BODY COMPOSITION STUDIES ON THE ROMNEY EWE

(In Two Parts)

A Thesis Presented in Partial Fulfilment
of the Requirements for the Degree
Master of Agricultural Science
in the University of New Zealand

by

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May 1960

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ACKNOWLEDGEMENTS

The author wishes to thank his supervisor Mr. R.A. Barton for the assistance and advice given throughout this project. The interest and guidance of Professor A.L. Rae, particularly in statistical matters, is also gratefully acknowledged. Mr. A.H. Kirton gave much invaluable help and advice.

The author is indebted to many members of the Massey Agricultural College and D.S.I.R. staffs, and particularly to: Dr. R.H. Jackman for conducting the Kjeldahl analyses; Mr. M.F. McDonald for information on liver damage caused by facial eczema; Drs. D.S. Flux, G.W. Butler and F.R. Cockrem for constructive advice and criticism, and Miss M.G. Campbell and her library staff for assistance in obtaining literature.

Special acknowledgement is due to Mrs. F. Puckey for typing this thesis.

Plant Chemistry Laboratory, D.S.I.R. supplied the sheep used in this project.

This work was carried out while the author was assisted by N.Z. Wool Board, Shell Oil Company and University Senior Scholarships.

PART I

COMPARISONS OF GROWTH AND BODY COMPOSITION OF SHEEP GRAZING FOUR DIFFERENT PASTURES

CHAPTER I

INTRODUCTION

Plant breeders have been improving pasture species towards higher production for many years. Unfortunately, in many cases, because of associated ill effects on animal health, the great potential of these improved species for increased animal production has not been realised. Animal metabolic and deficiency disorders due to these high producing pastures are well known. In New Zealand, where there is a tendency to reduce the pasture species to a high producing ryegrass - clover combination, nutritional disorders such as hogget ill thrift, goitre, rickets, bloat and mineral imbalances appear with disquieting regularity. Considerable local work has been done on these disorders. One outcome has been the demonstration that improved strains of white clover have goitrogenic properties. Also, various different grass species grown on the same soil type have been shown to contain different amounts of iodine. As a further contribution to this field the present experiment was designed to study among other things, the goitrogenic effect on sheep of perennial ryegrass (high in iodine) and short rotation ryegrass (low in iodine) both alone and in association with goitrogenic white clover. This experimental plan has also enabled a study to be made on the effects of these four pasture types on the body composition of the Romney ewe. This latter aspect forms the study reported in Part I and in addition observations on the effects on body composition of lambing status are presented.

CHAPTER II

REVIEW OF LITERATURE

1. MEASUREMENT OF GROWTH AND DEVELOPMENT

Growth is a fundamental characteristic of living organisms and realization of this has led to detailed study by many investigators. Yet the literature is confused mainly due to two factors: first that growth is an extremely complex process, and secondly that the methods used to study it have been inconsistent and in many cases inadequate. Waddington (1950) says that -

> . . .the realization of the complexity of the growth of all but the most elementary isolated biological systems has largely removed the interest from attempts to discover the formal properties of growth by mathematical analysis.

There are a number of different schools of thought in this field which have similar ideas but different means of expressing them. Thus Richards and Kavanagh (1945) state:

> ....growth has most frequently been defined as multiplicative increase of self-perpetuating living matter, although each school of thought uses a characteristic wording.

They might have added that the schools seem to have different approaches to the problem of measuring the three primary variables which define growth and development: size, shape and age.

In the present work we are concerned with measuring the relative changes in the components of the body with size. It is really a question of differential change in size. Much of the work in this field has been pioneered by Huxley (1932), who, using his allometric concept, noted that all but the simplest animals reach their adult shape and size by differential growth in different directions. Huxley (1924) introduced the allometric equation: $y = bx^a$ and has used it extensively to study problems of relative growth. This exponential relationship has been severely criticized in the literature but it must be realized that Huxley is perfectly aware of its shortcomings. Recently (Huxley 1950) he stated that:

> .... the large number of cases of quite different kinds of organs and other constituents of the body whose growth shows an approximation to the simple allometric formula indicates that some general principle must be involved, and it is difficult to see what this could be except a constant ratio between the rates of self-multiplication in different parts. I would suggest that this is the basic factor but that there is some second order factor at work which prevents the allometric formula from ever being precisely realized, and relates or adjusts the growth rates of separate parts to that of the whole.

A few attempts have been made to investigate this possibility. Robb (1929), Lumer (1937), Glaser (1938) and Zucker and Zucker (1942) have tried adding constants to the allometric formula, however these have little theoretical justification. Some members of the Hammond school studying the growth and development of farm animals at Cambridge have criticized the use of the allometric equation in situations where external environment affects growth and development. Huxley (1932) says that growth is -

> . ..much affected by the external environment, e.g. by temperature and nutrition,

and that external environment

> ....affects all parts of the body equally.

Wallace (1948) and Pálsson and Vergés (1952) claim that this assumption of Huxley's is invalid and that external factors such as the level of nutrition alter the equilibrium constant between one part of the animal and the rest of its body, and thus do not affect all parts equally. Waddington (1950) sums up the situation as follows:

> ....the allometry equation has the status, not of a physiological principle, but of a rough and ready short-hand method of description.

The biological changes which take place during evolution are not, according to Waddington, due to alterations in the allometric growth partition, because this growth partition is not a real physiological variable, but merely a derivative function from an empirical description which is a reasonably good approximation. It seems therefore that allometric equations may be regarded as simple forms of regression with both sets of variables in a logarithmic form which fits reasonably well in many situations presumably because much growth is essentially multiplicative in nature. It is not a fundamental law of growth and much of the confusion in the literature appears to be due to workers who have not realized its limitations.

A great amount of work on relative growth has been conducted by the Hammond school at Cambridge, (Hammond, 1932; Pálsson, 1939, 1940; McMeekan, 1940, 1941; Wallace, 1948; Robinson, 1948; Pálsson and Vergés, 1952; Joubert, 1956) and much of this has been reviewed by Pálsson (1955). These workers have not been concerned so much with the purely theoretical aspects of growth and development, but have a more practical bias. They have used many methods of measurement and the more common ones will be discussed below:

(a) The relative development of an organ or part as a percentage of the whole body, part or tissue in question. This method has the serious disadvantage that proportions of one organ, part or tissue are affected by changes in others, e.g., muscle and fat might both be increasing absolutely, yet because fat is increasing relatively more the percentage of muscle declines.

(b) Comparison of parts or tissues of the body with a standard organ or part. The weight of brain plus eyes is favoured on the grounds that they make the smallest growth of all organs after birth, and that they are less affected by differential nutrition than any others. This comparison has little, if any, advantage over the mean weights of organs being compared, due to the very fact that there is little variation in brain plus eye weight. Cannon bone weight and heart muscle weight are often taken as standards for bone and muscle respectively; however the same disadvantage holds here. Any small variation in the standard chosen would seriously affect any comparison.

Pálsson and Vergés (1952) compare organs at different ages using the ratio

$$\frac{\text{"Weight of organ}}{\text{weight of brain}} \times 100 \text{ expressed as percentage of}$$

$$\frac{\text{Weight of organ}}{\text{weight of brain}} \times 100 \text{ at birth," as the dependent variate.}$$

This is a particularly complex and meaningless comparison (Cockrem 1960) and is virtually the same as comparing the part as a percentage of its weight at birth (see next paragraph).

(c) Comparison of the weights of organs, parts or tissues at different ages, with the weight of the same organs, parts or tissues at a constant age, e.g. birth or maturity. These are often plotted on a percentage basis. There are two main objections to this method. First any error in the part at the standard age will be magnified through the whole growth series. Secondly, large numbers of animals are required because killings must be at frequent intervals throughout the series.

(d) Rate of gain in weight of an organ or part per fixed unit of time. For accuracy this method also requires a sufficient number of animals to be killed at frequent intervals.

(e) Expression of the weight of organs, parts or tissues of different treatment groups at any age as a percentage of the weight of the same organs, parts or tissues, of one of the treatment groups, usually the low plane group, at the same age. This method which has been used extensively by McMeekan (1940, 1941), Pálsson and Vergés (1952) and Joubert (1956), has been criticized by Wallace (1948). Wallace claimed that it was sounder to compare animals at equal tissue weights rather than equal ages. Although Pálsson and Vergés agree with this criticism they do not like Wallace's allometric approach and so fall back on the method of McMeekan and compare at equal ages. These workers used this method to study the effects of environmental factors such as plane of nutrition, on developmental changes. As this is the aspect of growth and development of direct interest in the present study the literature of the disagreement between the above workers will be reviewed in detail later.

In fairness to the Cambridge School it should be pointed out that they were aware of most of the faults in their methods and in fact many of the criticisms have been self-imposed. These criticisms do not affect the economic considerations which their experiments have brought out, and from the butcher's point of view the results are very good. The criticisms apply only to the more theoretical aspects of the measurement of growth.

In the present study mean weights and percentages of components have been weighted to allow for unequal subclass numbers using the method of fitting constants by least squares, and testing for differences by simple analysis of variance (Kempthorne 1952). The weighted means were then compared directly to determine the effects of plane of nutrition and birthrank on body composition. Heeding the advice of Sholl (1950) no attempt was made to extra-polate beyond the data. It was thought by keeping the analysis simple and studying means there was less chance of encountering the type of errors mentioned above.

2. THE PATTERN OF GROWTH AND DEVELOPMENT WITH PARTICULAR REFERENCE TO THE SHEEP

(1) Change in Anatomical Components.

Jackson (1928) postulated a "Law of Developmental Direction", in which -

> ....growth correspondingly appears at first relatively more rapid in the dorsal head region, and less rapid in the parts located ventralward and tailward. Only gradually, through progressive changes in the relative growth rate, do the various regions of the body later attain their adult proportions.

Huxley (1932) puts this in more formal language and states that, according to the law -

> ....anterior (and proximal) regions are formed first, are soonest through with their origin and histological differentiation, and can embark earlier on their main growth period.

These laws have been shown to apply to the growth and development of many vertebrates by Robbins *et al* (1928) and Huxley (1932). Hammond (1932), Pálsson (1939, 1940), McMeekan (1940, 1941), Wallace (1948), Pálsson and Vergés (1952), Wilson (1952, 1954*a*, 1954*b*, 1958*a*, 1958*b*) and Joubert (1956) have extended these laws by studying the growth and development of the constituent tissues and organs of the farm animal.

Pre-natal growth in the sheep has been studied extensively by Curzon and Malan (1935), Winters and Feuffel (1936), Cloete (1939), Green and Winters (1945), Wallace (1948) and Joubert (1956) and so will not be detailed here.

Hammond (1932) initiated the study of the relative changes in body composition of sheep during post-natal growth and development by examining data from completely dissected animals.

Earlier workers (Nathusius, 1905; Eckles and Swett, 1918; Moulton, et al., 1921; Brody and Ragsdale, 1924; Lush, 1928) using external body measurements had established that the skeleton was relatively more developed than the flesh at birth. They also concluded that the head, limbs, and forequarters were better developed at birth than the hindquarters.

The work of Hammond (1932) and Pálsson (1939, 1940) was conducted on sheep that were not under complete experimental control. Few sheep were used for comparisons yet these workers were able to outline the fundamental principles involved. Later McMeekan (1940, 1941) with the pig, and Wallace (1948), Pálsson and Vergés (1952), and Joubert (1956) with the sheep confirmed and extended these findings under strict experimental conditions. Thus results of this work will be given briefly below.

By dividing the animals into anatomical joints it was possible to detect a primary wave of growth from the cranium down to the facial parts of the head and backwards to the lumbar region. Secondary waves start in the limbs at the level of the metacarpals and metatarsals and pass down to digits and upwards along the limbs and trunk to the lumbar region. Thus the lumbar region is the last part of the body to reach maximum growth rate and is consequently the latest developing part of the body. McMeekan (1940) defines an early developing part as one which, relative to another, makes a greater proportion of its growth early in life. These waves of growth were detected within each major tissue as well as for the whole body. Thus, for example, in the hind limbs in post-natal life the cannon bones are the earliest maturing bones, followed by the tibia, femur and pelvis. A similar pattern exists in the fore limbs. The axial skeleton develops in an antero-posterior manner. Pálsson (1940) found that his data did not agree exactly with this pattern but attributed the differences to the affect of differential nutrition. These growth gradients appear to run in the opposite direction to those postulated by Jackson (1914) in his Law of Developmental Direction. However, Wallace (1948) and Joubert (1956) have clarified the picture with their studies of prenatal development in the sheep. Wallace (1948) suggested that the growth pattern changes during post-natal growth. In the limbs initially the growth gradient runs proximo-distally, but the high point of the gradient early becomes more distal, the cannon bone at some time prior to 56 days in prenatal life becoming the site of maximum growth impulse. During the remainder of the foetal period the gradient gradually becomes reversed so that the growth centre migrates back up the limb. Joubert (1956) confirmed this result. Wallace's interpretation is, in the case of the hind limb, that he would prefer to consider that the most proximal, and therefore oldest part of the limb, the femur, early attains its maximum specific growth rate, followed in turn by the more distal bones.

After this initial period the specific growth rate of each of the bones declines, this being more abrupt in the distal bones.

Thus at birth the cannon bone is growing slowest of all limb bones. This work reconciles the proximo-distal idea of Jackson with the centripetal one of Hammond and his followers. Another facet of bone growth is that length is an earlier developing characteristic than thickness.

The above mentioned gradients affect all tissues - not just the bones. Thus the development of muscle and fat in the different body regions is governed by growth gradients similar to those described for the skeleton.

The various tissues also reach their maximum growth rates in a definite order with age. Thus nervous tissue is the earliest developing followed by bone then muscle and finally fat. On top of this, fat is accumulated in the various fat depots with age in the following order: mesenteric fat, kidney fat, intermuscular fat, subcutaneous fat and intramuscular fat. This work has also shown that muscular tissue increases mainly in fibre numbers pre-natally and fibre diameter post-natally.

The various internal organs also show marked differential growth. Pálsson (1955) sums up the findings of the Hammond school as follows:

> The heterogonic growth of the individual organs appears to be primarily functional. Those organs of most vital function to the life of the animal like the brain, eyes, lungs, kidneys, heart, oesophagus, abomasum and small intestines are relatively well developed at birth and consequently grow proportionately less in post-natal life than organs like the rumen and reticulum, which have an unimportant function until some time after birth, when the lamb begins to eat fibrous foods, or those whose function is largely that of storage of nutrients such as the abdominal fat depots, which develop mainly in the later stages of growth.

