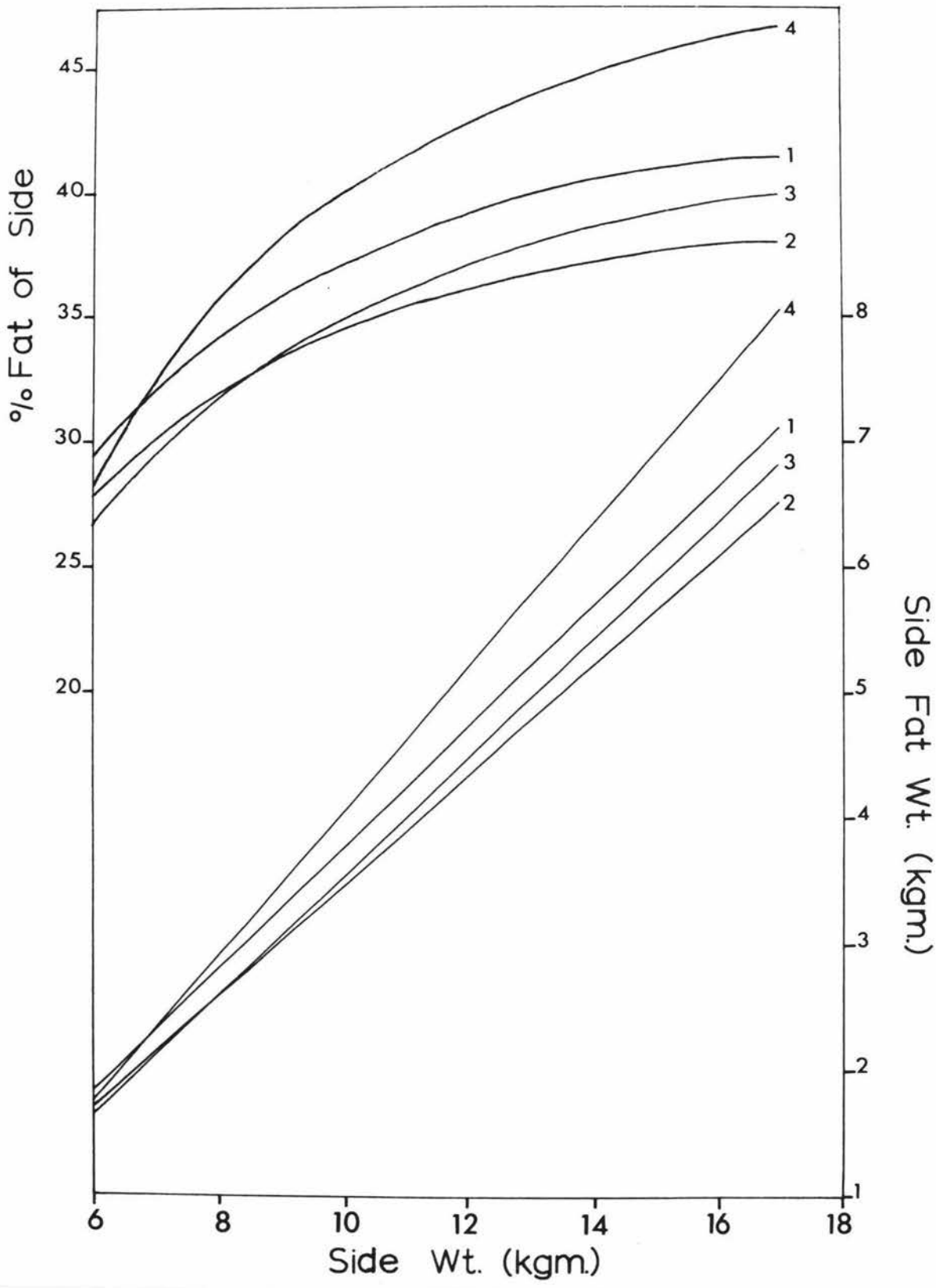


Fig. 4.9. A graph of the simple linear regressions of side fat weight on side weight for the four sire groups, shown as the change in side fat weight with side weight (straight lines), and as the change in side fat per cent with side weight (curves).

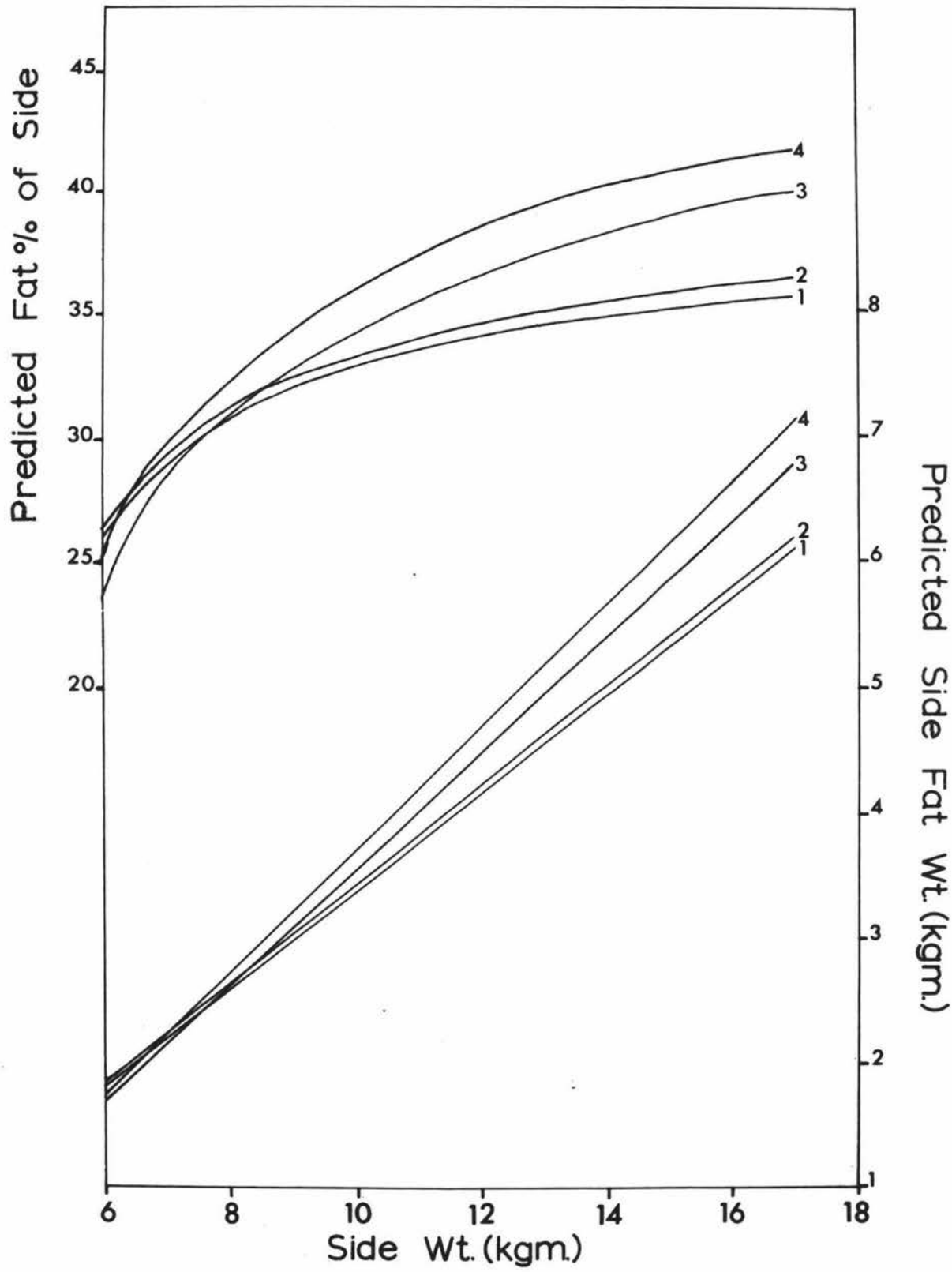


Fig. 4.10. A graph of the simple linear regressions of predicted side fat weight on side weight for the four sire groups, shown as the change in predicted side fat weight with side weight (straight lines), and as the change in predicted side fat per cent with side weight (curves).

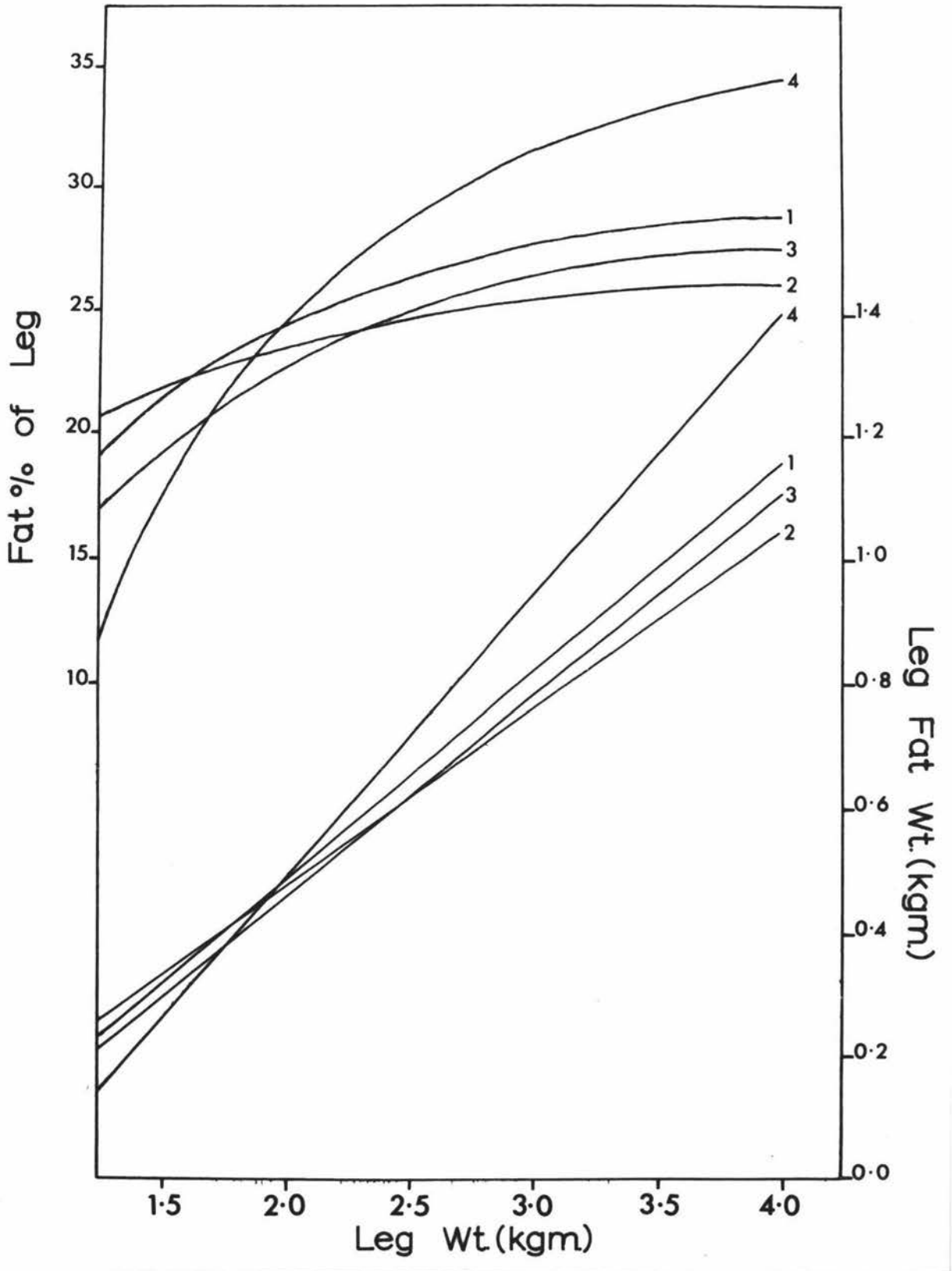


Fig. 4.11. A graph of the simple linear regressions of leg fat weight on leg weight for the four sire groups, shown as the change in leg fat weight with leg weight (straight lines), and the change in leg fat per cent with leg weight (curves).

Chapter 5

DISCUSSION

5.1. Significance of Sires as a Source of Variation in Carcass Quality

5.1.1. Growth Rates, Live Weights, and Carcass Weight

Seebeck and Campion (1964), in a paper concerning the use of liveweight data in the performance testing of beef cattle, used a multiplicative statistical model to correct for year, sex, age of dam, and sire effects because "...liveweight growth is basically a multiplicative process." Brinks et al. (1961) pointed out that whereas additive adjustments require that standard deviations be the same between groups for validity, multiplicative adjustments will be correct when coefficients of variation are the same. In most other growth studies where correction factors have been calculated for lambs (e.g., Donald, 1962; Field et al., 1963b; Ray, 1964), additive models have been assumed valid, probably because they are simpler to apply. Brothers and Whiteman (1962) considered the use of additive correction factors and partial regression coefficients, as estimated by least squares techniques (e.g., Harvey, 1960) and assessed their repeatability under different circumstances, for weight gain in lambs from 50 to 90 lb. They showed that within a year the constants were reasonably repeatable, but that corrections for birthrank and type of rearing changed drastically and unpredictably from year to year. Sex corrections however, were more repeatable. They concluded that the accuracy of adjustment factors may be improved if these were obtained by using least squares models that include adjustments only for known sources of variation. Other ways to overcome effects such as those of sex and birthrank include the use of animals all of the same sex and birthrank

(Weller et al., 1962), or by carrying out computations within each subclass (Broadbent and Bowman, 1964). In the present experiment an additive model was used.

The usefulness of birth weight as a measurement to take in progeny tests seems questionable, as not only is it very difficult to weigh every lamb under comparable conditions (Donald and McLean, 1935), but also it has been shown that characteristics at birth are not very closely related to the same characteristics at a later age, e.g., at slaughter (Eloksh et al., 1962; Bichard and Yalcin, 1964; Galal et al., 1965). This could be explained by Dickinson's hypothesis of growth (Dickinson, 1960), which claims that birth weight, especially of twins, is more closely related to the inherent mature size of an animal than to its weight at weaning, when the effects of the genes controlling mature size are masked by the different 'juvenile growth potentials' of the individuals. In meat-type sheep a high juvenile growth potential is required. Birth weights are required in order to calculate average daily gains of lambs, but the strong correlations between this measurement and other measurements of growth rate, such as carcass gain per day of age, suggest that birth weights are dispensable in this regard.

Because the lambs in this experiment were slaughtered over a narrow range of ages in all trials, the following four characteristics could be considered as measurements of growth rate: live weight at slaughter, cold carcass weight, average daily weight gain, and carcass weight gain per day of age.

Sex and birthrank effects on liveweight and on birth weight, which cannot be considered very meaningful for reasons given in Chapter 4 (section 4.2.), are compared in Table 5.1. with results from published studies. These effects are characterized by their variability, and although

this could be largely attributed to breed and seasonal differences, the variation between the three trials in this experiment suggest that the repeatability of such differences is not very high.

TABLE 5.1.

Some reports of the effects of birthrank and sex on the birth weight and the weaning weight of lambs

Reference	Material	Ram	Wether	Ewe	Single	Twin
		Birth wt. (lb.)				
Nelson and Venkatachalam (1949)	5 Breeds	0	-	-5%	+22%	0
Sabin and Brown (1962)	Dorset and Hampshires	0.15	-	0	1+	0
Campbell (1963)	Dorper	0.60	-	0	1.46	0
Donald and McLean (1935)	English Leicester	0.18	-	0		
	Southdown	0.61	-	0		
	Romney-Southdown cross	0.78	-	0		
This experiment	Romney-Southdown cross	1.44	-	0	1.22	0
		Weaning wt. (lb.)				
Nelson and Venkatachalam (1949)	5 Breeds	0	-	-6%	+17%	0
Blackwell and Harrison (1955)	Dorset	4.38	-	0	7.89	0
	Corriedale, Hampshire, Shropshire.	3.30	-	0	8.29	0
Felts et al. (1957)	Mixed breeds	5 to 6	-	0	9.00	0
Donald (1958)	Blackface cross	3.60	-	0	10.00	0
Givens et al. (1960)	Hampshire cross	-	4.7	0	0.037	0

Cont.....

Table 5.1. (Cont.)

Reference	Material	Ram	Wether	Ewe	Single	Twin
		Weaning wt. (lb.)				
Donald (1962)	Blackface cross	7.00	-	0	14.00	0
Shelton and Campbell (1962)	Rambouillet	4.67	-	0	6.45	0
Campbell (1963)	Dorper	9.70	2.40	0	8.80	0
Bichard and Yalcin (1964)	Suffolk cross	2.2 to 4.3	-	0	8.0 to 13.0	0
Donald and McLean (1935)	English Leicester Southdown	8.22 7.60	- -	0 0		
Ch'ang and Rae (1961)	Romney	-	3.00	0	10.20	0
Hazel and Terrill (1945)	Rambouillet	8.30	-	0	9.20	0
Hazel and Terrill (1946)	Columbia, Corriedale, Targhee.	10.8	-	0	11.70	0
Lambe et al. (1965)	Suffolk, Hampshire, Southdown.				7.80	0
This experiment	Romney-Southdown cross	-	5.92	0	8.68	0

The significant sire effect on dressing-out per cent in Trials 1 and 2A, together with the highly significant sire-year interaction, and lack of sire effect in Trials 1 plus 2A, present a situation which is difficult to explain. With the unsatisfactory nature of the liveweights however, it is probably best not to attempt to attach any meaning to these results.

The best measurements of growth rate (at least in this experiment) appear to be carcass weight, and carcass gain per day of age, as not only

can these be more easily and accurately measured, but also they incorporate the effect of dressing-out per cent, and are therefore a step closer to the final product than live animal measurements. That these two items are measuring the same characteristic is shown by the almost identical ranking of the sire groups in each trial; hence variance components were estimated for carcass weight only, and these indicate that birthrank is by far the most important of the sources of variation considered. This is supported by Ch'ang and Rae (1961), who demonstrated in Romney lambs that birthrank accounted for 45.5% of the variation in weaning weight. They also found that age (5.3%) accounted for more, and that sex (3.2%) accounted for less of the variation than in the present experiment. In the case of age it is probably the result of the greater range, and in the case of sex the superiority of wethers over ewes in liveweight would be expected to decrease in carcass weight due to the greater dressing-out per cent of the ewes shown in this and in other experiments (e.g., Walker, 1950). Lambe et al. (1965) also estimated variance components for the weaning weight of lambs, but in their experiment different breeds and years also contributed to the variation. This means that although comparison of relative variance percentages will be valid between their experiment and the present study, the comparison of actual percentages will not be.