Scammon (1923) grouped human organs into four classes according to the character of their post-natal growth. His classification into general, genital, neural and lymphoid types, while similar to that of the Hammond school, does not bring out the functional aspect as well. This aspect appears to be perhaps the most important one with regards to post-natal development. Those parts, tissues, or organs which are required immediately after birth are the ones which have the earliest post-natal development, and as the animal ages, development follows a markedly functional path.

(2) Change in Chemical Components.

The literature on the changes in the chemical constituents of the body during growth and development follows a somewhat different path to the anatomical approach. Very little work has been done following the changes through a growth period. Rather the approach has been to determine body composition *per se* at, say, the end of an experiment. This is particularly true in the case of the sheep.

We will deal first with general changes in the chemical composition of mammals, and then specifically with the sheep.

Spray and Widdowson (1950) and Reid *et al.* (1955) review the effects of growth on the chemical composition of mammals. The greatest cause of change during growth is due to increase in fat. Callow (1948) has shown that chemical fat closely follows dissectible fat during growth. This is reasonable on the grounds that dissectible fat includes all but intramuscular and bone fats. Various workers (Callow, 1948; Kraybill et al, 1951; Reid et al, 1955; Barton and Kirton, 1958a) have shown that there is a high negative correlation between fat per cent and water per cent. This led Reid et al (1955) to suggest that as these two components constitute the major part of the animal body, fattening appears mainly to be a replacement of water by fat. However, this is not quite correct and Keys and Brožek (1953) point out that to some extent water and fat are laid down together, although fat relatively more. Murray (1919) pointed out that most of the variation in the composition of mature animals was due to fat, and that the chemical composition of the non-fat matter was relatively constant. This general idea was first attributed to von Bezold (1857) who analysed large numbers of various species of animals. Moulton (1923) continuing this work said that where fattening does not intervene to obscure changes in the other constituents, age and species largely determine composition. Murray (1922) and Moulton (1923) studied from data in the literature the chemical development of the fat-free bodies of many mammals. Moulton (1923) showed that in all cases studied,

> ....mammals show a rapid decrease in relative water content and increase in protein (nitrogen) and ash content from earliest life until the time of chemical maturity is reached. At this time the change becomes rather suddenly less, and nearly constant composition is shown.

Many people have continued this early work. Spray and Widdowson (1950) conducted experiments and concluded that Moulton's term "chemical maturity", can only be applied to the body as a whole when all its constituents except fat have reached a constant level. However, the constancy of this fat-free body with age has been queried, and Hopper (1944), Reid et al. (1955), and Kirton et al. (1959a) have shown that water percentage decreases while protein and ash percentages increase with age, in the fat-free body. Fatness has also been shown to affect this constancy (Mitchell et al. (1928b; Clawson et al. 1955; Kirton et al. 1959a). So we have the general picture of relative constancy of the fat-free body after chemical maturity, while chemical fat increases with age. However it has been shown that the decrease in water and increases in protein and ash still continued their trends, although at a diminishing rate, after chemical maturity. Moulton (1923) points out that chemical maturity is reached at different ages in all species, but that these ages are fairly constant relative to the whole life cycle. There are very few cases in the literature where the chemical composition of sheep has been followed through a growth series. Many workers however, give the body composition at one stage; usually the mature animal (Hankins, 1947; Shorland et al. 1947; Barnicoat and Shorland, 1952; Barton and Kirton, 1958; Kirton et al. 1959b; Garrett et al. 1959). These workers have usually been interested in body composition *per se* and not in growth. Armsby and Moulton (1925) report that work on the soft parts of the carcass was conducted by Henneberg (1881), Kern and Wattenberg (1878, 1880), Friske (1909), and Pfeiffer and Friske (1911). Lawes and Gilbert (1859), Mitchell et al. (1926, 1928a) and Callow (1947, 1948, 1958) present data showing the chemical composition of sheep at various ages while Kirton et al. (1959a) show the fat-free composition of a series of sheep from foetal lambs to mature ewes.

The chemical composition of the five sheep analysed by Lawes and Gilbert (1859) are presented in Table 1.

TABLE 1

Composition of Entire Bodies of Sheep - Empty Weight Basis
(Lawes and Gilbert)

		Percentage Composition					
Age	Condition	Ash	Protein	Fat	Dry Matter	Water	Nitrogen
6 months	Fat	3.2	13.4	31.2	47.8	52.2	2.14
1 year	Store	3.4	15.8	19.9	39.0	61.0	2.53
1¼ years	Fat	3.0	13.0	37.8	53.8	46.2	2.08
1¾ years	Extra fat	3.1	11.6	48.3	62.9	37.1	1.86
3¼ years	Half fat	3.5	15.5	25.9	44.8	55.2	2.48

Data abstracted from Mitchell et al. (1926, 1928a) are presented in Table 2.

TABLE 2

Composition of Empty Bodies (Mitchell *et al*)

Age	Condition	No.	Water	Crude Protein	Crude Fat	Crude Ash
			Percentage Composition			
Newborn	-	4	76.58	15.50	2.72	3.39
3 months	Average	6	60.54	17.54	16.85	3.32
5 "	"	8	60.63	19.52	14.15	4.79
11 "	Maintenance	8	53.32	18.29	21.57	4.09
8 - 11 "	Fat	9	50.88	17.43	24.89	4.17
15 "	Maintenance	6	60.42	18.12	15.52	4.37
21 "	Fat	6	53.45	16.82	23.51	4.18

The figures above should be interpreted with care. The methods of chemical analysis used by Lawes and Gilbert were crude by present day standards. No breed effects were taken into account. The range of fatness is limited and even those sheep classed as "fat" are not markedly so.

It is difficult to interpret data of these type which were collected originally for non-growth purposes; however certain general age trends are obvious. These are: an increase in fat percentage; decreases in protein and water percentage. Ash percentage is very variable and it is impossible to detect any trend.

3. EFFECT OF NUTRITION ON BODY COMPOSITION

In the previous section we have drawn a picture of the pattern of growth and development in the sheep. The next step is to see how this is affected by plane of nutrition.

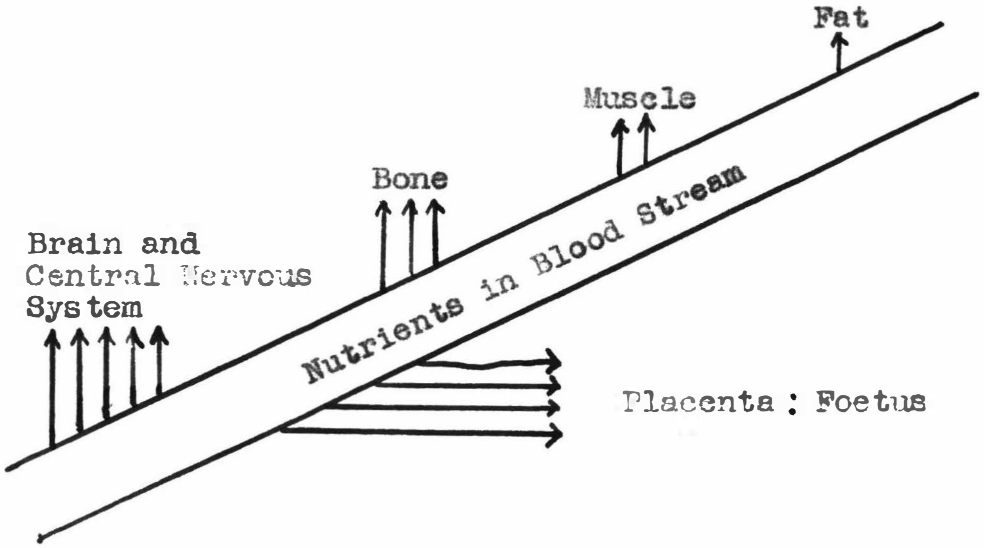
(1) Change in Anatomical Components.

Knowledge on the effects of nutrition on the farm animal has progressed a long way since the pioneering work on cattle at the Missouri Agricultural Experimental Station (Moulton et al, 1921, 1922a, 1923). Most of the work has been conducted at Cambridge under carefully controlled experimental conditions by the Hammond school (Vergés 1939a, 1939b; Wallace 1948 and Pálsson and Vergés, 1952 in the sheep: McMeekan 1940, 1941; and Pomeroy 1941, in the pig.) The generalized plan of those experiments was to submit two groups of animals to a high and a low plane of nutrition. After a period on this treatment each group was divided into a high and low plane sub-group. This type of experiment has also been conducted by Wilson (1952, 1954a, 1954b, 1958a, 1958b) on poultry and on the goat. These authors have demonstrated that an animal's form is greatly dependent on the shape of its growth curve. We will not be concerned here with the effects of differential nutrition during pregnancy on foetal development, but rather with the more general effects on the growing and mature animal. In general terms we can think of three levels of nutrition: super-maintenance, maintenance and sub-maintenance. Maynard and Loosli (1956) define maintenance in its simplest form as, "the amount of food required to hold adult animals at constant weight." This definition also implies constant body composition. Hammond (1947) argues that an animal must be bred under optimal environmentel conditions to enable it to fully express its genotype. While this contention is inaccurate from a breeding point of view (Falconer and Latyszewski, 1952) it is helpful in defining plane of nutrition. Thus to get optimal development super-maintenance is involved. This is essentially what we described in the previous section on "the Pattern of Growth and Development." Therefore all that remains to be done in this section is to describe the affects of sub-maintenance on body composition.

The findings of the workers mentioned above will be described in the following. Restricted nutrition at any stage during growth retards the parts or tissues in the direct order of their maturity. The earliest maturing parts or tissues are least, and the late maturing ones most affected, e.g., fat is more affected than muscle which is more affected than bone. The loin is the area most affected by bad nutrition.

During growth any part, organ or tissue is proportionately most affected at the age when it has its highest growth intensity. When an animal is kept on a sub-maintenance diet the different tissues and body regions are utilized for the supply of energy and protein required for the maintenance of life in the reverse order of their maturity, i.e., fat is utilized first, followed by muscle then bone; these tissues are first depleted in the latest maturing body regions such as the loin and pelvis. Hammond (1944) attempted to explain this in his "theory of partition of nutrients according to metabolic rate". Child (1920).

FIGURE 1



first suggested that the incoming nutrients are partitioned according to the metabolic rates of the various tissues; those with the highest metabolic rate having priority. Hammond (1944) shows the situation diagrammatically in Fig. 1 where the number of arrows indicates the relative metabolic rates of the tissues involved. If the plane of nutrition is limited an arrow may be deducted from each tissue and thus fat growth is stopped. If the plane is further reduced another arrow may be deducted and in this case muscle growth stops while fat deposits are broken down. This may go on until the level is reached where the brain and central nervous system are affected and at that stage the animal dies.

These workers have noted a great recuperative capacity when an animal which has been on a low plane of nutrition, is switched to a high plane, providing it has not been undernourished for too long. Robinson (1948) noted with sheep that the various parts of the body increased and decreased along similar developmental curves. This is not in agreement with Keys and Brožek (1953) who found with humans that there is a tendency to put on extra fat during a period of nutritional rehabilitation. They found that after a period of time this extra fat was lost and body composition returned to near its value before under-nutrition.

There is one major point over which some workers of the Cambridge school disagree. McMeekan (1940, 1941) and Pálsson and Vergés (1952) agree that not only does restricted nutrition affect individual organs and tissues of the body differentially, but also that within a tissue some parts are penalized proportionately more than others. Wallace (1948) agrees with this hypothesis as regards the differential effects on the individual organs and tissues, but he did not find differential effects within a tissue due to poor nutrition. Wallace disagrees with McMeekan's method of measuring relative growth whereby, at a constant age or body weight, the low plane group is expressed as 100 and the other groups relative to this. Wallace claimed that it was sounder to compare plane of nutrition effects at equal tissue weights and so he followed an allometric analysis for his data. He also re-examined some of McMeekan's (1940, 1941) data using his own method, and concluded that the apparent differential effects on anatomical units within a tissue were not caused by the low plane of nutrition having changed the normal pattern of development, but were due to McMeekan's method of analysis. Wallace thus concluded that the pattern of development of a tissue is the same in a rapidly grown and in a stunted animal, the proportions each made of the whole tissue depended solely on the weight attained by the tissue. In other words, Wallace claimed that under-nutrition did not affect the pattern of development within a tissue differentially, e.g., the later developing loin muscle is not penalized any more than muscle in any other part of the body by a low plane of nutrition. Thus there would be no priorities within a tissue for nutrients from the blood stream.

Pálsson and Vergés (1952) agree with Wallace that it is sounder to compare animals at equal tissue weights, but they do not like his method of analysis and fall back on the one used by McMeekan (1940, 1941). They claim that plotting part against whole on logarithmic paper will disguise any effects present by contracting the scale and thus crowding the plotted points. To support their ideas they carry out regression comparisons on some parts of the skeleton using the skeleton itself (less the part being studied) as independent variate. From this they come to the conclusion that plane of nutrition does have a differential effect on different anatomical units of the same tissue. Cockrem (1960) criticized this regression approach on the grounds that Pálsson and Verges (1952) have compared relative absolute increases in size and not growth rates, and also that the results from this type of analysis do not agree with their earlier conclusions using different methods of measurement.

In an interesting series of papers on the effects of nutrition on the fowl (1952, 1954a, 1954b) and the East African dwarf goat (1957, 1958a, 1958b), Wilson presents evidence which tends to support Wallace's (1948) contentions. Wilson analysed birds on the basis of equal age and equal weight and found that there were no consistent age or treatment effects on the fat content of cockerels. He found a significant effect on the weight of muscle of birds of the same age but no significant differences on the basis of equal bird weight. Wilson concluded from his work that there was no orderly sequence of fat deposition comparable to the growth of organs and other tissues. He thought, along with Brody (1945) and Wallace (1948), that while fat was closely related to growth it was not an integral part of it, and that varying amounts of fat in a carcass lead to serious difficulties in the interpretation of other body tissues and organs. Wilson (1957) claimed that the large differences found by other workers in the carcass proportions of mature animals reared on different planes of nutrition must be largely ascribed to the differences which such treatments exert on the percentages of fat in the body. He therefore proposed that this type of nutritional work should be analysed on a fat-free carcass basis. In support of this Wilson re-analysed McMeekan's (1940) data on muscle weight and found that re-calculating the muscle percentages in the carcass on a fat-free basis led to a complete reversal of many of the significant results claimed. While Wilson throws doubt on the validity of the methods used by McMeekan and Pálsson and Vergés he does not provide any evidence on the effect of nutrition within a tissue. The comparison of animals on a fat-free basis would seem to be a useful technique in this type of work. However, it should be regarded as a technique only bearing in mind that the final biological interpretation of the effects of nutrition on body composition must also include fat.

(2) Change in Chemical Components.