Sire effects, accounted for any carcass weight variation in only two of the three trials, were statistically significant in only one trial, and showed a highly significant interaction with year effects when the first two trials (1 and 2A) were combined. This last result alone, would be of major practical significance as it suggests that evaluation of the relative merits of a group of sires in one season, based on the rate of growth of their offspring, may not be any indication of their relative merit in subsequent seasons. However, as differences between sire groups were not

statistically significant, either in the interaction model or in Trials 1 and 2A separately, then such differences can be assumed to have arisen by chance, making any interaction shown between sire effects and other effects meaningless.

Rae (1956), in reviewing knowledge on the genetics of the sheep, notes that estimates of the heritability of weaning weight had been mainly from 0.2 to 0.4. Some other estimates of the heritability of various measurements of growth rate made since 1956 are given in Table 5.2. No direct estimates of heritability were made in this experiment, but the sires were selected on the basis of their average daily gain to weaning. (Sires 1 and 2 had the highest ADGs, followed in decreasing order by sires 3 and 4.) This is reflected in their offspring only insofar as the progeny of sire 1 had the highest or second highest average corrected carcass weight in all trials and that the progeny of sire 4 had the lowest or second lowest average corrected carcass weight in all trials. Despite the dubious nature of the liveweights, and therefore of the average daily gains, the variance components of this latter characteristic are of interest in that, relative to carcass weight, more of the variation can be ascribed to sex, and less to birthrank effects.

Variability of maternal environment is generally recognized as being a major source of variation in measurements of lamb growth, and probably accounts for much of the error variation of carcass weight and ADG in the present experiment. Two possible ways of decreasing this maternal effect are: (1) remove the lambs from their mothers and raise them under artificial, but standardized, environments; or (2) measure growth rates only after the lambs have reached a certain age, on the assumption that as the lamb becomes less dependent on maternal milk supply, the dam's effect on lamb growth rate will decrease.

TABLE 5.2.

Some estimates of the heritabilities of various measurements of growth in sheep

Reference	Material	Estimate	Method of estimation	Characteristic
Blackwell and Henderson (1955)	Mixed breeds	33%	Intra sire regression	Birth wt.
Bichard and Yalcin (1964)	Suffolk cross	8%	Paternal half sib	Birth wt.
Butcher et al. (1964)	Corriedale Hampshire Shropshire Southdown	-0.22 ± 0.15 -0.13 ± 0.21 -0.10 ± 0.62 -0.08 ± 0.15	Intra sire regression	Birth wt.
	Corriedale Hampshire Shropshire Southdown	-0.17 ± 0.14 -0.09 ± 0.18 -0.29 ± 0.48 -0.11 ± 0.16	Intra sire multiple regression	Birth wt.
	Corriedale Hampshire Southdown	0.07 0.12 0.16	Paternal sib regression	Birth wt.
	Corriedale Hampshire Southdown	-0.15 -0.35 -0.05	Intra sire correlation	Birth wt.
Bichard and Yalcin (1964)	Suffolk cross	3%	Analysis of covariance	6 week wt. corrected for Bth. wt.
		13%	Analysis of covariance	15 week wt. corrected for Bth. wt.
Butcher et al. (1964)	All breeds	Approx. 0.00	All methods	140 day weaning wt.
Carter and McClure (1962)	Hampshire cross	0.12	Paternal half sib	120 day wt.
		0.08	Sire progeny regression	120 day wt.
Shelton and Campbell (1962)	Rambouillet	33.1%	Half sib correlation	Weaning wt.
		14-20%	Intra sire regression	Weaning wt.

Cont.....

Table 5.2. (Cont.)

Reference	Material	Estimate	Method of estimation	Characteristic
Givens et al. (1960)	Hampshire cross	0.067	Paternal half sib	120 day wt.
Ch'ang and Rae (1961)	Romney	0.35	Regression on dam	Weaning wt.
Carter and McClure (1962)	Hampshire cross	-0.02	Paternal half sib	Daily gain to weaning
		0.03	Sire progeny regression	Daily gain to weaning
Givens et al. (1960)	Hampshire cross	0.181	Paternal half sib	Daily gain to weaning
Hundley and Carter (1956)	Hampshire cross	37%	?	Daily gain
	Southdown cross	4%	?	
Harrington et al. (1962)	Dorset cross	34-35%	Paternal half sib	Average daily gain
Botkin (1955)	?	84%	Paternal half sib	Average daily gain
		15%	Paternal half sib	Feed/lb. gain

The first approach involves considerable labour input, and may also be complicated by genotype environment interactions. Broadbent and Bowman (1964), after discussing the second approach, conclude that until more is known about the relationships between different periods of growth, it would be best to use the growth rates from birth. Bichard and Yalcin (1964) studied this aspect more thoroughly by calculating the heritabilities and also the phenotypic and genetic correlations between the liveweights at birth, and at 6, 9, 12, and 15 weeks of age. They conclude "...that birth weight has little useful connection with weight at subsequent ages, but

that 9, 12, and 15 week weights are measuring essentially the same trait."

Field et al. (1963b) showed, with 12 Southdown rams, that an increase of 0.10 lb. in the ADG of the rams would result in approximately 0.018 lb. increase in the ADG of their progeny. In their experiment the growth rate of the sires was measured over a period of 120 days from 180 days of age, while that of the lambs which were slaughtered at an average of 183.9 days was presumably measured from birth, indicating some connection between these two periods of growth.

5.1.2. Carcass Chemical Components and Cuts

Although carcass weight is a useful carcass quality indicator, a more realistic end point in experiments involving carcass quality is the quantity of meat in a carcass suitable for sale to customers (Bray, 1963). An end point that is even closer to the consumer is that of retail carcass value, as used by Carpenter et al. (1964), or yield in pence per pound (Broadbent and Bowman, 1964). The main disadvantage of these approaches is the difficulty of standardizing the cutting and trimming procedures. In this experiment the chemical analysis of four untrimmed cuts (leg, loin, 9-10-11 rib-cut, and rest) was carried out.

Kemp and Barton (1965) compared the method of carcass chemical analysis of Barton and Kirton (1956) (B-K method) with the standard AOAC (1960) method of analysis. They showed highly significant correlations between fat, water, and protein estimations, but in the case of ash the correlations were not statistically significant at the 5% level of probability, and they concluded that: "These data suggest that the use of the B-K method for determining ash in individual cuts or carcasses is not valid." As protein content is estimated by difference in the B-K method of analysis, any error in estimation of ash will be present also in the protein estimate. However, as Kemp and Barton point out, although the error will be of the same

absolute size, it will be much smaller as a percentage error due to the greater weight of protein than ash in any carcass.

As calculated by the B-K method of chemical analysis:-

$$\% \text{ Ash of an individual sample} = \frac{\text{Wt. of dried residue}}{\text{Wt. of original sample}} \times \% \text{ ash of bulked dried residue,}$$

and similarly:-

$$\% \text{ Protein of an individual sample} = \frac{\text{Wt. of dried residue}}{\text{Wt. of original sample}} \times \% \text{ protein of bulked dried residue.}$$

It is evident from these equations that when the B-K method of analysis is used, all the individual samples that have their dried fat-free residues grouped together for ash analysis will have the same estimated ash to protein ratio. Variability in the actual ash to protein ratio within these groups therefore, could result in a low correlation between the actual ash and protein values, and those estimated using the B-K method. In the present experiment, for example, the dried fat-free residues were bulked within sire groups each year, so that any effect on the ash to protein ratio by a variable other than year or sire would not be known.

Carroll and O'Carroll (1964), in assessing the difference between left and right sides of lamb carcasses, calculated the 'efficiency' of estimating any particular component of a side as being the number of whole carcasses that would be required to achieve the same standard error as 100 sides. Their results showed that the estimation of bone, which contains nearly all the carcass ash, was the least efficient, and they attributed this to the inaccurate splitting of the sternum and the vertebral column. Other workers comparing the two sides of the same carcass have also, in the main, attributed differences to errors in the splitting of the carcass, c.f. Kirton *et al.* (1962) with lambs, Butler *et al.* (1956) with cattle, and Lasley and Kline (1957) with pigs.

Because of these factors which will tend to reduce the accuracy of the ash determinations of individual carcasses and joints, it seems that the reduction of the chemical components of the carcass to water, fat, and ash plus protein, would give more valid results than when ash and protein are estimated separately. Kemp and Barton (1965) proposed that ash be calculated from the fat content of each carcass, using a regression equation. For accurate estimates to be obtained in this way a separate regression equation should be produced for each new set of data, and also the fact that fat is generally recognized as the most labile of the tissues (Wood, 1964; Elsley et al., 1964) means that in some cases the ash and the protein estimates may be more variable than the true values. Furthermore, the problem of inaccurate splitting of the carcass is not overcome by the use of regression equations.

No obvious relationships between growth rate and carcass composition of sire groups, or between growth rate and proportion of cuts of sire groups were shown in this experiment. This is at variance with the results of Field et al. (1963b), which indicated that faster-gaining rams sired lambs that had leaner carcasses. It also conflicts with the findings of Broadbent and Bowman (1964), who noted "...an apparent correlation between growth rate and the carcass quality measurements," which in their case were yield in pence per pound, leg cut per cent, all chops per cent, and eye muscle area. Fox and McArthur (1963) however, found no close relationship between the growth rates and retail carcass values of eight sire groups. In their experiment this lack of relationship was probably due to the fact that only three offspring were evaluated per sire, but in the present experiment the only explanation seems to be the absence of any sire effects on growth rates.

Of the chemical components and cuts that were shown to be significantly affected by sires, the main pattern that arises is that the right sides of

sire groups 1 and 4 have more fat, less water, less protein and ash, lighter legs, and heavier rib-cuts than the right hand sides of sire groups 2 and 3, after adjustments have been made for side weight, birthrank, sex, and age.

Ulyatt and Barton (1963) showed in Romney Marsh ewes, highly significant correlations between carcass water weight and dissectible muscle weight (r = 0.97), and between chemical fat and dissectible fat weights (r = 0.99). It was assumed that similar relationships existed for the lambs of this experiment. As fat is a later-developing tissue than muscle, and as the rib-cut contains more late-developing muscles than the leg (Butterfield, 1963), then it seems that sires 1 and 4 produce lambs that mature at a lower carcass weight than those of sires 2 and 3. Together with growth rates, this stage of maturation is probably the most important of the characteristics of meat-type lambs, and although less than 10% of the variation in the above characteristics can be ascribed to sire effects, in most cases the high repeatability between trials suggests that selection for them would be effective.

5.1.3. Carcass Measurements and the Weights of Non-Carcass Parts

Correlations between carcass linear measurements and fat per cent or leg per cent in this experiment were generally lower than the correlations between carcass weight and these two characteristics. Of those that were analysed using the least squares models, none showed significant sire effects with any consistency. Timon and Bichard (1965c) reported a number of correlation coefficients between carcass linear measurements and weights of non-carcass body components in lambs, with fat, muscle, and bone per cents. Most of the correlations with fat per cent are comparable to those estimated in this experiment. They however, estimated a correlation coefficient of 0.35 between carcass weight and fat per cent, which is

approximately half those estimated between carcass weight and fat per cent in the present experiment. Such a discrepancy is difficult to explain, but is probably partly due to the slightly greater variation in both characteristics in this experiment. The comparable correlations reported by Boylan and Seale (1965) are also generally lower than those in this experiment, possibly because they used data from lambs of three different crossbreeds.

The only measurement that closely followed fat weight from the point of view of the ranking of the sire groups was the depth of the fat over the eye muscle (C). No other trials with lambs appear to have investigated the use of linear carcass measurements to predict differences between sire groups in carcass quality characteristics such as chemical composition. However, Barton et al. (1949) showed that linear measurements were heritable in the Southdown breed, and a number of studies have been made correlating linear measurements with carcass quality characteristics (e.g., Palsson, 1939; Walker and McMeekan, 1944; Robinson et al., 1955; Hoke, 1961; Hiner and Thornton, 1962; Malkus et al., 1963; Judge and Martin, 1963; Jordan et al., 1964; and Cunningham et al., 1965). The use of single measurements has generally not proved very satisfactory, but the combinations of several measurements, especially when some weights of body parts are included, in the form of a multiple regression equation have been useful in the prediction of carcass quality. An example of this type is the equation reported by Hoke (1961), in which conformation grade, fat thickness over the rib eye, and per cent kidney fat were shown to account for 78% of the variation in the yield of the five main cuts (leg, sirloin, loin, rib, and shoulder). This equation, in a slightly modified form, is being used in the commercial progeny testing scheme run by the University of California (Spurlock et al., 1964). No regression equations were

investigated in the present experiment, mainly because no single characteristic, such as yield of retail cuts, or carcass retail value, that would serve as a meaningful dependent variable, was available.

Of the non-carcass components omental fat weight was the only one analysed for sire effects, because of its correlations with fat per cent. Significant sire effects on omental fat in Trial 2B only, together with an inconsistent ranking of sire groups, suggests that this is not a particularly useful measurement. Its main advantage is that it can be taken without affecting the carcass.

The cross-sectional area of the Longissimus dorsi muscle did not show any significant sire effects in either of the trials in which it was measured. The linear measurements made on this area did not show sire effects either, except for measurement A in Trial 2B, in which case it was only at the 5% level of significance, and as this measure was shown to be less closely correlated with the total area than measurement B, then it cannot be considered very important. Most investigations concerning the progeny testing of meat-type sheep have included eye muscle area as a carcass quality index (e.g., Fox and McArthur, 1963; Field et al., 1963b; Broadbent and Bowman, 1964). However, none of these workers have reported any significant differences between sire groups, although Broadbent and Bowman (1964) did show that eye muscle area was positively correlated with growth rate and carcass weight. Its alleged relationship with lean content of carcasses, and its contribution to the appearance of some cuts of meat, are the two properties of eye muscle area which have brought about its extensive use as a carcass quality index. Justification for its use on the basis of the former property however, is questionable, and some studies concerning this aspect are reviewed by Bray (1963). Also, Tulloh (1963) points out that the relation between the cross-sectional area of the eye

muscle and, say, muscle weight cannot be linear over wide ranges in body weight. Furthermore, Hedrick et al. (1965) found in beef cattle that subcutaneous fat measurements were associated with two to three times more variation in retail yield than was eye muscle area. A major problem in the use of eye muscle area is to devise an accurate cutting and measuring procedure which can easily be standardized for all carcasses. The three most common methods of measurement are through a combination of linear measurements, by the use of a standardized grid, and by the use of a planimeter, either on a tracing or on a photograph of the area. Bodwell et al. (1959) compared these three approaches on beef carcasses, and showed that the use of the grid was some 25% less accurate than the planimeter, and that area estimated by combinations of linear measurements is highly repeatable, but predicts true area with insufficient accuracy for experimental use.

The unsatisfactory nature of some cutting techniques, with regard to measurement of eye muscle area, has been well demonstrated. Hedrick et al. (1965), for example, showed in one experiment a highly significant difference between the area in left and right sides of the same cattle. They also showed that the cross-sectional area of the L. dorsi muscle at positions between the 11th and 14th ribs varied considerably, but not systematically. Stouffer (1961) reported similar results and set out in detail a cutting procedure for beef cattle that he claimed would cut through a portion of the L. dorsi that is relatively constant in cross-sectional area.

In general, it would seem that linear carcass measurements and/or the weights of non-carcass components, either singly or in combination, would be insufficiently accurate or sensitive, to detect the magnitude of real differences in carcass composition, that are likely to exist between sire groups.

5.1.4. Weight of the Contents of the Stomach plus the Oesophagus (SOc)

The presence of a significant difference between the corrected weight of SOc of sire groups, in each trial, and in Trials 2A and 2B combined, is of interest, but the presence of a significant sire-year interaction, and the high coefficients of variation (19.8%, 25.7%, and 23.8% for Trials 1, 2A, and 2B, respectively), suggest that these may not be meaningful results. This character was analysed for sire effects mainly because significant differences in gastro-intestinal contents have been shown in some other experiments for no apparent reason (e.g., Hight et al., 1962; Ulyatt and Barton, 1964).

5.1.5. Tenderness

It appears from the tenderness results that sires do exert an appreciable influence on tenderness, and the fact that this was shown to be statistically significant in only one trial could at least partially be attributed to the large percentage of the variation that was not removed by any of the corrections applied. It is difficult to explain this error variation within trials or for the differences in corrected means between trials, but the most likely explanation seems to be the variation in the treatment of individual lambs from immediately before slaughter until they are frozen. The relative periods of time when any lamb was in the pen before slaughter, hanging as a carcass before freezing, and being frozen, would have varied considerably between individuals even within a killing lot. The importance of the immediate post-mortem period in relation to tenderness is emphasized by Marsh (1963). Other work that has involved a study of sire effects on tenderness is reviewed in Chapter 2, section 2.2.4.2.(a).

From a progeny testing point of view, it appears that the procedure followed in this experiment is satisfactory for demonstrating differences

in tenderness between sire groups, but from a practical point of view it may be possible to increase tenderness more rapidly by first determining and then producing, if possible, the optimum post- and ante-mortem environments (Marsh, 1963; Briskey, 1963).

5.2. Repeatability of Sire Performance in Successive Seasons

Results of this experiment indicate fairly clearly, both through the calculation of sire by year interactions, and in the comparison of the rankings of sires in successive years, that where there are statistically significant sire effects, the relative effects of sires are highly repeatable.

The notable exceptions are dressing-out per cent, which is probably due to the nature of the liveweights (c.f. Chapter 4, section 4.2.), and the weight of the contents of the stomach plus the oesophagus, for which there appears to be no satisfactory explanation.

Rowe et al. (1965) tested the repeatability of the performance of 10 rams by comparing the average retail cutout values of their offspring over two years. In their study, although the rankings of the rams between years were not identical, there were definite similarities between them.