From the results of workers such as Moulton *et al.* (1922*b*), Mitchell *et al.* (1928b), Armsby and Moulton (1925) and Callow (1947, 1948, 1949, 1950) it is possible to ascertain in general terms the effect of nutrition on the chemical composition of the carcasses of farm animal.

Mitchell *et al.* (1928*b*) compared the composition of sheep which were well-fed and then emaciated in a comparative slaughter type of experiment. They found that bone fat was the last of the fat depots to be depleted in under-nutrition and also that the withdrawal of fat from the tissues was accompanied by an increase in moisture on a fat-free basis. This meant that the ratio of protein to water was greatly decreased by under-nutrition. Kirton *et al.* (1959*a*) found similar results on a fat-free basis.

Barnicoat and Shorland (1952) and Garrett *et al.* (1959) present the carcass compositions of various commercial grades of sheep. Although these are not in nutritional classes and the ages are not known, they have been graded according to condition. By comparing these data with that provided by the workers mentioned above it is possible to see the following trends: with a lowering of grade there is a reduction in fat percentage and an increase in water, protein and ash percentages.

4. EVALUATING PASTURES BY MEANS OF SHEEP

As most grassland products are converted to human use via the grazing animal it is of importance to be able to measure the value of pastures in terms of animal production, i.e., wool, meat or milk. The value of this type of assay has been realized for many years and Watson (1948) reports that Somerville in 1897 started an experiment at Cockle Park in an effort to measure the effect of various systems of manuring on the liveweight gains of the sheep grazing the various plots. The work reported in the literature has improved very little in technique since these early days and does not seem to have progressed beyond liveweight as a measure of pasture worth. Williams (1947) realized that many factors influenced the final liveweight in this type of trial. He included the following: size or initial liveweight; age; food intake or appetite; variations in the composition of the liveweight gain; sex; efficiency of digestion; efficiency of metabolism. Williams showed that the variability in liveweight between animals on grazing trials is considerable. The reduction of such variability between animals and the standardization of techniques used have been the subject of a report submitted by a Joint Committee of the American Society of Agronomy, the American Dairy Science Association and the American Society of Animal Production in 1943. This report suggests procedures for following in this type of work.

Watson (1948) considered that sheep are not suitable for long term experiments because the ewe will not put on the full increase which might be expected from the nutrients, while the lamb which grows very quickly at first has a different composition of increase to the mature wether. He states that the growth rate of the wether falls as the season progresses. However, the Joint Committee (1943) consider that it is best to use wethers.

Following the pioneering work at Cockle Park a series of experiments were conducted using sheep by some Welsh workers. This was started by Stapledon and Jones (1927), who conducted a behavioural trial on grazing sheep. They found that the amount of pasture eaten per day varied considerably and that more dry matter was consumed if they ate a greater amount of clover stem than leaf. They also showed that sheep preferred: grass blades to sheath or stem; green leafage to either burned or drying material or to weeds; and red clover to grasses.

Jones (1928) compared a temporary and a permanent pasture using four-month-old lambs. The liveweight increment was much greater on the temporary pasture and this was thought to be due to the fact that the sheep obtained a higher proportion of leaf to stem, and therefore a more nutritive ration on the temporary pasture.

Roberts (1931) studied the effect of sowing wild white clover on the meat producing capacity of temporary pasture three years old. Both cattle and sheep of various ages were used. He concluded that the effect of adding wild white clover to a temporary pasture was to increase the productivity by about 35 per cent as measured by liveweight increase. This was due mostly to an increased stock carrying capacity. In a continuation of this trial for a further year Roberts (1932) showed that the animals on the plot containing wild white clover gained 22.5 per cent more in liveweight than the animals on the plot without clover. Again this difference was due to an increase in stocking rate. Concurrently, Roberts (1932) compared these two temporary pastures with a permanent one and found that the liveweight increase from the wild white temporary pasture was 46 per cent greater, and that from the temporary pasture without wild clover 18 per cent greater than that from the permanent pasture. The increased production from the temporary pasture was again due to greater stock carrying capacity. However, the ewes and wethers on the temporary pasture thrived better. Roberts (1935) showed that when these trials were continued similar differences appeared between the pasture types as measured by liveweight.

Davis and Bell (1957, 1958) compared two pastures, one of birdsfoot trefoil and Kentucky bluegrass, and the other of Ladino white clover and Kentucky bluegrass, using the response of lambs as a measure of production. During the first grazing year the Ladino clover-bluegrass mixture was more productive in terms of carrying capacity, gain per acre, and T.D.N. consumption per acre. The trefoil-bluegrass mixture was more productive for the remaining two years of the test. Herbage yield and animal gain per acre were not related.

It appears from the type of trial described above that real differences between pasture types can be detected using animal production as a method of evaluation. It is also noticeable that most of the differences in liveweight are due to increased carrying capacity and not to increased growth by the individual sheep. Thus most of the differences in pasture types could probably be attributed to differences in pasture growth. An interesting finding with regards to the present work is the demonstration of the ranking order of the differences between temporary pasture, with and without white clover, and permanent pasture, by Roberts (1932, 1935). It is a pity that the above workers did not follow the example set by Mitchell et al. (1926, 1928) who evaluated various sheep foodstuffs by determining differences in body composition using a comparative slaughter technique. Differences between the pasture types in terms of body composition may have been detected.

In a very thorough experiment Clarke et al. (1953) studied the effect of highly improved and topdressed pastures on the thrift and production of sheep. Their experiment comprised two parts: first a fertilizer trial consisting of five treatments and secondly a pasture strain trial which compared five pasture types. Characters of economic importance such as wool growth, carcass grade, and lamb production were measured. Carcass measurements described by Pálsson (1939) were used to estimate carcass composition. In the pasture strain trials there were large differences in annual and seasonal production between the five pasture types. However there was no evidence of any differential effects on the thrift and production of ewes and lambs under the system of management adopted. Similarly in the manurial trial the differential pasture production effected by the various fertilizers did not cause any differences in animal production. This work by Clarke et al. (1953) appears to be the only account in the literature in which some attempt has been made to determine the effect on body composition of various pasture types.

5. EFFECT OF BIRTHRANK ON BODY COMPOSITION

The effects of birthrank or lambing status on the body composition of the ewe may be expressed during two periods; gestation and lactation.

The literature of the changes in body composition during the gestation period have been reviewed by Spray (1950), Marshall (1952) and Dewar (1957). In most species it seems that the pregnant female stores more fat, water, protein and mineral than can be accounted for by the foetus and its associated tissues. There appear to be species differences however, and it seems that those species which lactate abundantly lay in a store during pregnancy, while those that do not produce much milk pass on more to the foetus before it is born.

Kirton et al. (1959a) compared the fat-free body composition of three pregnant ewes with that of the non-pregnant ewes and wethers presented by Garrett et al. (1959). From this they concluded that pregnancy has no effect on the fat-free body composition of the ewe. However this result must be interpreted carefully as the sheep being compared were of different breeds and in various states of fatness.

The literature on the effect of lactation on the body composition of the ewe is scant; however, the effect of birthrank on lactation and lamb production has been well investigated (Bonsma, 1939; Underwood and Shier, 1942; Wallace, 1948; Barnicoat et al. 1949; Barnicoat, 1952).

Pálsson (1953) has studied in detail the effects of pregnancy and milk production of yearling ewes on their growth and development. With two exceptions he used the carcass measurements described by Pálsson (1939) to measure growth and development. The exceptions were the width of chest behind the shoulders and the minimum circumference of heart girth. In the first part of this experiment Pálsson studied the effects of pregnancy and lamb production of ewes lambing at 12 months of age on their growth and development up to 16 months. At this stage 43 ewes in the three birthrank categories, barren (11), lost lamb (11), or suckled (21) were killed. The figures in parentheses refer to the number of sheep in the respective groups. Pálsson concluded from the measurements taken that pregnancy from seven to 12 months of age had a significant retarding effect on the growth of fat while it had no effect on the growth and development of the earlier maturing tissues. However, a four month lactation period resulted in a lighter, narrower carcass with reductions in the ascending order of bone thickness, muscle development and fat deposition.

The second part of his trial was designed to study the extent to which ewes that had been retarded at 16 months by rearing lambs could make up the loss by 28 months. The birthrank categories studied are shown in Table 3.

TABLE 3

Birthrank Categories of the Ewes Studied by Pálsson (1953)

No. of Ewes	12 months	24 months
10	Barren	Barren or L.L.
15	Barren	Single
29	Single	Single
5	Single	Twins
5	Single	Dry

Results from this part of the work showed that ewes whose growth and development had been retarded up to 16 months of age by suckling lambs as yearlings, can make up by 28 months about 60 per cent of the retardation in carcass weight, whether they are rearing singles or twins when two years old, compared to ewes which were barren as yearlings and reared singles as two-tooths.

Thus it appears that the body composition of sheep, while mainly unaffected by pregnancy, does show changes due to lactation. Fat is most severely depleted, followed by muscle, and then to a lesser extent bone.

CHAPTER III

MATERIALS AND METHODS

1. INTRODUCTION

The pasture types to be described below were sown in November 1956. From March to April 1957 a trial was conducted on these pasture types to study any effect of facial eczema on Southdown cross lambs removed for slaughter at weekly intervals. From 10 May 1957 until 16 December 1958 the main trial was carried out to study the effect of short rotation and perennial ryegrasses with and without white clover on the iodine status of sheep. It was from this trial that 40 carcasses became available for analysis. Thus sections 2 and 3 of this chapter describe the experimental design and management of the whole experiment, while the remaining sections deal solely with those ewes taken for carcass analysis.

2. EXPERIMENTAL DESIGN

(1) Pastures.

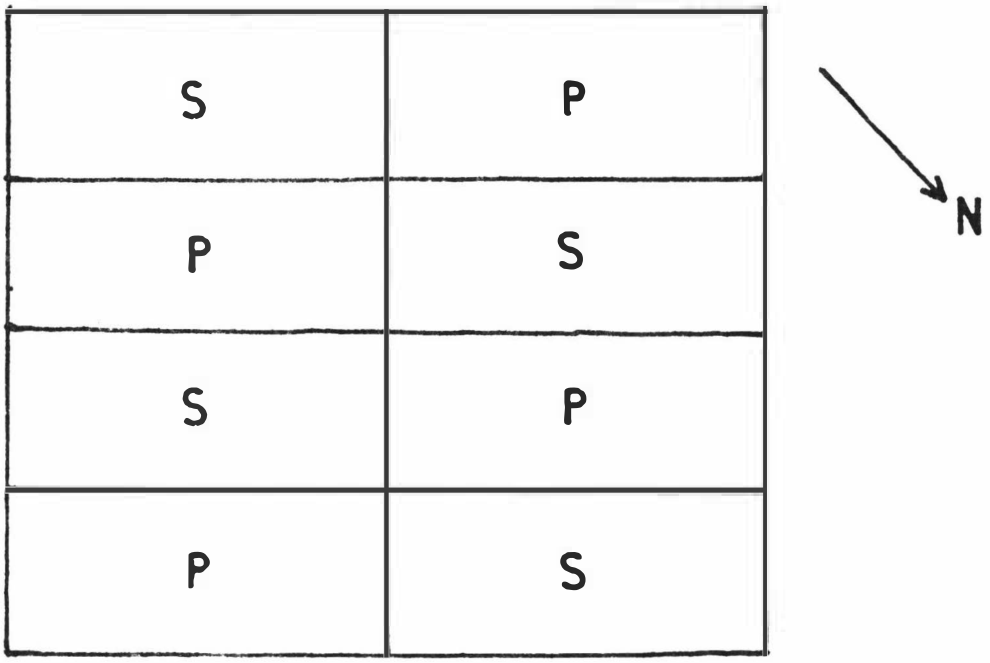
Two paddocks on the Massey College Terrace Sheep Farm were used for the experiment. They were of the same soil type (Yellow Grey Earth (Tokomaru Silt Loam)) and separated by approximately half a mile. Fig. 2 shows the division of the paddocks. Paddock 16 is approximately eight acres in area and was subdivided into eight one acre plots. Four of these plots were sown with perennial and four with short rotation ryegrass. The ryegrass strains were the latest released by the Grasslands Division, D.S.I.R. and were allotted to plots by a system of restricted randomization. These plots were topdressed in the first instance with superphosphate and ground limestone. Sulphate of ammonia was applied as required throughout the experiment. Paddock 30 is approximately five acres in area and was divided into four plots as in Fig. 2. Two of these, diagonally opposite, were chosen by a system of restricted randomisation to be sown in perennial ryegrass plus white clover while the other two were sown in short rotation ryegrass plus white clover. These plots were topdressed with superphosphate and ground limestone only. The difference between the two paddocks in the topdressing programme is due to the fact that it was necessary to supply nitrogen to the plots which were without clover.

(2) Sheep.

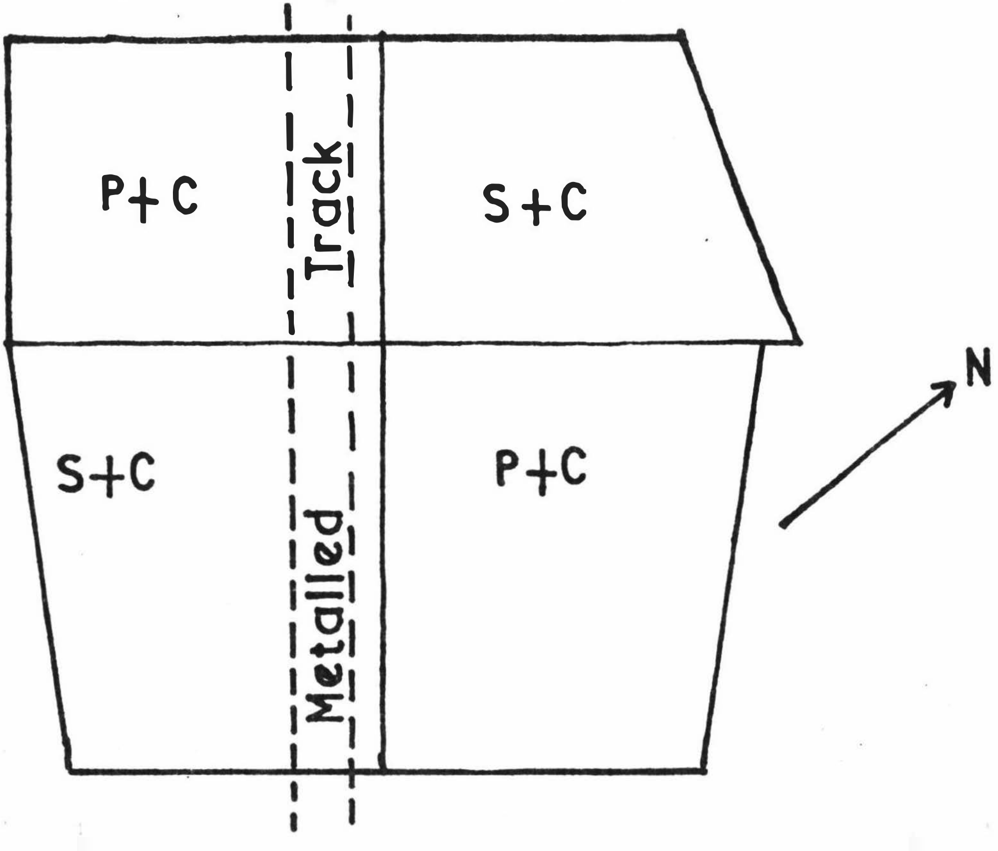
On 10 May 1957 Romney ewe lambs were put on to the plots

FIG. 2. DIVISION OF PADDOCKS.