5.3. Repeatability of Sire Performance when Lambs are selected for Slaughter in different ways

The choice of a time to slaughter lambs in a progeny test may be based on a number of criteria. Some desirable features of such criteria are:-

(1) Objectivity, which is usually associated with accuracy and sensitivity.

(2) Simplicity, which is usually highly correlated with economy.

(3) Maximum reduction in the number of extraneous variables.

(4) Removal of those variables in particular that cannot be corrected

for statistically, i.e., intangible, factors as opposed to easily measured factors.

The criteria for selection that were considered in this experiment, and their evaluation in terms of the above features, are as follows:-

(a) Selection on constant liveweight.

(1) Objectivity: good.

(2) Simplicity: repeated weighings would be necessary in order to be able to select with a satisfactory degree of accuracy, and apart from the extra work involved, the effect of the handling of the lambs may be significant, as some will be weighed more times than others.

(3) Corrections for liveweight are unnecessary, but it may still be desirable to correct for variations in carcass weights, depending on the constancy of the dressing-out percentage.

(4) Killing at a constant liveweight would mean that a series of slaughter dates ranging over a period of time would be unavoidable, and this would mean that the environment, particularly from the nutritional and climatic points of view, just prior to slaughter, may vary considerably for different killing lots. These variables are intangible and cannot easily be corrected for statistically.

(b) Selection on constant age.

(1) Objectivity: good.

(2) Simplicity: good.

(3) Corrections for age at killing are unnecessary.

(4) The same situation that applies to selection on constant weight applies here, although probably not to the same extent, as the

age range of the lambs could probably be minimized by the use of procedures such as oestrus synchronization in conjunction with artificial insemination.

(c) Selection at a constant point in time.

(1) Objectivity: good.

(2) Simplicity: very good.

(3) It does not remove any variables that would normally be corrected for.

(4) It removes the intangible effect of varying environment as outlined above.

(d) Selection of the lambs by a commercial lamb buyer.

(1) Objectivity: poor.

(2) Simplicity: good.

(3) No variables are removed.

(4) A series of killing dates will still be necessary so that the situation is the same as for (a) above.

In this experiment selection was based on a constant age (Trials 1 and 2A), and a constant date (Trial 2B), but no interactions between sire and method of selection of offspring were computed. The ranking of the sires in the trials do however, indicate that where statistically significant sire effects exist, then the relative effects of the four sires are highly repeatable when different methods are used.

The weight of the contents of the stomach plus the oesophagus is an exception. It is also of interest to note that, in general, the error mean square is smaller when an age correction is included and, mainly as a result

of this, more statistically significant results are shown in Trial 2B.

In most other progeny testing trials involving meat-type lambs, the lambs have been selected for slaughter at a constant weight, or within a certain weight range (e.g., Broadbent and Bowman, 1964; Bichard and Yalcin, 1964), but from this experiment it seems that slaughter of all the lambs at the same time would be the most satisfactory, assuming that age and weight effects can be accurately corrected for over the existing range. These corrections are likely to increase in accuracy as the ranges of age and weight decrease.

5.4. Sample Cuts and Prediction Equations

One of the main requirements of a commercial progeny testing scheme is that it should be simple, hence the relevance of indirect methods of estimating carcass composition. Of the three indirect methods evaluated by Timon and Bichard (1965a, b, c) for use on lambs, the use of sample cuts proved to be the most effective. They investigated the use of all wholesale cuts singly, and in combination, and concluded that the best cuts were the loin, and the best neck. The muscles of both these cuts consist essentially of those adjacent to the spinal column, and these have been described by Butterfield (1963), when referring to cattle, as "...those muscles whose weight relation to that of the total carcass muscle remains virtually unchanged during post-natal life." On this basis they would be expected to be good sample cuts at all ages.

Numerous reports concerning the use of sample cuts and prediction equations exist in the literature, and in the case of the prediction of of lamb carcass composition, the papers of Kirton and Barton (1962), and Timon and Bichard (1965a) provide good examples. The approaches of various workers have varied with regard to a number of aspects of sample cuts and prediction equations. Some of these are as follows:-

(a) Whether physical (Barton and Kirton, 1958; Field et al., 1963a; Timon and Bichard, 1965a) or chemical (Kirton and Barton, 1962) components of the carcass are being estimated.

(b) Whether these components are treated as percentages of the total carcass (Kirton and Barton; Timon and Bichard), or as absolute weights (Barton and Kirton). Field et al. predicted carcass component per cent from the weight of the component in the cut. Millar (1963), and Dinkel et al. (1965) discuss fully the use of percentages, as opposed to weight correction by regression equations, and the situation can best be summarized by the statement of Dinkel et al. (1965), that in the analysis of carcass data there is only one situation where ratios or percentages appear useful as weight adjustment procedures, and this is "...when the regression line passes through the origin, and is linear from the origin through the region of interest."

(c) Whether simple or multiple regressions are used. Timon and Bichard calculated both simple regression equations, and also multiple regression equations, with components of separate cuts as the independent variables. Barton and Kirton also investigated the use of a multiple regression equation in the prediction of side fat weight, with the fat weights of the leg and the loin as independent variables, but on the basis of the standard errors they concluded that such an equation had no advantages over a simple regression equation with the leg plus loin fat weight as the independent variable.

(d) How they have assessed the accuracy, sensitivity, and general effectiveness of particular equations. In early work (e.g., Palsson, 1939; Walker and McMeekan, 1944) emphasis was placed on the correlation coefficients between the dependent and independent variables, but as Timon

and Bichard point out, the magnitude of these coefficients is very much dependent on the variability of the experimental material. More recent studies give both correlation coefficients, either between the dependent and independent variables, or between the predicted and the actual dependent variable, together with the standard error of the regression, which may be expressed in the same units as the dependent variable or as a percentage of it. Expression of the standard errors in the latter way enables easier comparisons to be made of the accuracies with which different components can be predicted. Timon and Bichard, as well as estimating the correlation coefficients and the standard errors, have also assessed the usefulness of prediction through sample cuts, by estimating the maximum probable errors associated with the prediction of carcass composition from sample cuts, both with individual and with group means.

(e) Finally, workers have differed in their cutting procedures, and the basis on which various joints or cuts have been suggested as the most suitable for practical purposes. Palsson (1939) suggested that the leg plus the loin would be the most suitable cut, as it incorporates an early- and a late-developing portion of the body, and can easily and accurately be removed from the rest of the carcass. It is also easily dissected relative to other cuts. It was pointed out by Barton and Kirton (1958) that although the thorax or 'rest' cut often gives the highest correlations with carcass composition, these are, to a large extent, spurious correlations, and the difficulty associated with the accurate jointing and dissection of this portion makes it unsatisfactory as a sample cut. Like Timon and Bichard, Field et al. found cuts from the rib region were the best, and again like Timon and Bichard, but unlike Barton and Kirton, they used a cutting procedure that did not leave the abdominal muscles as part of the rib-cuts. This probably explains in part the superiority of these cuts over rib-cuts

as used by Barton and Kirton, as the abdominal muscles have been shown in cattle (Butterfield, 1963) to be a particularly late-developing group.

In the present experiment the weights of the chemical components of four cuts (see Kirton et al., 1962) were estimated, and used together with side weight in multiple regression equations. The effectiveness of these equations was gauged from the correlation coefficients between the predicted and the actual values of the dependent variable (multiple correlation coefficient), and from standard errors, both in absolute terms and as a percentage of the mean of the dependent variable. No outstanding differences in the usefulness of these and other forms of prediction equation are apparent from the correlations and standard errors. The equations showed generally higher multiple correlation coefficients and standard errors for fat weight than water weight, which was to be expected with the characteristically greater variation in fatty tissue content. This generalization, together with the fact that the loin and the 9-10-11 rib-cut are more effective in predicting side fat weight than side water weight, is supported by other studies (e.g., Field et al., 1963a).

The best set of prediction equations that arise from this experiment are presented in Table 4.21. and these should be most suitable for use with Southdown-Romney cross lambs having carcass weights in the range of 20-40 lb. Some further indication of the effectiveness of these equations is given by the results of their use in predicting side fat and water weight in Trial 1 data (Table 4.22.). Trial 1 lambs were the progeny of the same four sires, but were born in a different year, and had approximately a 3 lb. greater average carcass weight.

The use of side weight together with the chemical composition of a sample cut to estimate lamb carcass composition, appears to be unique, although carcass or side weight alone have been shown to be good indicators

of carcass composition. Kirton and Barton (1962), for example, present simple regression equations which enable prediction of carcass fat, protein, ash, and water from the carcass weights of lambs. Correlation coefficients between independent and dependent variables were 0.63, 0.78, 0.48, and 0.77, respectively. Callow (1962) discussed the use of sample cuts, and showed with data from a group of 24 cattle that the standard errors associated with prediction of carcass composition using a sample cut were greater than those associated with the estimation of muscular tissue as one third of liveweight, the estimation of bone from the weight of the radius-ulna, and the estimation of fat by difference.

A major disadvantage of sample cuts and prediction equations is that the groups being compared in an experiment, such as sire groups, hormone treatments, or nutritional treatments, may have differential effects on the relationships between the dependent and independent variables in each group (c.f. Kirton and Barton, 1962).

The objectives in any progeny testing scheme, rather than including a specific carcass composition at which to aim, are likely to set out aims such as the maximization of the lean to fat ratio, or the minimization of the change in fat per cent over a specified weight range. This means that accuracy in a method of carcass composition estimation will not be so important as economy, simplicity, and ability to detect small differences (i.e., sensitivity). Within any test the relative values will be the most important, and the ability of a technique to produce true relative values is a reflection of its sensitivity rather than its accuracy. In this respect, comparison of the use of regression equations with the use of the composition of the sample cut <u>per se</u>, to predict relative carcass compositions, was considered.

Correlation coefficients do not normally constitute a valid basis for

the comparison of methods, but in this case, where the same data have been used for each method, the degree of variability will be constant, and the comparison of the correlation coefficients in Tables 4.21., 4.22., and 4.23. should give a valid picture. A further indication is given by the comparison of the rankings of sire groups in Table 4.11. On the basis of these results, the use of the sample cut (leg) composition *per se* seems superior, as for Trial 1 it reflected the relative values of actual side composition more closely than did the predicted side composition results.

Another technique that can be used to evaluate these two approaches (whether or not prediction equations are used), is that suggested by Cockrem (1965), whereby the regressions of fat weight, say, on side weight or cut weight are compared between sire groups. This involved, in the present study, a comparison of the regressions of predicted side fat weight on side weight, and of leg fat weight on leg weight, with the regressions of actual side fat weight on side weight (Table 4.24., Figs. 4.9., 4.10., and 4.11.). This again favours the use of the chemical composition of the leg cut *per se*, rather than its use in a prediction equation to produce results which, although more accurate in absolute terms, are less accurate in relation to each other. As Cockrem (1965) pointed out, the production of a uniform carcass over a range of weights requires that the fat percentage remain constant over this range, and in this regard sires 3 and 2 appear to produce the best progeny.

5.5. General

The establishment of a commercial progeny testing scheme, with the object of facilitating selection of sires of meat-type lambs, will involve the consideration of at least the following three aspects. First, the laying down of objectives, in terms of productive characteristics, at which to aim; secondly, the choice of suitable techniques enabling measurement of

these characteristics; and thirdly, the organization of the scheme, particularly as regards collection and analysis of data.

Morris et al. (1963), and Rae (1964), amongst others, have emphasized the importance of having a small number of simple, and objectively defined breeding aims. Morris also noted that in the case of meat-type lambs the most important characteristics are growth rate and carcass quality, but admitted that carcass quality is a characteristic that is neither simple nor objective. It seems that conformation as it was traditionally considered is not of real importance to carcass quality, and that the simplest aims concerning lamb carcasses would be to decrease the fat content, and increase the tenderness of the meat. The fact that decreased fat at a particular weight or age seems, in some cases at least, to be associated with an increased growth rate to that stage, and also with an increased proportion of the high-priced leg cut, indicates that selection for decreased fat and increased growth rate may be complimentary. It should be emphasized however, that in most of the studies suggesting the above associations, only a few sires have been involved; too few in most cases to be considered a representative sample of the particular population. Some support can however, be gained for these associations on a physiological basis, as the relatively faster-growing lamb with less fat, and a larger proportion of leg cut, fits in with the general concept of a lamb which reaches maturity at a greater weight and age.

The age, weight, and environmental conditions under which top quality carcasses are produced, are likely to be characteristics that are peculiar to a particular breed or crossbreed, and it is important that the appropriate breed societies recognize this when drawing up breeding aims, but that they also recognize the necessity to integrate these aims with market requirements and demands. The Southdown-Romney cross lamb appears

to be well suited to the 28-33 lb. carcass weight range, but there is considerable scope within this range to select for decreased fatness. Initially selection for this, and increased growth rate, seems likely to be the most effective method of improvement of that cross.

A large amount of information exists in the literature concerning the combining of a number of characteristics into an overall index, based on the heritabilities and relative economic values of the characters, and the genetic correlations between them. For example, Givens et al. (1960) compared five different indices involving different combinations of 120-day weight, daily gain, and market grade, of weanling Hampshire cross lambs. They concluded that selection based on daily gain alone was most effective. The statistics necessary for the computation of selection indices were not estimated in the present experiment, but the low economic values currently attached to degree of fatness, and to tenderness, would suggest that growth rate would be the most important characteristic in New Zealand lambs as well.

The aspect of measurement of possibly important productive characters is more closely linked with the objects of this experiment and, assuming that the characters to be considered are growth rate, fatness, and tenderness, then, from the results presented here, the best ways of assessing them appear to be as follows.

In the case of growth rate, again taking accuracy, sensitivity, economy, and simplicity, as the main criteria of excellence, then carcass weight gain per day of age seems to be the best. Not only does it dispense with the necessity of taking liveweights, but it also incorporates a measurement of dressing-out per cent, which may vary between sire groups.

An accurate assessment of the relative fatness of the sire progeny groups was given in this experiment by the fat weight of the leg cut. Sire groups may be compared after first correcting this weight for sex,

birthrank, age, and leg weight, or by calculating regression equations for the regression of leg fat weight on leg weight within sire groups.

Measurement of the tenderness of a cooked sample from the Longissimus dorsi muscle, as carried out in this experiment, appears to detect sire differences satisfactorily, although it was not compared in any way with other methods.

Administration and organization of progeny testing schemes for sheep have been discussed by Rae (1964), and accounts of the operation of schemes are given by Stevens (1957), and Spurlock et al. (1964). One of the most important decisions that must be made is whether or not to have a central testing station at which the progeny, and possibly the sires, would be kept. Turner (1964) discusses the various alternatives, and Groenewold (1963) makes the following points when comparing the collection of data under field conditions, and under standardized environmental conditions at central stations:-

(1) The more the environmental variation can be reduced, the higher will be the heritability estimate of any trait, and the lower will be the number of progeny required to evaluate each sire.

(2) Testing of progeny from all areas under the same environmental conditions will prevent recognition of any genotype-environment interactions that may exist.

(3) Testing in the field makes comparison of sires between farms invalid, due to different environmental conditions.

In the case of meat-type lambs, all the data can be collected after slaughter, except for their age, birthrank, and pedigree, so that on farm testing would probably be satisfactory; especially if suitable arrangements could be made with the freezing companies, and/or the abattoirs, concerning

collection of data. In order to avoid the need to take the liveweights of the lambs at any stage, it would be necessary to select them for slaughter either at a constant age, or at a constant date. Selection at a constant date was successfully carried out in this experiment, the results produced being similar to those obtained when selection was based on a constant age.

As regards statistical analysis, the variation in the correction factors for sex and birthrank, and in the coefficients of regression shown in this and other experiments, suggest that the use of standard values would decrease the accuracy and sensitivity of any test, and with computer facilities available it would probably be best to analyse each lot of data separately.

A final aspect, concerning the optimum number of progeny per sire, is discussed in detail by Bichard and Yalcin (1964). They showed that when the number of sires that are to be selected is equal to one hundredth of the number of ewes available in the test flock, then the maximum effectiveness of progeny testing (as measured by the superiority of the selected sires over the unselected ones) does not vary by more than 5% over a range of progeny group size from 14 to 42. This applies to any characteristic with a heritability between 0.05 and 0.30.

The findings of this experiment then, can probably best be summarized within the following suggested set-up for a commercial progeny testing scheme. It would involve the testing of sires on a within farm basis with, say, 20 lambs per sire being slaughtered all on the same day, and at a freezing works or an abattoir, from which it would be possible to collect the leg and loin cuts from one side, plus the carcass weight. From these the growth rate (carcass weight gain per day of age), the degree of fatness of the leg, and the tenderness of the loin, could be determined as outlined earlier. Selection of a date for slaughter should not be too critical, but

it would be desirable to achieve a mean carcass weight which is realistic for the particular breed or cross.

Chapter 6

SUMMARY and CONCLUSIONS

1. An experiment comprising three trials and involving 188 Southdown-Romney cross lambs is described. Four Southdown rams selected to represent a range of growth rates to weaning were used, and were mated to mature Romney ewes, as ram lambs (1963), and as two tooths (1964).

2. The 68 lambs of Trial 1 were born in August and September 1963, and were slaughtered in December 1963, selection for slaughter being based on age. The 60 lambs in Trial 2A, and the 60 in Trial 2B were born in August and September 1964, and were slaughtered in December 1964, selection for slaughter being based on age for Trial 2A, and on a constant date for Trial 2B.

3. A number of simple correlation coefficients between leg per cent, fat per cent, and carcass weight; and carcass measurements and weights of non-carcass parts are reported, but it is concluded that the latter measurements and weights are not suitable for detecting differences in carcass quality between sire groups.