Paddock 16, Area 8 Acres.



Paddock 30, Area 7 Acres.



at the rate of 10 per acre. Half the sheep from each plot, selected at random, were injected intra-muscularly with 1 ml. iodinated poppy seed oil (Neo-Hydriol, May and Baker). This compound contained 40 per cent iodine and formed a depot giving a continuous release of iodine into the blood. On 27 February 1958 a second similar injection was given to these sheep. Experimental sheep were removed at random from the plots and were not returned to the experiment when the stocking rate was found to be too high. When increased numbers of sheep were needed, wethers were added but were not included as experimental sheep.

In an experiment of this nature a certain amount of flexibility is needed in the design to take into account unforeseen circumstances. That this design was quite good in this respect is borne out in the following section on Experimental Management.

3. MANAGEMENT

(1) Pre-experimental.

The 13 acres of Massey College Sheep Farm set aside for this experiment had been in crop and consequently were very weedy. Therefore a pre-emergent spraying with 24D was given prior to sowing the pasture, in November 1956. There was excellent establishment but the dry summer resulted in paddock 30 going to grass dominance. A fairly heavy contamination of this paddock with Black Nightshade (Solanum nigrum) necessitated treatment of the area with M.C.P.B. The pure grass swards of paddock 16 were in good condition and essentially weed free. The short rotation ryegrass persisted well through the dry summer and was noted to be superior to perennial ryegrass in rust resistance.

After subdivision into plots paddocks 16 and 30 were stocked from February to April 1957 with Southdown cross lambs at the rate of six and seven per acre respectively.

(2) Experimental.

On 10 May 1957 the ewe lambs being used to study the effect of short rotation and perennial ryegrass, with and without white clover, on the iodine status of sheep, were placed on the plots.

The sheep at the hogget stage were shorn on 13 September 1957.

Considerable difficulties were encountered in establishing the perennial ryegrass plus clover pastures on paddock 30. The reason was the very poor clover establishment which was followed by stunted grass growth. Sheep on this pasture type showed very poor liveweight gains and so were taken off the plots for two months from December to January to enable the pasture to be spelled. (See Fig. 4) These sheep were put on to a similar type of pasture elsewhere on the College sheep farm. Although they made up some of the lost weight on this pasture they were still in poor condition at mating. However, when these ewes were put back on the plots they made an excellent recovery.

Because of the absence of clover in paddock 16 it was necessary to topdress with sulphate of ammonia at frequent intervals to keep the nitrogen levels in the soil high and thus to maintain lush growth for as much of the year as possible. There was slow death of the short rotation ryegrass over a period of weeks following an application of sulphate of ammonia to paddock 16 in February 1958. At the same time the perennial ryegrass plots responded well. It is thought that the death of the short rotation ryegrass was more likely due to an infestation with Argentine stem weevil (Hyperodes griseus) than to damage caused by the nitrogenous fertilizer at that season of the year. This conclusion was reached when the short rotation plots were killed off by Argentine stem weevil in the following summer. The death of short rotation ryegrass on paddock 16 meant that these plots became very sparse and unpalatable and that the sheep on them were subject to very poor nutritional conditions. Thus it was necessary to oversow with the latest release of short rotation seed early in March 1958. The animals grazing these plots were put on to short rotation ryegrass plus clover during the establishment of the new pasture. Unfortunately, the first oversowing was unsuccessful and thus it was necessary to resow. The second oversowing was successful and when establishment was complete the ewes were returned at a stocking rate of six per acre.

Paddock 16 sheep were shut up as a precaution against facial eczema on 4 February 1958 and released seven days later. These precautions were repeated from 18 to 26 of February 1958. Facial eczema precautions however were not thought necessary for the sheep in paddock 30. During the period the sheep were shut up they were fed short rotation ryegrass hay. Despite the precautions taken some of the sheep on the perennial ryegrass plots in paddock 16 became affected and two of them died.

Over the late summer period the fence lines in both paddocks were sprayed with "phytazole" (a mixture of 3-(p-chlorophenyl)- 1, 1- dimethyl urea and 3 - animo - 1,2, 4 triazole). The same compound was used for the control of weeds and the spot-spraying of invading clover plants in paddock 16.

On 25 March 1958 Romney rams were put out with the ewes. This is later than usual farmer practice in the district. The reason being that delayed mating could result in higher fertility (McDonald, 1958). The rams were rotated around the plots so that any fertility differences among them would be distributed randomly over the treatments. This aspect is important with regards to the effect of birthrank on the body composition of the ewes.

The perennial plots of paddock 16 were grazed down hard during mating so they were spelled for a short time during which the animals were run on the College Sheep Farm. On paddock 30 the animals grazed the short rotation plus clover treatment hard so they were removed for approximately a fortnight and grazed on a mixed pasture containing little perennial ryegrass.

Apart from final liveweight, no weighings were taken of the ewes after 7 May 1958 because differences due to pregnancy were becoming marked.

Weaning of all lambs took place on 4 December 1958 and the ewes were slaughtered approximately two weeks later.

Over the whole experiment the total number of deaths was seven; of these three occurred on perennial ryegrass, one on short rotation ryegrass, one on perennial ryegrass plus clover, and two on short rotation ryegrass plus clover.

Fig. 4 gives a general picture of the management over the experimental period.

4. THE SELECTION AND MANAGEMENT OF THE ANIMALS USED FOR CARCASS ANALYSIS

(1) Selection.

Towards the end of the experiment the 38 surviving Neo-Hydriol injected ewes were made available for carcass analysis. It was thought that because of the injection they should not be sold for human consumption. Table 4 compares the final liveweights of the injected and non-injected ewes within pasture types. Liveweight differences between iodine treatments within pasture types were not significant. Therefore as far as could be ascertained from the available evidence, it was assumed that there were no differences in body composition, between the injected and non-injected ewes. On the basis of this assumption two dry non-injected ewes were added to the carcass analysis group to make up group numbers for the study of birthrank effects. No. 5 was from the perennial ryegrass group and No. 37 from the perennial ryegrass plus clover group.

TABLE 4

Comparison of the Liveweights (lb.) of Injected and Non-Injected Ewes.

	S		P		S + C		P + C	
	NI	I	NI	I	NI	I	NI	I
No. Ewes	12	11	14	11	6	8	8	8
Liveweight	116	116	102	104	134	137	119	119

At slaughter one of the ewes from the short rotation plus clover pasture was very light compared to the rest of its group. At dissection, this ewe (No. 120) had extremely yellow body fat, and was markedly different from the rest of the group in body composition. It was thought that facial eczema might have been the cause of this abnormality but examination of the liver at slaughter had shown none of the typical facial eczema lesions. Bartlett's test of homogeneity of variance (Snedecor, 1957) was applied to several components of liveweight both including and excluding No. 120, and these analyses showed that, in general, the group means were much more homogeneous with No. 120 excluded. On this further evidence it was considered wise to discard data from No. 120.

Thus data on the composition of 39 ewes were available for analysis. Of these, 12 were from perennial ryegrass, 11 from short rotation ryegrass, nine from perennial ryegrass plus clover and seven from short rotation ryegrass plus clover. The breakdown of the 39 ewes into type of birthrank was as follows: 21 ewes reared single lambs, four ewes reared twins, five ewes bore a lamb but did not rear it, and nine ewes were dry. For the distribution of individual sheep to the various sub-groups see Table 16.

(2) Management

The ewes were allotted randomly into three slaughter groups. These groups contained 13, 13 and 14 ewes which were killed on 16, 17 and 18 of December 1958 respectively. The sheep were taken off pasture 24 hours before slaughter. They were then lorried to the Massey College woolshed and kept indoors without food or water until slaughter.

5. PRE-SLAUGHTER TECHNIQUES

Lean-meter measurements were taken. These measurements will be dealt with in detail in Part II.

6. SLAUGHTER TECHNIQUES AND RECORDS

Slaughter commenced at approximately 2.00 p.m. each day. The killing and dressing was done by a skilled professional butcher and was in accordance with normal commercial practice, with the exception that the kidneys were removed. In addition to the butcher, five other assistants were required in the collection of data.

The following information was obtained for each ewe:

(1) Liveweight
(2) Bled wt.
    Blood wt. (by difference)
(3) Feet wt. (four together)
(4) Skin wt.
(5) Head wt. (with tongue)
(6) Hot carcass wt. (minus kidneys)
(7) Wt. left fore cannon bone.
(8) Wt. stomach + oesophagus (full)
(9) Wt. stomach + oesophagus (empty)
    Wt. stomach contents
(10) Wt. small and large intestines (full)
(11) Wt. small and large intestines (empty)
    Wt. intestinal contents
    Wt. stomach + intestinal contents

(12) Wt. heart
(13) Wt. lungs + trachea
(14) Wt. spleen
(15) Wt. liver
(16) Wt. omental (Caul) fat
(17) Wt. mesenteric (gut) fat
(18) Wt. kidneys
(19) Wt. genital tract + bladder
(20) Wt. Rest (includes diaphragm and miscellaneous pieces of skin).

A piece of trachea including the thyroid gland was removed and the gland dissected out. After slaughtering had finished the carcasses were hung in a chiller on standard gambrels.

7. POST SLAUGHTER TECHNIQUES

On the morning following slaughter the carcasses were removed from the chiller and weighed to determine cold carcass weight and then specific gravity determinations were carried out as detailed in Part II.

The carcasses were then transported to the Manawatu Meat Company for freezing and storage.

8. CARCASS DATA

(1) Whole Carcass Treatment.

Detailed descriptions have been made elsewhere of the bandsaw and chemical techniques used in this work (Barton and Kirton, 1956; Kirton 1957; Kirton and Barton 1958a). However the procedure followed in the present study, differs in many respects from the above mentioned investigations and so will be described in detail. Laboratory work commenced on 14 January 1959. Normally three carcasses were brought from the cold store on Monday mornings and two on Wednesday. Thus dissection was finished by Friday afternoons and chemical work by Saturday evenings. To keep up to this schedule it was usually necessary to dissect two nights a week. Three persons were usually employed most of the time, but towards the end of the laboratory period an extra person was needed for eight to ten hours a week.

Each frozen carcass was weighed when brought into the meat laboratory. It was divided down the middle of the back with a meat bandsaw while still frozen, and then each side was weighed. Following this both sides were divided with the bandsaw into four joints; leg, loin, 9-10-11 rib cut and "rest". This was done in the following manner: the leg was removed by making a cut at right angles to the backbone at the level of the lumbar-sacral junction; a further cut at the thoracico-lumbar junction which followed down the curve of the rib removed the loin; the 9-10-11 rib cut was removed by making two cuts midway between the 11th and 12th, and 8th and 9th ribs respectively. These cuts also followed the curve of the ribs. The remainder of the side constituted the "rest". Fig. 3 illustrates this method of jointing. The joints from each side were weighed.

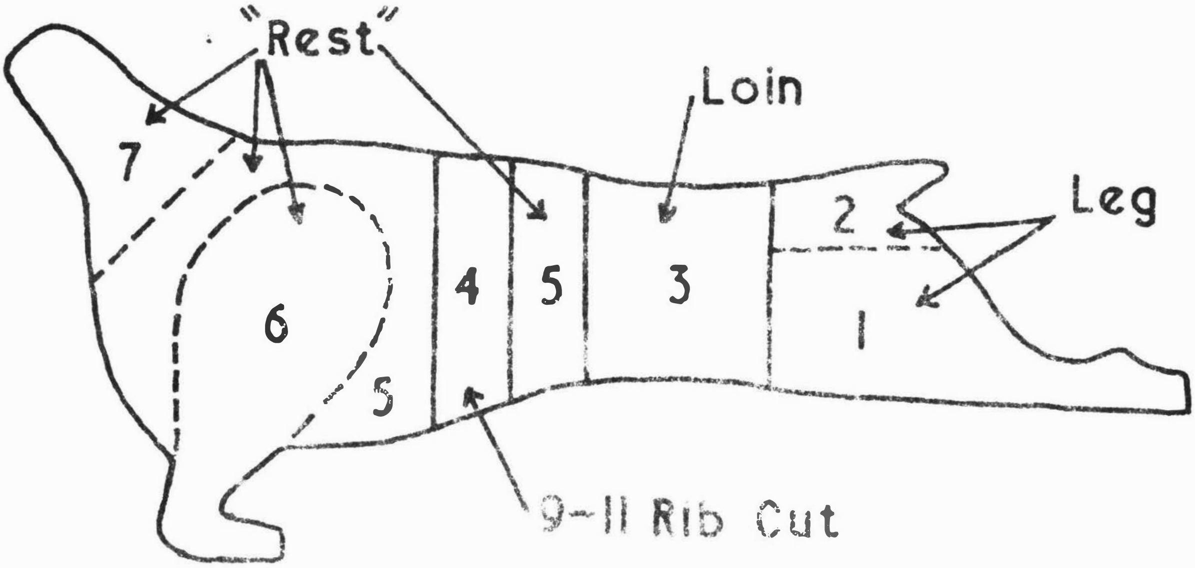
(2) Right side.

Each of the four joints was bandsawed while still frozen into approximately $\frac{1}{4}$ inch slices. The slices were then minced thrice to give a homogeneous mixture and two 50 gm. samples taken from each joint. The remaining mince from all the joints was then bulked and minced again. As it was minced it was subsampled at regular intervals until, at the end, a sub-sample of 4 to 6 lb. was obtained. This was minced twice and six 50 gm. samples taken for chemical analysis. When chemically analysed these six samples gave an estimate of the chemical composition of the right side of the carcass.

Kirton and Barton (1958a) describe the chemical analysis as follows:

> A modification of the methods reported by Barnicoat and Shorland (1952) was used. Samples were dried in an oven (not an air-draught type) at 105°-110°C for approximately 18 hr. and then weighed to give water loss by difference. Liquid fat was decanted off, petroleum ether was added and the residue was crushed with a metal rod. After settling, the ether was decanted off and the foregoing fat extraction procedure was repeated twice more. The material was then replaced in the oven to drive off the ether.

FIG. 3. METHODS OF JOINTING



Bandsaw Joints:

As Indicated By Arrows.

Anatomical Joints:

1. Leg.
2. Pelvis.
3. Loin.
4. 9-11 Rib Cut.
5. Thorax.
6. Shoulder.
7. Neck.

Following this, the sample was weighed to give the uncorrected fat weight (ether extract) by difference and the dried fat-free residue directly.

This procedure was followed exactly in the present experiment. However, in the present work the so-called "fat-free-residue" will be referred to as "crude residue" because in fact it can contain over 20 per cent fat.

The crude residues from the six side samples were bulked for each side enabling correction factors for chemical fat, and ash to be calculated separately for each carcass. The crude residues from the two samples from each joint were bulked for all 39 carcasses.

The samples of crude residue were powdered in a hammer mill. Following this a powder sample from each side sample and each joint was extracted with petroleum ether for six hr. in a Soxhlet apparatus to obtain fat correction factors. Further powdered samples were ashed in a muffle furnace to give figures for ash per cent. From the fat and ash percentages in the crude residue, together with the weight of each residue, it was possible to calculate the weights of fat and ash in each crude residue. The fat correction figure was then added to the uncorrected fat weight to give total chemical fat weight in the original 50 gm. mince sample. The weight of crude residue, minus the fat correction weight and minus ash weight, gives an estimate of the weight of protein in the 50 gm. sample. Kirton (1957) gives a numerical example of the whole calculation.

(3) Left Side.

The four bandsawed joints of the left side were allowed to thaw prior to dissection. However before they had thawed tracings were made on the anterior and posterior faces of the loin for later studies on tissue areas. At the same time measurements were made of the depth of fat at the Lean-meter probe sites. This was done by cutting away the subcutaneous fat and measuring its depth with callipers. This aspect however, will be dealt with in Part II.

The four bandsawed joints were subdivided to give seven smaller joints similar in definition to the anatomical joints of the Hammond school (Pálsson, 1939). The leg was divided from the pelvis in the manner described by Pálsson (1939). "rest" was divided into neck, thorax, and shoulder following the procedure of Pálsson (1939). The loin and 9-10-11 rib cut were untouched. The only major discrepancy between the jointing and that of Pálsson is that in this case part of the ilium was removed with the loin in the original bandsawing. This small piece of bone was, however, weighed separately. The jointing is illustrated in Fig. 3. The anatomical joints were then weighed.

The joints were dissected into fat, muscle, bone and tendon plus waste as described by Pálsson (1939). The fat was subdivided into subcutaneous and intermuscular components while other fats such as kidney, channel, and mammary were weighed separately and included in the loin, pelvis and leg respectively. Muscle usually comprised "skin" and "general" with the exception that individual weights of the psoas muscle in the loin were determined. All bones except the vertebrae and ribs were weighed and recorded individually.

Chemical analysis was carried out on the muscle and fatty tissues. The total muscle from each joint was minced three times and two 50 gm. subsamples taken. The total fat from each joint was minced once only before sampling. Further mincing was known to produce a sticky tenacious mass that was extremely difficult to sub-sample effectively. The chemical procedures used were as described earlier.

9. STATISTICAL METHODS

The data resulting from this study are arranged according to a 2-way classification (pasture type and birthrank) with unequal subclass numbers. The statistical procedure most appropriate in these circumstances is the method of fitting constants by least squares. The model chosen in this case was:

$$y_{ijk} = \mu + p_i + b_j + (pb)_{ij} + e_{ijk}$$

$$i = 1,2,\ldots,r \quad ; \quad j = 1,2,\ldots,s$$

$$k = 0,1,2,\ldots,n_{ij}$$

y_{ijk} is the observation on the k^{th} animal of the j^{th} birthrank on the i^{th} pasture type.

The constant μ is an effect common to all ewes in the population. It is in effect a population mean.

The constant p_i is an effect common to all ewes on the i^{th} pasture type. The types of pasture are represented by the symbols: p_1 (or P) for perennial ryegrass, p_2 (or S) for short rotation ryegrass, p_3 (or P + C) for perennial ryegrass plus clover and p_4 (or S + C) for short rotation ryegrass plus clover.

The b_j constant is an effect common to all ewes in the j^{th} classification of birthrank.

The four types of birthrank studied here are represented by: b_1 for ewes that reared single lambs, b_2 for ewes that reared twins, b_3 for lost lamb ewes (bore a lamb but did not rear it), and b_4 for dry ewes.

The interaction contribution to the individuals in the $(i,j)^{th}$ cell is measured by the constant $(pb)_{ij}$.

The constant e_{ijk} is a deviation or error. In testing the significance of differences between the classifications the deviations are assumed to be normally and independently distributed around a mean of zero with variance σ_e^2.

A formal presentation of the procedure followed in estimating the unknown parameters in this particular model is set out by Kempthorne (1952).

In the present study the normal equations for estimating the parameters $(\mu + p_i)$ and b_j may be written:

	$\mu + p_1$	$\mu + p_2$	$\mu + p_3$	$\mu + p_4$	b_1	b_2	b_3	b_4
$\mu + p_1$	12				7	2	1	2
$\mu + p_2$		11			5	1	2	3
$\mu + p_3$			9		5	1	1	2
$\mu + p_4$				7	4	0	1	2
b_1	7	5	5	4	21			
b_2	2	1	1	0		4		
b_3	1	2	1	1			5	
b_4	2	3	2	2				9

The $\mu + p_i$ were then absorbed in the b_j to form a matrix of coefficients in terms of b_j. To obtain an unique solution the condition that $b_4 = 0$ was then imposed. Thus the following 3 x 3 matrix was obtained:

$$\begin{vmatrix} 9.580448, & -2.176769, & -2.619404 \\ 2.176767, & 3.464646, & -0.459595 \\ -2.619408, & -0.459596, & 4.299063 \end{vmatrix}$$

This matrix was then inverted following the method of Mood (1950). The solutions of the equations for b_j were thus:-

$$\begin{Vmatrix} b_1 \\ b_2 \\ b_3 \end{Vmatrix} = C . \begin{vmatrix} Q_1 \\ Q_2 \\ Q_3 \end{vmatrix}$$

where C is the inverse matrix and

$$Q_j = y_{.j.} - \sum_i \frac{n_{ij} y_{i..}}{n_{i..}}$$

In order to estimate each $\mu + p_i$ it was necessary to substitute back in the normal equations the values obtained for the $\hat{b}_j$s. In the results the pasture effects are presented as $(\widehat{\mu + p_i})$ and the birthrank effects as $\hat{b}_j$

The next step was to compute the following reductions in sums of squares due to fitting the constants in the brackets

$$R\ (T) = \sum_{ijk} y_{ijk}^2$$

$$R\ (\mu,\ p,\ b,\ pb) = \sum_{ij} \frac{(_k\, y_{ijk})^2}{n_{ij}}$$

$$R\ (\mu,\ p,\ b) = \sum_i (\widehat{\mu + p_i})\, y_{i..} + \sum_j \hat{b}_j y_{.j.}$$

$$R\ (\mu,\ p) = \sum_i \frac{(\sum y_i)^2}{n_i}$$

$$R\ (\mu,\ b) = \sum_j \frac{(\sum y_j)^2}{n_j}$$

The analysis of variance testing for interaction, pasture and birthrank effects can be presented as follows:

TABLE 5

Source	df	SS		MS
Interaction	$rs-m-r-s+1$	$R(\mu,p,b,pb)$	$- R(\mu,p,b)$	I
Pasture	$r-1$	$R(\mu,p,b)$	$- R(\mu,b)$	P
Birthrank	$s-1$	$R(\mu,p,b)$	$- R(\mu,p)$	B
Error	$n-(rs-m)$	$R(T)$	$- R(\mu,p,b,pb)$	E

Here m equals the number of subclasses containing no observations which in this case equals one (pb_{42}). Interaction was tested first. Where it was found non-significant it was possible to proceed to the test for the significance of pasture and birthrank effects. However, when interaction was found significant, the tests of significance of the pasture and birthrank main effects are no longer applicable. In these circumstances it was necessary to refer back to subclass means for interpretation of results.

CHAPTER IV

RESULTS

1. LIVEWEIGHT GROWTH

Liveweight growth curves are presented in Fig. 4. Weighing was stopped after 7 May 1958 because pregnancy was beginning to affect liveweight and therefore final liveweight was the only weight affected by birthrank. Thus differences at all previous weighings were due to pasture type alone and were analyzed by simple analysis of variance (Snedecor, 1957).

Table 6 presents mean liveweights on 10 May 1957, 10 July 1957 and 16 December 1958, and shows any significant differences between pasture types within each of those dates. The reason for choosing these three dates is to show that at the beginning of the trial there were no differences in liveweight between the four pasture types but that by the second weighing two months later, significant differences had appeared.

The treatments remained statistically different throughout the rest of the trial. In an effort to guage the pattern of these differences Duncan's (1957) multiple range test was used. It showed that on 10 May 1957 there were no significant differences between any individual means. By 10 July 1957 the mean of the S group was significantly larger than any of the others, which were not significantly

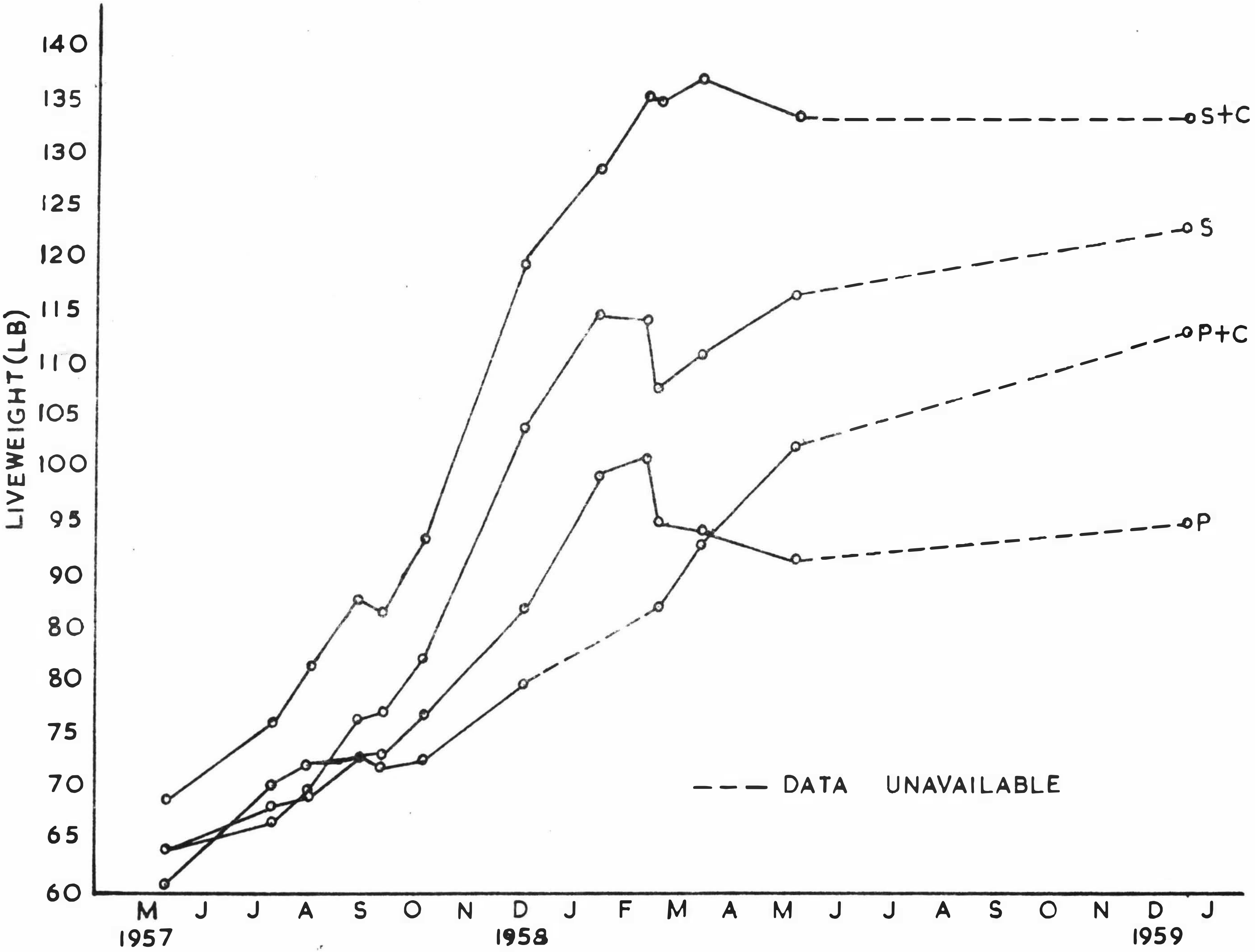


FIG. 4. GROWTH CURVES (FIRST TRIAL)

different from each other. This situation was maintained until 3 December 1957. At this date all means were significantly different from each other. By the end of the trial these differences had declined somewhat and with final liveweight there were non significant differences between S + C and S, and between S and P + C.

The growth curves shown in Fig. 4 demonstrate quite clearly some of the effects of management on liveweight. The poor establishment of the P + C pastures is reflected in the slow growth of the animals on them. The effect of shutting up the sheep on the P and S plots (that is, paddock 16) as a precaution against facial eczema is most marked. The liveweights of both these groups of animals dropped sharply at this time while sheep on paddock 30 which were not shut up continued to grow over the same period. Also noticeable is the fact that while sheep on the S pasture made a good recovery after the precautions had been relaxed, those on the P did not and continued to lose weight. This latter situation is probably due to the fact that most of the P sheep had contracted facial eczema to some extent as shown by the presence of liver lesions at slaughter, while there was little sign of liver damage in the S sheep.

Up to this stage it has been inferred that any differences discovered between sheep have been due to the particular pasture type they were grazing. However this assumption is far from being a proven fact. The section on experimental management has shown that it was at times necessary to graze sheep off the pastures allotted to them in the experimental design. Also, in many cases management on the allotted pastures had a profound effect on liveweight growth. However a similar trial to that being described was started on 16 July 1959 and preliminary results are available. Appendix I shows the liveweight growth so far in this second trial. In this case there were no pasture establishment problems so probably a truer picture is given. A point of great importance is the ranking order of the means. If both trials are compared at the end of their first December it will be seen that the ranking order is not the same. The difference is due to the P + C group. In the first trial this group ranks fourth while in the second trial it is third. This difference can be explained as before in terms of pasture establishment. The interesting thing is that on 21 January 1960 the second trial means rank in the same order as the first trial means at the end of its experimental period. This ranking order $(P < P+C < S < S+C)$* is of great importance, for, as will be shown later in this chapter most of the components of liveweight follow it.