4. The importance of sire genotype as a source of variation in a number of lamb characteristics was assessed, and the results can be summarized as follows:-

Characteristic	Importance of the mean differences between sire groups	Repeatability of ranking of sire groups between trials	Importance of sire by year interactions
Liveweights	Mainly non-significant	Low	Unknown
Carcass wt.	Mainly non-significant	Low	Significant
Growth rates	Mainly non-significant	Low	Unknown
Dressing-out per cent	Significant in two trials	Low	Significant
Side fat and water weights	Consistently significant	High	Non-significant
Side ash plus protein weight	Significant in two trials	Fair	Non-significant
Weight of leg	Consistently significant	High	Non-significant
Weight of rib-cut	Significant in two trials	High	Non-significant
Weights of loin and rest	Mainly non-significant	Low	Significant for rest
Carcass measurements	Mainly non-significant	Low	Unknown
Weights of non-carcass parts	Mainly non-significant	Low	Unknown
Weight of contents of stomach plus oesophagus	Consistently significant	Low	Significant
Tenderness	Significant in one trial	Fair	Non-significant
Leg fat weight	Consistently significant	High	Unknown
Leg water weight	Significant in two trials	High	Unknown

5. Variance components, expressed as percentages of the total variance, are given for a number of characteristics. It is shown that the characteristics considered can be classified into the three categories of:-

   (a) weights of chemical components and of cuts;

   (b) carcass weight and growth rate; and

   (c) tenderness;

   with the proportion of variance attributable to unaccounted sources increasing from categories (a) to (c).

6. It is shown that when there was a statistically significant sire effect on a characteristic, then the rankings of the sire groups between years was generally highly repeatable.

7. Selection of lambs for slaughter, based on a constant date and on a constant age, are shown to result in similar rankings of sire groups only if the characteristic concerned displays statistically significant differences between sire groups.

8. Multiple regression equations are presented which should be suitable for the prediction of side fat and water weights of Romney-Southdown cross lambs with carcass weights from 20 to 40 lb. Independent variables are the weight of fat and water in a particular cut, and side weight.

9. A multiple regression equation involving the leg as a sample joint is used with some data, and although side chemical composition predicted in this way was highly correlated with actual side chemical

composition, statistical analysis of predicted and actual fat and water weights, has resulted in different rankings of the sire groups.

10. Analysis of leg fat and water weights resulted in the same ranking of sire groups as when the whole side fat and water weights were analysed.

11. Some aspects of a commercial progeny testing scheme, applicable to meat-type sheep, are discussed. It is suggested that the existence of differences between sire groups of lambs in growth rate, degree of fatness, and tenderness, could be satisfactorily investigated by making three measurements, namely, carcass weight gain per day of age, chemical fat weight of the leg cut, and the force required to shear unit depth of the cooked L. dorsi muscle.

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APPENDIX

LIST OF APPENDIX TABLES

Table

TABLE A.1.

Means and standard deviations of some weights and measurements taken in the three trials

Variable	Trial 1		Trial 2A		Trial 2B	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Carcass wt.	13.97	2.05	12.84	2.32	12.66	2.59
Age (days)					102.35	5.35
Fat % of side	30.54	4.26	26.66	5.46	27.04	5.82
Leg % of side	31.67	1.81	32.57	1.47	32.67	2.00
Feet wt. (kgm x 10)			7.65	1.57		
Head + tongue (kgm x 10)	10.92	1.31	11.61	1.12	11.60	1.43
Stomach + oesophagus) empty wt. (kgm x 10))	7.79	0.79	7.63	1.11	7.55	1.08
Stomach + oesophagus) contents wt. (kgm x 10))	17.92	3.54	18.25	4.80	17.03	4.06
Heart wt. (kgm x 10)	1.41	0.17	1.33	0.23	1.31	0.19
Lungs, trachea,) + diaphragm wt.) (kgm x 10))	4.99	0.64	5.38	0.91	5.71	0.89
Liver wt. (kgm x 10)	5.35	0.62	4.95	0.77	4.95	0.69
Kidney wt. (kgm x 10)	1.08	0.15	0.97	0.15	0.97	0.13
Omental fat wt.) (kgm x 10))	4.32	1.18	3.11	1.31	3.34	1.43
A (mm)	51.02	5.66	51.40	3.18	50.85	3.12
B (mm)	30.97	2.76	29.80	3.12	29.35	3.69
C (mm)	5.02	2.10	3.41	1.71	3.38	1.57
D (mm)	5.94	2.46	4.13	2.32	4.03	1.98
J (mm)			7.96	3.79	8.33	4.16
Y (mm)			3.25	1.32	2.93	1.33
X (mm)			15.78	3.02	15.36	3.54
Eye muscle area (sq.in.)			1.75	0.24	1.73	0.28
G/F ratio	1.00	0.05	1.01	0.05	1.00	0.06
F (cm)	21.73	0.99	21.18	0.98	21.11	0.83
G (cm)			21.50	0.97	21.13	1.17
WF (cm)	18.20	1.26	18.70	1.45	18.50	1.88
T (cm)			16.02	0.78	16.05	0.69
K (cm)			51.11	2.98	50.52	2.44
L (cm)	50.64	2.19	51.05	2.94	50.45	2.12
Th (cm)			23.47	1.17	23.33	1.42
P (cm)			30.05	1.27		

TABLE A.2.

Estimation of side water weight from leg water weight (X_2), and side weight (X_1), in Trials 2A and 2B.

Data involved	No. of lambs	Regression equation	Multiple correlation coefficient	Standard error	
				Absolute	as % of $\bar{Y}$
Total	120	$Y = 3.4400 + .1541 (X_1 - 6.4128) + 1.7327 (X_2 - 1.1964)$	.9676	.1276	3.70
Sire group 1	30	$Y = 3.4209 + .1570 (X_1 - 6.6188) + 1.6966 (X_2 - 1.1902)$	.9646	.1367	3.99
Sire group 2	30	$Y = 3.6112 + .1410 (X_1 - 6.7615) + 1.7886 (X_2 - 1.2825)$	.9769	.1283	3.55
Sire group 3	30	$Y = 3.3754 + .1916 (X_1 - 5.9963) + 1.7619 (X_2 - 1.1659)$	.9725	.1089	3.22
Sire group 4	30	$Y = 3.3526 + .1865 (X_1 - 6.2748) + 1.5355 (X_2 - 1.1472)$	.9641	.1222	3.64
Ewes	50	$Y = 3.2121 + .2039 (X_1 - 6.0295) + 1.3612 (X_2 - 1.1118)$	.9781	.0946	2.94
Wethers	70	$Y = 3.6028 + .1394 (X_1 - 6.6867) + 1.7715 (X_2 - 1.2569)$	.9545	.1441	4.00
Trial 2A	60	$Y = 3.4818 + .1214 (X_1 - 6.4653) + 1.9670 (X_2 - 1.2132)$	.9659	.1254	3.60
Trial 2B	60	$Y = 3.3982 + .1782 (X_1 - 6.3604) + 1.5547 (X_2 - 1.1796)$	.9698	.1301	3.83

TABLE A.3.

Estimation of side fat weight from leg fat weight (X_2), and side weight (X_1), in Trials 2A and 2B.

Data involved	No. of lambs	Regression equation	Multiple correlation coefficient	Standard error	
				Absolute	as % of $\bar{Y}$
Total	120	$Y = 1.7719 + .1454 (X_1 - 6.4128) + 2.8748 (X_2 - .4735)$	.9673	.1652	9.32
Sire group 1	30	$Y = 1.9876 + .1845 (X_1 - 6.6188) + 2.4198 (X_2 - .5298)$	.9711	.1603	8.06
Sire group 2	30	$Y = 1.8692 + .1179 (X_1 - 6.7615) + 2.8359 (X_2 - .5207)$	.9735	.1545	8.26
Sire group 3	30	$Y = 1.4512 + .0830 (X_1 - 5.9963) + 3.7855 (X_2 - .3855)$	.9655	.1142	7.87
Sire group 4	30	$Y = 1.7798 + .2479 (X_1 - 6.2748) + 2.6025 (X_2 - .4582)$	.9765	.1620	9.10
Ewes	50	$Y = 1.6976 + .2264 (X_1 - 6.0295) + 2.1342 (X_2 - .4515)$	.9728	.1395	8.22
Wethers	70	$Y = 1.8251 + .1540 (X_1 - 6.6867) + 2.9660 (X_2 - .4893)$	.9689	.1714	9.39
Trial 2A	60	$Y = 1.7658 + .1286 (X_1 - 6.4653) + 3.0406 (X_2 - .4689)$	.9697	.1539	8.71
Trial 2B	60	$Y = 1.7781 + .1688 (X_1 - 6.3604) + 2.6606 (X_2 - .4781)$	.9658	.1789	10.06

TABLE A.4.

Estimation of side water weight from loin water weight (X_2), and side weight (X_1), in Trials 2A and 2B.

Data involved	No. of lambs	Regression equation	Multiple correlation coefficient	Standard error	
				Absolute	as % of $\bar{Y}$
Total	120	$Y = 3.4400 + .3086 (X_1 - 6.4128) + 1.0950 (X_2 - .4814)$	.9278	.1885	5.48
Sire group 1	30	$Y = 3.4209 + .3107 (X_1 - 6.6188) + 0.9632 (X_2 - .4870)$	.9485	.1642	4.80
Sire group 2	30	$Y = 3.6114 + .3264 (X_1 - 6.7615) + 1.2514 (X_2 - .4897)$	.9373	.2093	5.79
Sire group 3	30	$Y = 3.3754 + .4252 (X_1 - 5.9963) + 0.3115 (X_2 - .4861)$	.9236	.1794	5.31
Sire group 4	30	$Y = 3.3526 + .2713 (X_1 - 6.2748) + 1.0226 (X_2 - .4627)$	.9386	.1589	4.73
Ewes	50	$Y = 3.2122 + .3205 (X_1 - 6.0295) + 0.7485 (X_2 - .4553)$	.9604	.1268	3.95
Wethers	70	$Y = 3.6028 + .2753 (X_1 - 6.6867) + 1.3653 (X_2 - .5000)$	.9082	.2024	5.62
Trial 2A	60	$Y = 3.4819 + .3203 (X_1 - 6.4653) + 0.8076 (X_2 - .4924)$	.9133	.1975	5.67
Trial 2B	60	$Y = 3.3982 + .2909 (X_1 - 6.3604) + 1.5025 (X_2 - .4703)$	.9414	.1801	5.30

TABLE A.5.