The additional evidence supplied by the second trial suggests that the differences observed in final liveweight in the first trial are influenced to a large extent by pasture type. However, on the evidence available we cannot

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* $<$ indicates, "is less than", and $>$ "is greater than". This nomenclature will be followed throughout.

state definitely that the differences were due to pasture type. We can only say that the animals were on different planes of nutrition. For convenience the four planes of nutrition will be named P, S, P + C and S + C throughout this work.

The effect of birthrank on final liveweight was non significant, although it can be seen from the means that ewes with twins were more affected than those with singles. This type of result is to be expected, as the strain of lactation is much greater with twins than with single lambs.

All analyses of variance for liveweight and its components are presented in Appendix II and will not be referred to in the text.

2. CARCASS WEIGHT AND COMPOSITION

(1) Carcass Weight.

Table 7 sets out the effects of pasture type and birthrank on mean carcass weight. The pasture type effects are significantly different at the 1 per cent level of probability. The S + C sheep have the highest

TABLE 7

Mean Frozen Carcass Weight (lb)

	Pasture Effect					Birthrank Effect				
	P	S	P + C	S+C	Sig.	Single	Twin	L.L.	Dry	Sig.
Carcass Weight	56.2	74.7	70.2	81.5	**	-10.6	-16.6	0.7	0	N.S.

carcass weight followed in descending order by S, P + C, and P. This is the same order as was found with liveweight. The birthrank effects are non significant for carcass weight although the carcasses from ewes that reared twins are again lighter than from those which reared singles. Lost lambs and dry ewes are very similar in weight.

(2) Carcass Composition.

By using chemical and dissection analyses the results are presented from two slightly different views. Chemical data shows any changes in chemical components while dissection data shows changes at the tissue level which are often due to combinations of the chemical components.

Weight components give results in absolute terms while percentage components give a better idea of changes in body composition. However, both are needed for a full interpretation of results.

(a) Chemical Data.

(i) Weight Components. The mean weights of the chemical components of carcass weight are presented in Table 8. The means are significantly different for pasture effect in the

TABLE 8

Weight of Chemical Components (lb)

	Pasture Effect					Birthrank Effect				
	P	S	P + C	S + C	Sig.	Single	Twin	L.L.	Dry	Sig.
Fat	25.48	36.81	35.36	40.63	**	-9.09	-14.37	0.51	0	**
Water	22.86	28.12	26.05	29.73	**	-1.30	-1.76	-0.59	0	N.S.
Protein	6.47	7.95	7.40	8.59	**	-0.18	-0.36	0.39	0	N.S.
Ash	2.03	2.49	2.28	2.62	N.S.	-0.16	-0.31	0.19	0	N.S.

case of fat, water and protein but non significant for ash. The ranking order of the means in each case follows the pattern noted before (S + C > S > P + C > P).

With birthrank effect only fat weight shows a significant difference between means. The ewes that reared lambs are by far the most affected. Also twin rearing ewes have less carcass fat than ewes with singles, although interpretation of this must be cautious because there are only four ewes in the twin rearing classification. Thus the differences in carcass weight due to birthrank seem to be due to fat differences.

(ii) Percentage Components. The analysis of variance is based on the assumption that the errors are not correlated, are normally distributed, have the same variance and have a mean of zero. Percentages have a multinomial distribution and therefore theoretically violate the homogeneity of variance assumption. However experience has shown that where the probabilities involved in a multinomial distribution are near neither zero or 100 per cent, the analysis of variance procedure and tests of significance are not greatly distorted. Therefore in the present work percentage data were analysed by analysis of variance.

Mean percentages in terms of fat, water, protein and ash for pasture type and birthrank effects are presented in Table 9.

The differences in fat percentage are highly significant

TABLE 9

Percentages of Chemical Components

	Pasture Effect					Birthrank Effect				
	P	S	P + C	S + C	Sig.	Single	Twin	L.L.	Dry	Sig.
Fat	39.6	47.6	48.9	49.6	**	-5.1	-10.3	1.4	0	*
Water	43.9	38.1	37.2	36.4	**	3.7	7.8	-1.5	0	**
Protein	12.6	10.8	10.5	10.6	**	1.3	2.4	0.2	0	*
Ash	3.8	3.4	3.3	3.2	*	0.2	0.3	0.2	0	N.S.

between the four pasture effects and significant at the five per cent level for birthrank effects. For pasture effects the ranking order is not the same for fat per cent as with fat weight. Here the ascending order is P, S, P + C, S + C. For birthrank effect differences in the means are significant only at the five per cent level of probability, with twin rearing ewes being the worst affected followed by ewes with singles. Dry and lost lamb ewes are as usual fairly similar and are not affected much.

Mean water percentages are highly significantly different for pasture effects. However, they rank in the reverse order to fat percentages. This pattern was also noted for the mean percentages of protein and ash. Birthrank effects are also statistically different for water percentages. Here twin rearing ewes have the highest percentage followed by ewes with singles, dry ewes and finally lost lamb ewes.

The differences in mean protein percentages are mainly due to the P group which is markedly higher than the other three. Birthrank effects are only significantly different at the five per cent level and follow the same order as water percentage.

Mean ash percentages are significantly different at the five per cent level for pasture effect and are not significantly different for birthrank effect. In both

TABLE 10

Weight of Dissectible Components (lb)

	Pasture Effect					Birthrank Effect				
	P	S	P + C	S + C	Sig.	Single	Twin	L.L.	Dry	Sig.
Fat	25.58	37.41	35.20	41.81	**	-9.56	-14.86	0.16	0	**
Muscle	22.76	29.13	26.29	29.86	**	-0.70	-1.80	0.09	0	N.S.
Bone			Significant				Interaction			
Tendon + Waste			Significant				Interaction			

TABLE 11

Percentages of Dissectible Components

	Pasture Effect					Birthrank Effect				
	P	S	P + C	S + C	Sig.	Single	Twin	L.L.	Dry	Sig.
Fat	40.2	46.3	50.1	51.1	**	-5.7	-10.9	0.8	0	*
Muscle	43.9	39.7	37.6	36.7	**	4.6	7.7	-0.8	0	**
Bone	10.7	8.0	8.3	8.2	**	1.0	2.5	-0.2	0	N.S.
Tendon + Waste	3.6	2.7	2.6	2.5	*	0.2	0.5	-0.1	0	N.S.

cases the means follow the same order as water and protein percentages.

(b) Dissection Data.

(i) Weight Components. Results are presented in Table 10. Mean dissectible fat weights have the same ranking order as chemical fat weight for both pasture and birthrank effects. Both these effects are statistically different at the one per cent level.

Muscle weight shows a highly significant difference in means for pasture effect. It exhibits the same general ranking order as noted before. The effect of birthrank on mean muscle weight is not significant.

Both bone and tendon plus waste weights showed significant interaction of pasture and birthrank, and are dealt with in section 5 below.

(ii) Percentage Components. Mean percentages are presented in Table 11. Fat per cent shows a progressive increase in the order P < S < P + C < S + C for pasture effect. These means are highly significantly different. Birthrank effects on dissectible fat per cent are significantly different at the five per cent level of probability. They rank in the order twin < singles < dry < L.L. Thus dissectible fat per cent follows a very similar pattern to chemical fat per cent.

Muscle percentages are highly significantly different

TABLE 12

Organ and Offal Weights

	Pasture Effect					Birthrank Effect				
	P	S	P + C	S + C	Sig.	Single	Twin	L.L.	Dry	Sig.
Feet (gm.)	817	942	862	1047	**	-9	-4	-3	0	N.S.
Skin (lb)	9.48	12.01	10.49	13.10	**	-0.95	-0.81	-0.15	0	N.S.
Head (lb)	4.16	4.43	4.31	4.50	**	-0.08	-0.07	-0.05	0	N.S.
Stomach + Oesophagus (lb)			Significant				Interaction			
Small + large Int. (lb)	3.23	3.60	3.29	3.41	N.S.	0.36	0.43	0.07	0	N.S.
Heart (gm.)	239	258	251	275	N.S.	4	-4	5	0	N.S.
Lungs + Trachea (gm.)	468	525	541	778	**	8	21	-60	0	N.S.
Spleen (gm.)	78	93	77	100	**	-5	-7	-8	0	N.S.
Liver (lb)	1.52	1.59	1.50	1.83	*	0.03	0.06	-0.01	0	N.S.
Gut Fat (lb)	1.41	1.59	1.73	1.83	N.S.	-0.09	-0.36	0.05	0	N.S.
Caul Fat (lb)	3.70	5.86	5.16	6.55	**	-1.45	-2.21	0.46	0	**
Kidneys (gm.)	124	135	124	153	**	3.39	10.71	1.58	0	N.S.
Genital tract + Bladder (gm)	119	190	160	171	N.S.	24	36	34	0	N.S.

for pasture effect. Here they rank in the opposite order to fat per cent. Birthrank effects on muscle per cent are also highly significant. Here the twins have the highest muscle per cent followed in order by single, dry and lost lamb ewes.

Mean bone percentages are highly significantly different for pasture effect and non significant for birthrank effect. As with ash per cent most of the difference in the pasture effect is in the P group.

Differences in mean tendon plus weight per cent are significant at the five per cent level for pasture effect and non significant for birthrank effect.

3. ORGAN AND GASTRO-INTESTINAL CONTENT WEIGHTS

(1) Organ Weights.

In this section offals are included with the organs. Table 12 presents the mean weights of organs studied in this trial.

Stomach plus oesophagus weight is the only item showing significant interaction and will be dealt with separately in section 5.

All organs showing a highly significant difference in mean weights for pasture effect, with the exception of lungs plus trachea weight, exhibit the same general ranking order as noticed before.

Mean liver weights are significantly different at the

TABLE 13

Weights of Stomach and Intestinal Contents (lb)

	Pasture Effect					Birthrank Effect				
	P	S	P + C	S + C	Sig.	Single	Twin	L.L.	Dry	Sig.
Stomach Contents	6.78	5.47	5.25	5.15	*	1.75	2.01	0.82	0	*
Intestinal Contents	1.80	1.46	1.18	1.56	*	0.33	0.83	0.29	0	*
Stomach + Intestinal Contents	8.59	6.95	6.45	6.73	*	2.06	2.82	1.10	0	**

five per cent level. Most of the difference comes from the S + C mean which is higher than the other three.

Mean caul fat weight is the only item showing any significant difference in birthrank effect. It exhibits the same ranking order as total dissectible and chemical fat weights. Although non significant, gut fat weight has this same ranking order.

(2) Gastro-intestinal Content Weights.

The means shown in Table 13 present the effect of pasture type and birthrank on gastro-intestinal contents. The picture here is different to anything previously encountered. For pasture effect the P sheep had the greatest contents followed by S, S +C and finally P + C. All means were significantly different at the five per cent level. The combination of stomach plus intestinal contents did not improve significance levels.

For birthrank effect, ewes with twins had the largest gastro-intestinal contents. They were followed by ewes which reared singles, lost lamb ewes and finally dry ewes. In this case total intestinal plus stomach contents were statistically more significant than the contents of the organs alone.

TABLE 14

Effect of Pasture and Birthrank on the Fat-Free Carcass and its Components

	Pasture Effect					Birthrank Effect				
	P	S	P + C	S + C	Sig.	Single	Twin	L.L.	Dry	Sig.
Fat-Free Carcass Wt. (lb)	30.6	37.8	34.7	39.6	**	-0.98	-1.79	0.56	0	N.S.
Percentage Muscle in Fat-Free Carcass	73.8	76.7	75.5	75.1	*	0.51	-0.91	-0.56	0	N.S.
Percentage Bone in Fat-Free Carcass	17.6	15.5	16.5	16.7	**	0.12	1.17	-0.03	0	N.S.
Percentage Tendon + Waste in Fat-free Carcass	5.7	5.1	5.2	5.1	N.S.	-0.04	0.12	-0.01	0	N.S.

4. THE FAT-FREE CARCASS AND ITS COMPONENTS

In an effort to evaluate the findings of Wilson (1952, 1954a, 1954b, 1957, 1958a, 1958b) an analysis of the dissectible components of the fat-free carcass was made. The muscle still contained intra-muscular fat and the bones contained bone fat. This is the same method as used by Wilson.

As can be seen from Table 14 none of the birthrank effects were significant. Only the per cent tendon and waste was non significant for pasture effect.

Fat-free carcass weight was significantly different at the one per cent level for the various pasture types. The ascending order was $P < P + C < S < S + C$.

The percentage of muscle in the fat-free carcass is significantly different only at the five per cent level. It does not show any marked trend.

There is a highly significant pasture effect in the bone percentage of the fat-free carcass. The means rank in the ascending order $S < P + C < S + C < P$.

5. INTERACTION

In order to be able to interpret items which have an interaction between birthrank and pasture type it is necessary to study the ranking order of subclass means because the model described in "Materials and Methods" is no longer applicable. Table 15 presents these means.

TABLE 15

Subclass Means of Items Showing Interaction (lb)

	P				S				P + C				S + C			
	b_1	b_2	b_3	b_4	b_1	b_2	b_3	b_4	b_1	b_2	b_3	b_4	b_1	b_2	b_3	b_4
Bone Wt. (lb)	5.47	5.50	5.14	4.53	5.40	6.03	5.67	6.57	5.41	5.76	6.69	5.80	6.87		6.73	5.94
Tendon plus waste Wt.(lb)	1.73	1.77	1.54	1.49	1.78	1.81	1.80	2.14	1.64	1.64	2.15	1.96	2.04		2.37	1.65
Stomach + Oesophagus Wt. (lb)	3.17	3.29	3.19	2.72	3.25	3.25	3.30	3.62	2.98	3.53	2.92	2.65	3.78		3.43	2.49

The following items displayed interaction:

(1) Bone Weight.

Study of the ranking order of subclass means shows the reason for interaction. The order within each pasture type is different. In the P the order is b_2 b_1 b_3 b_4, in the S it is b_4 b_2 b_3 b_1, in the P + C it is b_3 b_4 b_2 b_1, and in the S + C it is b_1 b_3 b_4. These orders are different in each case.

(2) Tendon plus Waste Weight.

A similar situation exists here and within pasture types the ranking order of subclass means is in a different order each time.

(3) Stomach plus Oesophagus Weight.

As in the previous two cases the presence of interaction can be explained by the ranking order of subclass means within a pasture type.

6. DISCUSSION

(1) Pasture Effect.

Experimental results show that the ewes were on four difference planes of nutrition. Because of varying managemental conditions it is not possible to state definitely whether the differences in nutrition seen in the trial were due to pasture type. However, preliminary results from a similar trial conducted from July 1959 have shown an identical pattern and make it likely that pasture type was the cause. Thus the animals were exposed to four differing planes of nutrition in the ascending order P, P + C, S, S + C. Because liveweight and carcass weight follow this order so too do most of their components.

Pasture type affects the means of dissectible fat and muscle weights significantly. However, although both are statistically different at the one per cent level of probability, fat is relatively much more affected than muscle. This can be seen in Table 10 where mean fat weights range from 25.58 to 41.81 lb while muscle weight has the smaller range of 22.76 to 29.86 lb. Neither bone or tendon plus waste weights vary much over the whole range as can be seen from Table 15. This type of result fits in very well with the results obtained by the group of workers at Cambridge (Hammond, 1932; Pálsson, 1939; McMeekan, 1940; Hammond, 1944; Wallace, 1948; and Pálsson and Vergés, 1952) who have shown that on a declining plane of nutrition tissues are affected in the reverse order to that of their development. Thus, in this case the late developing fatty tissue is relatively more affected by plane of nutrition than the early developing muscle as the plane of nutrition declines from S + C through to P. The picture is somewhat different with the percentage dissectible components. Here the means are not affected in the same order as the weight components. The per cent of dissectible fat increases in the order P, S, P + C, S + C. This type of result stems from the fact that percentages are proportions and so either numerator, denominator or both of them may be affected. In this case the S sheep had a greater absolute fat weight than the P + C group but they also had a higher mean carcass weight so that the P + C had proportionately more fat. While muscle weight increased over the nutritional range muscle per cent decreased significantly. This is obviously due to the fact that the fat weight increased proportionately more than muscle weight. The decline of bone and tendon plus waste percentages is explained in a similar manner. Thus we have a situation where with rising plane of nutrition the proportion of fat in the carcass increases while the proportions of other components decrease.

Chemical components follow a similar pattern to dissectible ones. On an increasing plane of nutrition the weights of all chemical components increase in the order P $<$ P + C $<$ S $<$ S + C. On a proportional basis the percentage of fat increases while those of water, protein and ash decrease. This may be explained in a similar manner to the proportional changes in the dissectible components. That is, while all components increase absolutely with a rising plane of nutrition, fat increases proportionately to a greater extent, and so the percentages of water, protein and ash decrease.

Organ and offal weights were broadly affected by nutrition in the same order as liveweight. However there were many exceptions and it is impossible to see any stratification in order of development as was found by the Cambridge school.

The results from the work on a fat-free carcass basis are quite interesting. They do not agree with Wilson (1957) who found no differences in fat-free carcass weights of animals on different planes of nutrition. In the present work there are highly significant differences in fat-free carcass weights. The variability in muscle percentage has been reduced by comparing the pasture types on a fat-free basis. It is noticeable that most of the difference can be attributed to the perennial ryegrass group (see Table 14). This was also the case for muscle percentage on a whole-carcass basis, as is shown in Table 11. A similar picture exists in the case of bone. However here the comparison on a fat-free carcass basis has not reduced the significance of the differences between pasture groups as was the case with muscle. In both the whole carcass and fat-free carcass analyses most of the difference in bone percentage can be attributed to the perennial ryegrass group. From the present data it is difficult to assess the value of the fat-free type of analysis. It did not make much difference to the present results and did not lead to a complete reversal of the significance of results as found by Wilson (1958a). The removal from the carcass of the most variable of its components, namely fat, will reduce the variability of the remaining components. Whether or not the increase in the fat content of an animal can be regarded as true growth, the animal body must be regarded as an entity. Therefore any biological interpretations of fat-free carcass analyses must be regarded with caution.

(2) Birthrank Effect.

The type of statistical analysis used separated out the birthrank effects from any associated effects of plane of nutrition. Therefore the effect being studied in this section was acting on body composition from mating until weaning; that is, over a period of nine months. Kirton et al. (1959) have shown that the effect of pregnancy on the body composition of the sheep is negligible. Therefore it would seem that the differences in composition due to birthrank are due mainly to lactation. The results show a pattern in the effect of birthrank on liveweight and carcass weight. Ewes rearing twins lost most weight followed by ewes that reared singles. Lost lamb and dry ewes were very similar and not affected much. The results of dissection and chemical analyses show that most of the lost weight was fat. Caul and gut fat weights follow the same pattern.

Weight components other than fat were not significantly affected. These results give support to the generally held theory that lactational stress materially affects body composition.

Pálsson (1953) obtained similar results to these but he made no distinction between ewes rearing singles and those rearing twins. The present experiment has enabled this distinction to be made; however care should be taken to see that too much emphasis is not put on the results from the twin rearing ewes, as only four animals are concerned. However Pálsson's (1953) findings which were based on linear measurements are confirmed in the present work where complete dissection and chemical analysis was carried out. Thus the present work also substantiates the usefulness of Pálsson's technique of studying changes in carcass composition.

On a percentage basis the picture is rather different. In both the dissection and chemical data the significance of differences dropped to the five per cent level for fat per cent. However differences in mean muscle percentage were highly significant. Muscle per cent increased and fat per cent decreased with lactation. The reason for this can be seen by comparing percentages with absolute weights. Fat weight decreased markedly with the lactational burden while muscle weight only decreased minutely. Thus lactation reduces the proportion of fat to muscle to such an extent that muscle per cent increases.

A similar situation exists with the chemical components. The increases in water and protein percentages are due to the proportionately greater decrease in fat weight over water and protein weights.

Table 13 shows an interesting situation that is hard to explain. Twin rearing ewes had the largest stomach and intestinal contents followed by ewes that reared singles, lost lamb ewes and dry ewes. The only explanations seem to be that either with increasing stress of pregnancy and lactation the ewes ate more, or that these results were obtained by chance.

CHAPTER V

GENERAL DISCUSSION

The results presented, while showing quite comprehensively the effect of pasture type on body composition, can produce very little evidence as to the reasons for the differences described. This is due mainly to the fact that the experiment was designed for a different purpose to that which we are applying the data. Consequently managemental practices and experimental procedures were directed at using the pastures and sheep to the best advantage for the goitrogen trial. The author was also under the disadvantage of coming into the experiment in November 1958 just before the animals were killed, and thus had only an indirect knowledge of the experimental design and management prior to this time.

The following three facts are indicated from the data:

(a) From Fig. 4, Appendix I, and Table 6 it is obvious that the differences appeared very early in the trial, and that the pattern was well established by the late spring 1957.

(b) There are two effects causing the pasture differences; a ryegrass effect and a clover effect. The clover effect seems to add a fairly constant amount to each of the ryegrasses effects.

(c) The differences are of large magnitude and therefore of great economic importance. This is seen in the difference in mean liveweight of 35.4 lb between P and S + C.

It is possible, drawing evidence from the present work and from the literature, to suggest a number of possible reasons for the differences in body composition caused by the various pasture types.

1. Grass Growth Rate.

Roberts (1931, 1932, 1935) and Davis and Bell (1957, 1958) showed differences in liveweight production from various grass-clover pastures. They found that these differences were due to carrying capacity which was largely a reflection of pasture growth. Corkill (1954) has shown that short rotation ryegrass produces greater growth over the winter to spring period than perennial ryegrass. Thus it is possible that the sheep on short rotation pastures in the present experiment had more grass to eat. However, over this period of the experiment grass shortage was not a problem and the sheep had if anything too much on all treatments.

2. Presence or Absence of Intrinsic Factors.

It is possible that the plant breeders in aiming at higher pasture production have inadvertently omitted some important chemical constituent vital to animal health. This type of situation existed in the selection for improved strains of ryegrass used in this trial, where perennial was later found to be high in iodine and short rotation low.

Nitrate factions in the pastures were analysed throughout the experiment at regular intervals to see if there was any relationship between them and any incidence of ill-thrift. Apart from a sudden increase in nitrate levels in September 1957 there were no differences due to pasture type (Butler 1959).

The beneficial effects of clover are not due to additional protein, because at the time of the year when differences became apparent protein is high in all four pasture types (Butler, 1960).

Another possibility lies in the field of mineral imbalances. Campbell (1960) analysed blood serum from sheep on the four pasture types for calcium, phosphorus, and magnesium. He found no differences in phosphorus and magnesium over the period he studied. However, overall calcium level did fluctuate, particularly in the late winter to early spring period of the second trial. At this time calcium level dropped and later the sheep, particularly those on short rotation plots, exhibited clinical symptoms of rickets. The rickets could have been due to either low "available calcium" or to the presence of a rachitogenic factor (probably anti-vitamin D in effect) in the quicker growing short rotation pastures (Grant and O'Hara, 1957).

It is possible to postulate the presence of a subclinical calcium deficiency over the whole experimental period. Thacker (1959) working on anion/cation balance in nutrition has found that the availability of calcium in the food to the animal depends to a large extent on the type of anion associated with the calcium ion. If the anion is organic in nature and is metabolized to carbon dioxide and water the calcium is likely to be more available than if it was attached to an inorganic ion such as sulphate or chloride. White clover contains twice as much calcium as ryegrass (Van Den Hende et al., 1954) and the sheep on the plots containing clover had higher mean serum levels of calcium than those on the pure ryegrass plots (Butler, 1960). Therefore it is possible that the clover has its effect through providing a good supply of available calcium to the animals.

3. Palatability.

It seems that no work has been done on the comparative palatabilities of perennial and short rotation ryegrasses. However it is possible to theorize on the basis of observation. Over the winter to spring period where the differences in liveweight first appeared, perennial ryegrass was observed to be in its most palatable condition (Brougham, 1960). It is generally held that later in the season perennial ryegrass can become very tough and unpalatable.

It was noticed in the present trial that the S pastures were markedly more rust resistant than the P over the autumn period. While it is thought that this would make the P more unpalatable there is evidence (Butler and Rae, 1957) that rust has no deleterious effect on the thrift of sheep.

Butler (1959) suggests that the pastures may be unpalatable to the animals due to the presence of irritating chemical constituents.

4. Digestability of the Pasture Types.

The weights of gastro-intestinal contents (Table 13) suggest this as a possibility. The P sheep had larger "fill" than the S sheep. This could mean that sheep on P have to consume more feed to get the same nutritive value as a smaller amount of S. Short rotation may be quickly digested and passed down the tract while P stays for a long time in the rumen. The work of Balch (1950) and Blaxter *et al.* (1956) on the rate of passage of food through the alimentary tract does not confirm this explanation. In fact it contradicts it by showing that the longer food remains in the tract the better it is digested.

Recent work by Tayler (1959) on Hereford cross-bred steers may help in clarifying the picture. The cattle were wintered on different planes of nutrition and then all of them put onto the same pasture in spring, where intake data were collected. Tayler found that both gastro-intestinal "fill" and daily intake of herbage were significantly and negatively correlated with the weight of internal fat. It was found that those cattle wintered on a low plane of nutrition had less internal fat and higher "fill" after a

TABLE 16

Incidence of Liver Lesions due to Facial Eczema

Perennial				Short Rotation				Perennial + White Clover				Short Rotation + White Clover			
Single	Twin	L.L.	Dry	Single	Twin	L.L.	Dry	Single	Twin	L.L.	Dry	Single	Twin	L.L.	Dry
38 ++	57 0	105 +	5 +++	40 0	35 ?	30 0	16 0	25 0	67 0	34 0	8 0	4 ?		42 0	52 0
44 ?	101 ++		28 +++	49 0		98 0	74 +	77 0			37 0	26 0			70 0
72 +++				55 0			75 0	82 0				78 0			
80 +				69 0				97 0				84 0			
89 +				118 0				114 0							
110 +++															
116 ?															

<u>Key</u>				
	+	Mildly affected	?	Questionable
	++	Badly affected	0	Not affected
	+++	Very badly affected		

spring grazing than those wintered on a high plane. Tayler suggests two possible reasons for this phenomenon: first, physical reduction of the size of the body cavity by internal fat depots, and secondly that the amount of internal fat is itself associated with a stage of physiological maturity which affects or controls appetite. The correlation between weight of internal fat (caul, gut and kidney) and "fill" was calculated for the present data and found to be -0.4823 SS. These results of Tayler are pertinent to the present work as the above correlation shows; however, they do not shed any light on the cause of the differences in liveweight. They only show that relationships between intake, "fill" and internal fat weight exist after the animals have been subjected to different planes of nutrition.

5. Facial Eczema.

The effects of facial eczema on the sheep are well known (McMeekan *et al.*, 1959). Referring to Fig. 4 we can see that facial eczema precautions were taken on the P and S sheep and that these precautions did materially affect their liveweight. However despite the precautions some of the sheep contracted the disease and two of these died. Table 16 shows the incidence of facial eczema in the sheep used for the present study. The method of determining infection was a subjective one and based on *post mortem* macro- and microscopic examination of the livers. Table 16 shows the individual sheep in their respective sub-classes with the sheep number indicated in the top left hand corner of each square. It can be seen that the highest incidence was in the P group where nearly all sheep were affected. Thus facial eczema could have affected the liveweight of the P group adversely.

Much evidence has been presented in this section and many possibilities have been suggested. However, the only way of finding satisfactory answers to these problems is to conduct a series of experiments in which all the above mentioned possibilities are taken into account.

CHAPTER VI

SUMMARY AND CONCLUSIONS

1. An experiment is described in which the effects of four different pasture types and four birthrank categories on the body composition of 39 Romney ewes were studied. The sheep were set-stocked on the four pasture types, comprising perennial and short rotation ryegrasses with and without white clover, from 10 May 1957 when they were lambs, until 16 December 1958 by which time they had gone through a complete reproductive cycle.

2. All internal organs were weighed at slaughter. Later in the Meat Laboratory the frozen carcasses were split down the backline with a meat bandsaw. After this the right sides were chemically analysed using the method of Barton and Kirton (1956), then the left sides were dissected after the method of Pálsson (1939). Chemical and dissection data were statistically analysed by the method of fitting constants by least squares. Means were then compared and tested by analysis of variance to determine the effects of pasture type and birthrank on body composition.

3. There were marked differences in mean final liveweight between the animals on the four pasture types. However, from the data available it was not possible to determine whether the differences were caused by pasture type. All that could

be said in that the animals were exposed to four different planes of nutrition and that it was likely that these were caused by pasture type. However for convenience the plane of nutrition effects were named P, S, P + C and S + C.

Mean liveweights ranked in the following order: $P < P + C < S < S + C$. Most of the components of body composition also followed this order.

Three general facts emerged from these data:

(1) The differences appeared very early in the trial and the pattern was established by late spring 1957.