Estimation of side fat weight from loin fat weight (X_2), and side weight (X_1), in Trials 2A and 2B.

Data involved	No. of lambs	Regression equation	Multiple correlation coefficient	Standard error	
				Absolute	as % of $\bar{Y}$
Total	120	$Y = 1.7719 + .2326 (X_1 - 6.4128) + 2.5037 (X_2 - .3145)$	.9735	.1490	8.41
Sire group 1	30	$Y = 1.9876 + .3159 (X_1 - 6.6188) + 1.9431 (X_2 - .3510)$	.9765	.1445	7.27
Sire group 2	30	$Y = 1.8692 + .2062 (X_1 - 6.7615) + 2.5943 (X_2 - .3299)$	.9773	.1432	7.66
Sire group 3	30	$Y = 1.4512 + .1601 (X_1 - 5.9963) + 2.7625 (X_2 - .2562)$	.9737	.0999	6.88
Sire group 4	30	$Y = 1.7798 + .2457 (X_1 - 6.2748) + 2.3054 (X_2 - .3208)$	.9804	.1481	8.32
Ewes	50	$Y = 1.6976 + .2756 (X_1 - 6.0295) + 2.1023 (X_2 - .3071)$	.9757	.1320	7.77
Wethers	70	$Y = 1.8251 + .2460 (X_1 - 6.6867) + 2.4612 (X_2 - .3197)$	.9741	.1567	8.58
Trial 2A	60	$Y = 1.7658 + .1874 (X_1 - 6.4653) + 2.7595 (X_2 - .3202)$	.9764	.1360	7.70
Trial 2B	60	$Y = 1.7781 + .2668 (X_1 - 6.3604) + 2.3106 (X_2 - .3087)$	.9752	.1525	8.58

TABLE A.6.

Estimation of side water weight from rib-cut water weight (X_2), and side weight (X_1), in Trials 2A and 2B.

Data involved	No. of lambs	Regression equation	Multiple correlation coefficient	Standard error	
				Absolute	as % of $\bar{Y}$
Total	120	$Y = 3.4400 + .2657 (X_1 - 6.4128) + 4.6777 (X_2 - .2065)$	.9364	.1773	5.15
Sire group 1	30	$Y = 3.4209 + .2116 (X_1 - 6.6188) + 6.5683 (X_2 - .2063)$	.9651	.1358	3.97
Sire group 2	30	$Y = 3.6114 + .3192 (X_1 - 6.7615) + 3.6171 (X_2 - .2144)$	.9407	.2037	5.64
Sire group 3	30	$Y = 3.3754 + .2771 (X_1 - 5.9963) + 6.5123 (X_2 - .1975)$	.9546	.1393	4.12
Sire group 4	30	$Y = 3.3526 + .2626 (X_1 - 6.2748) + 3.0294 (X_2 - .2080)$	.9414	.1553	4.63
Ewes	50	$Y = 3.2122 + .3146 (X_1 - 6.0295) + 2.0853 (X_2 - .1970)$	.9561	.1334	4.15
Wethers	70	$Y = 3.6028 + .2242 (X_1 - 6.6867) + 5.9783 (X_2 - .2133)$	.9322	.1751	4.86
Trial 2A	60	$Y = 3.4819 + .2647 (X_1 - 6.4653) + 4.8326 (X_2 - .2061)$	.9299	.1783	5.12
Trial 2B	60	$Y = 3.3982 + .2599 (X_1 - 6.3604) + 4.7623 (X_2 - .2070)$	.9445	.1755	5.16

TABLE A.7.

Estimation of side fat weight from rib-cut fat weight (X_2), and side weight (X_1), in Trials 2A and 2B.

Data involved	No. of lambs	Regression equation	Multiple correlation coefficient	Standard error	
				Absolute	as % of $\bar{Y}$
Total	120	$Y = 1.7719 + .1909 (X_1 - 6.4128) + 6.5742 (X_2 - .1459)$	.9787	.1336	7.54
Sire group 1	30	$Y = 1.9876 + .1918 (X_1 - 6.6188) + 5.9081 (X_2 - .1681)$	.9758	.1466	7.37
Sire group 2	30	$Y = 1.8692 + .2023 (X_1 - 6.7615) + 6.5715 (X_2 - .1477)$	.9867	.1095	5.86
Sire group 3	30	$Y = 1.4512 + .1327 (X_1 - 5.9963) + 6.8467 (X_2 - .1174)$	.9612	.1210	8.34
Sire group 4	30	$Y = 1.7798 + .2550 (X_1 - 6.2748) + 5.7822 (X_2 - .1506)$	.9832	.1370	7.69
Ewes	50	$Y = 1.6976 + .2419 (X_1 - 6.0295) + 5.1263 (X_2 - .1431)$	.9739	.1366	8.04
Wethers	70	$Y = 1.8251 + .1938 (X_1 - 6.6867) + 6.8687 (X_2 - .1479)$	.9832	.1263	6.92
Trial 2A	60	$Y = 1.7658 + .1899 (X_1 - 6.4653) + 6.5224 (X_2 - .1470)$	.9813	.1211	6.86
Trial 2B	60	$Y = 1.7781 + .1946 (X_1 - 6.3604) + 6.5836 (X_2 - .1449)$	.9778	.1444	8.12

TABLE A.8.

Estimation of side water weight from rest water weight (X_2), and side weight (X_1), in Trials 2A and 2B.

Data involved	No. of lambs	Regression equation	Multiple correlation coefficient	Standard error	
				Absolute	as % of $\bar{Y}$
Total	120	$Y = 3.4400 + .1114 (X_1 - 6.4128) + 1.5617 (X_2 - 1.5558)$	.9800	.1005	2.92
Sire group 1	30	$Y = 3.4209 + .1290 (X_1 - 6.6188) + 1.4536 (X_2 - 1.5375)$	.9791	.1053	3.08
Sire group 2	30	$Y = 3.6114 + .0719 (X_1 - 6.7615) + 1.8194 (X_2 - 1.6249)$	.9876	.0943	2.61
Sire group 3	30	$Y = 3.3754 + .1816 (X_1 - 5.9963) + 1.3625 (X_2 - 1.5260)$	.9808	.0912	2.70
Sire group 4	30	$Y = 3.3526 + .1298 (X_1 - 6.2748) + 1.2921 (X_2 - 1.5346)$	.9814	.0882	2.63
Ewes	50	$Y = 3.2122 + .1836 (X_1 - 6.0295) + 1.1583 (X_2 - 1.4481)$	.9705	.1098	3.42
Wethers	70	$Y = 3.6028 + .0958 (X_1 - 6.6867) + 1.5951 (X_2 - 1.6327)$	.9828	.0891	2.47
Trial 2A	60	$Y = 3.4819 + .1351 (X_1 - 6.4653) + 1.4661 (X_2 - 1.5701)$	.9784	.1001	2.87
Trial 2B	60	$Y = 3.3982 + .0813 (X_1 - 6.3604) + 1.6945 (X_2 - 1.5415)$	.9826	.0990	2.91

TABLE A.9.

Estimation of side fat weight from rest fat weight (X_2), and side weight (X_1), in Trials 2A and 2B.

Data involved	No. of lambs	Regression equation	Multiple correlation coefficient	Standard error	
				Absolute	as % of $\bar{Y}$
Total	120	$Y = 1.7719 + .0542 (X_1 - 6.4128) + 1.9373 (X_2 - .8379)$	.9883	.0993	5.60
Sire group 1	30	$Y = 1.9876 + .0947 (X_1 - 6.6188) + 1.7047 (X_2 - .9385)$	.9850	.1158	5.82
Sire group 2	30	$Y = 1.8692 + .0369 (X_1 - 6.7615) + 2.0329 (X_2 - .8710)$	.9864	.1110	5.94
Sire group 3	30	$Y = 1.4512 - .0195 (X_1 - 5.9963) + 2.1869 (X_2 - .6917)$	.9835	.0793	5.46
Sire group 4	30	$Y = 1.7798 + .1177 (X_1 - 6.2748) + 1.7453 (X_2 - .8504)$	.9938	.0831	4.67
Ewes	50	$Y = 1.6976 + .1335 (X_1 - 6.0295) + 1.6250 (X_2 - .7955)$	.9871	.0962	5.67
Wethers	70	$Y = 1.8251 + .0460 (X_1 - 6.6867) + 1.9790 (X_2 - .8682)$	.9907	.0940	5.15
Trial 2A	60	$Y = 1.7658 + .0412 (X_1 - 6.4653) + 2.0621 (X_2 - .8297)$	.9849	.1091	6.18
Trial 2B	60	$Y = 1.7781 + .0601 (X_1 - 6.3604) + 1.8617 (X_2 - .8460)$	.9921	.0863	4.85