(2) There is evidence that there were two effects causing the pasture type differences; a ryegrass effect and superimposed on this, a clover effect.

(3) The differences were of sufficient magnitude to be of economic importance.

4. The components of body composition were also affected in a definite pattern by birthrank. Twin rearing ewes lost the most weight followed by ewes rearing single lambs. Lost lamb and dry ewes were very similar and not affected much. However the only component affected significantly was fat. It appeared that lactational stress could materially affect the body composition of the ewe.

5. An analysis of dissectible weight components on a fat-free basis showed that the four planes of nutrition studied caused statistically significant differences between fat-free carcass weight and all its components except tendon plus waste

per cent.

6. Possible reasons for the pasture type differences are discussed.

7. It is concluded that in order to obtain satisfactory explanations of the problems brought out in this work it would be necessary to conduct a series of trials taking into account the following points:

(1) The addition of a pure stand of white clover to the pasture types.

(2) Division of the experimental period into seasons. It is quite possible that pasture effects on liveweight were caused by different things in different seasons.

(3) Pasture growth data must be obtained. This should if possible, measure the type of pasture the animals are actually eating.

(4) Comprehensive chemical analysis of the pasture at regular intervals within the seasons is required.

(5) Animal behaviour studies would be of interest. They may tie in with (3) above in helping to determine precisely what the animals are eating.

(6) Intake work would provide data on how much the animals ate and how digestible it was.

(7) The management of the pasture and animals would have to be as uniform as possible.

PART II

STUDIES ON THREE METHODS OF ESTIMATING THE COMPOSITION OF ANIMALS

CHAPTER I

INTRODUCTION

One of the great problems handicapping animal husbandry and nutrition workers is that of quickly and accurately determining the composition of the live animal and/or its carcass. It is not sufficient in such studies to use liveweight gain or loss as the criterion for evaluating a nutritional regimen. It is essential to know the composition of the gain or loss. The ideal method of doing this would be one which estimated the composition of the live animal. However, failing this, a comparative slaughter technique involving adequate numbers of animals would be sufficient. Many methods of estimating composition have been tried and although several of these are reasonably good for a large population, none has been found sufficiently accurate on an individual basis. In the present work three recent methods have been used: the "Lean-meter" on the live animal, specific gravity (S.G.) and a new chemical analysis on the carcass.

It seemed, until recently, that the only way to obtain a critical appraisal of animal composition was by either complete dissection or by one of the standard methods of chemical analysis. Both methods are tedious, costly and time consuming, and thus workers may have been deterred from conducting body composition analyses. However by use of a recently devised technique (Barton and Kirton, 1956) it has become possible to estimate quickly and accurately the chemical composition of a carcass. In the present study the right side of each carcass was chemically analysed using this technique while the left side was divided into four tissues: fat, muscle, bone and tendon plus waste, using the method of Pálsson (1939). This provided an opportunity to assess the accuracy of estimating the anatomical composition of the left side from the chemical composition of the right side. There are, of course, occasions where dissection is necessary, e.g., studies of the partition of fat to the various fat depots. However, any method which would remove the necessity of tedious dissection and still allow dissectible components to be estimated accurately would contribute materially to progress in this field.

In addition to the above, the "Lean-meter", an electronic probing device, was used to determine the fat content of live sheep by measuring the depth of subcutaneous fat along the backline.

Carcass specific gravity determinations were also carried out in order to re-evaluate this technique in the estimation of the carcass composition of sheep.

CHAPTER II

REVIEW OF LITERATURE

1. CHEMICAL ANALYSIS OF MEAT

Chemical analysis in meat work usually involves the determination of water, fat, protein and mineral (ash). These components account for all but one to two per cent of meat. The composition of this small remainder is very complex and Bate-Smith (1942) has named over 50 substances. Although many workers have analysed meat into its four major components, most have used different methods and very few of them have described their methods in detail. This is well illustrated by Hall (1951) who summarizes the returns from questionnaires sent to meat workers in U.S.A. Very few used the same method. The most popular one was the A.O.A.C. (1955) method. The disadvantage of the methods described by A.O.A.C. (1955), Callow (1947), Hall (1953), Kelley *et al.* (1953) and Venn *et al.* (1947) is that they are tedious and very slow. Because of this the time involved using these methods to analyse carcasses in a big experiment is prohibitive.

Benne *et al.* (1956) are aware of the problems involved and give details of the methods used in their laboratory. They are particularly concerned about sampling procedures and give results of duplicate analyses which show that their samples were homogeneous.

Everson et al. (1955a, 1955b, 1956) were concerned with evolving rapid methods of boneless meat analysis. They were working on developing efficient plant-control methods for the meat by-products industry. Their methods, using capryl alcohol distillation for water, and an electrical capacitance measurement of fat which had been extracted with o-dichlorobenzene, take only 30 minutes. They found that unskilled operators could get results within three per cent of standard laboratory techniques.

The problem of obtaining a homogeneous sample of a carcass has also been investigated by Barton and Kirton (1956). They evolved a technique whereby the frozen carcass is cut with a meat bandsaw into quarter inch slices. These slices were then minced several times to obtain some degree of homogeneity. Samples of this mince were then chemically analysed using a modification of the method of Barnicoat and Shorland (1952). Details of the method have been given in Part I of this thesis. This method while not as fast as that of Everson et al. is much quicker than the others mentioned above. Kirton et al. (1960) have checked the efficiency of their chemical method on 20 lamb carcasses. These carcasses were split down the backline and both sides were analysed. Although no weight differences were found between the two sides, there were differences in the weight of loin and "fore" between sides. It was thought that these differences may have been due to cutting errors. Similar differences between sides have been found by Butler et al. (1956), Lasley and Kline (1957), and Harrington and Pomeroy (1959). The last of these authors claimed that their differences could not be explained as cutting errors and they suggested developmental differences between the left and right sides of their animals. Kirton <u>et al</u>. (1960) also showed that the individual compositions of the various joints compared on both sides except for the case of protein in the loin. Left side loins were significantly higher than right side loins. Butler <u>et al</u>. (1956) found that the eye muscle area of the left loin was higher in the beef carcasses studied by them. So it appears that there may be developmental differences between sides.

An analysis of the sampling errors by Kirton <u>et al</u>. (1960) showed that the variance of a treatment mean was decreased only slightly by increasing the number of samples per side or by sampling both sides instead of one. It would thus be possible to get an accurate estimate of composition taking only one sample. However, the authors suggest that at least two samples should be taken to eliminate any gross errors. They also found that the only way to substantially increase precision was to increase the number of carcasses per treatment. It seems therefore that the chemical method of Barton and Kirton (1956) will give very repeatable estimates of the chemical composition of a meat sample. At present the accuracy of ash determination is doubtful. Kirton <u>et al</u>. (1960) could not examine this component critically and it is thought that the chemical method might not determine ash as efficiently as other components.

2. RELATIONSHIPS BETWEEN CHEMICAL AND DISSECTIBLE COMPOSITION

Although many authors such as Trowbridge et al. (1918), Chatfield (1926), Lush (1926), Hopper (1944), Hankins and Ellis (1945), Callow (1947, 1948), Hankins (1947), Hankins and Howe (1946), Kirton (1957) and Barton and Kirton (1958b), present chemical and dissectible data for many species; as far as can be ascertained only a few work out relationships between chemical and dissectible components. The others are concerned more with part-whole relationships, i.e., estimating a chemical or dissectible component in the whole carcass from the same component in one or more of the joints or cuts. Many others give details of either chemical or dissectible composition.

Chatfield (1926) in a statistical treatment of data compiled at several research stations found that the chemical composition of particular wholesale or retail beef cuts could be estimated with reasonable accuracy from a dissection of of the cut into lean, fat and bone.

In a particularly thorough investigation into methods of estimating the physical and chemical composition of cattle, Hopper (1944) studied the relationships between physical and chemical constituents of various joints for fatness. He obtained a correlation of 0.994 between dissectible and chemical fat in the carcass. The correlation between the same components for the 9 - 11 rib cut was 0.992. Hankins and Howe (1946) found the correlation for the 9 - 11 rib cut was 0.96 for beef carcasses. Callow (1948) combined data for a number of species and found a correlation between dissectible and chemical fat in the carcass of only 0.872. However he found some indication of species differences which may explain this low correlation.

Correlations of 0.9056 and 0.9162 were found by Kirton (1957) between the percentage of dissectible fat in the 9 - 11 rib cut, and side and rib percentages of chemical fat respectively.

Only two sets of workers present relationships between muscle and protein. Hankins and Howe (1946) found a correlation of 0.82 between the separable lean of the 9 - 11 rib cut and the protein of the dressed carcass, while Kirton (1957) found a correlation of 0.5865 between the weights of muscle and protein in the 9 - 11 rib cut.

Hopper (1944) appears to be the only worker giving the relationship between bone and ash in the carcass. In this case the correlation was 0.678.

Shorland et al. (1947) conducted a regression analysis of the composition of New Zealand lamb and mutton. They give the following correlations between percentage chemical and percentage dissectible fat (calculated on a bone- and tendon-free basis): Total carcass r = 0.969; neck r = 0.888; shoulders r = 0.969; thorax r = 0.932; loin r = 0.980; legs r = 0.938; pelvis r = 0.960. These workers suggest that the chemical composition of the bone- and tendon-free carcass or joint could be used to estimate the corresponding physical characteristics but they make no attempt to give relationships.

It can be seen from the above that the literature on relationships between physical and chemical composition is scant. The present study attempts to rectify the position as regards the sheep.

3. ESTIMATION OF BODY COMPOSITION FROM SUBCUTANEOUS FAT THICKNESS

(1) Carcass Measurements.

It has long been realized that subcutaneous fat is one of the later developing fat depots and is thus liable to considerable fluctuation due to such factors as age and nutrition. The depth of back fat as measured at the cut sufaces of various commercial cuts has been used for many years as an indicator of fatness. Hankins and Ellis (1934) measured back fat thickness at five places on the split carcass of pigs and obtained a correlation of 0.84 between average back fat thickness and the percentage of ether extractable fat. In a later paper (Ellis and Hankins, 1937) these workers showed that the shoulder back fat depth had the lowest relationship with the average of the five measuring sites (seventh rib, shoulder, mid back, loin and ham). Hirzel (1939) analysed measurements taken over a number of years on mutton and beef carcasses at the

Smithfield show. He used back fat thickness as an indication of fatness. Pálsson (1939) presented a system of measurements which have been used a great deal since in carcass composition studies. Working with sheep he found that most of his fat measurements made on the cut surface of the cross-section at the level of the last rib were significantly correlated with total fat. McMeekan (1939) used similar subcutaneous fat measurements taken from the surfaces of both the split carcass and the cross-section at the level of the last rib. He found that average back fat thickness was highly correlated with total fat (r = 0.96). The rump site was the best and the shoulder the worst. Fat measurements at the loin cross-section were also highly correlated with total fat. He found that measurement C (fat depth over the dorsal edge of the eye muscle) had a correlation of 0.97 with total fat. Similar measurements to these were used by Underwood and Shier (1942), Walker and McMeekan (1944), Clarke and McMeekan (1952), Pálsson and Vergés (1952), Clarke et al. (1953) and Pálsson (1953) in their work on carcass composition.

Since this early work many investigators have included back fat measurements as a standard procedure of estimating fat during studies on carcass characteristics. Brown et al. (1951) found a highly significant negative correlation between S.G. and average back fat thickness in the pig. Aunan and Winters (1949) working on 30 swine carcasses showed a correlation of 0.79 between average back fat thickness and fat content. In a later trial Aunan and Winters (1952) used a coring device to estimate subcutaneous fat and thus total fat. However the results obtained were no better than those using back fat thickness. Kraybill et al. (1953) investigated the accuracy of back fat measurements for estimating the body fat content of swine. Back fat thickness was found to be well correlated with the percentage body fat ($r = 0.811$) and with the percentage water ($r = -0.856$) Whiteman et al. (1953) discovered that back fat thickness was not as good as S.G. for estimating various measures of pork carcass leanness. Whiteman and Whatley (1953) found that the area of the loin eye muscle was reasonably well correlated with back fat thickness.

The depth of back fat has also been used in many performance testing and carcass judging systems. In Great Britain the system of commercial grading of bacon pigs included back fat thickness measurements (Harrington, 1958). McMeekan and Walker (1950) and Woodward et al. (1954) include back fat measurements in their schemes for beef cattle while McMeekan et al. (1944) include it in a grading scheme for pigs. McMeekan (1939) gives the Cambridge block test for fat lambs.

A general criticism that may be levelled at this work is that no systematic study has been made to see if there is some area of the body where the depth of subcutaneous fat is more highly related to total fat than that along the backline. Up to the present time work has been concentrated on measuring the depth of subcutaneous fat at surfaces cut during normal commercial practice.

(2) Probes on the Live Animal.

The work described above shows that a good relationship exists between carcass back fat thickness and total carcass fat. Hazel and Kline (1952) used this relationship to estimate the fat content of the live animal by use of a "live probe". This consisted of making a small cut at the selected site and inserting a small metal rule until the underlying muscle layer was encountered. The depth of penetration was then noted. The method is quick and easy to apply and caused little discomfort to the pigs. The average of four sites on the back gave a correlation of 0.81 with the average of four back fat measurements on the carcass. It must be noted that the carcass measurements were not taken at the probe sites. The live probes were more accurate indicators of leanness and percentage primal cuts than were the carcass measurements of back fat thickness. Harrington (1958) says:

> Since this first report, American studies have been directed mainly towards establishing the relative accuracy of measurements made by probing live pigs at various body sites in predicting carcass back fat thickness and certain other measures of carcass value.

This statement sums up the situation. These studies may be detailed as follows. Hazel and Kline (1953) tested eight probe sites as measures of leanness and fatness and concluded that the best were shoulder, loin and top of the ham. De Pape and Whatley (1954) tested combinations of probe sites and concluded that a combination of probes behind the shoulder and over the loin on both sides of the animal was the most useful of those studied.

A correlation of 0.69 between the average of three probe sites and carcass back fat thickness was found by De Pape and Whatley (1956). Lasley et al. (1956) obtained a correlation of -0.57 between back fat probe and percentage lean cuts. Hetzer et al. (1956) found a correlation of 0.72 between average depth back fat and average probe depth for three sites. Price et al. (1957) found that S.G. gave a better indication of the chemical composition of the ham than did the live probe. Holland and Hazel (1958) compared probes with other live animal measurements and carcass measures. Pearson et al. (1958) found that most supplementary measures of leanness were related to live probes. In a series of papers Zobrisky et al. (1959a, 1959b, 1959c) found a good negative correlation between probe at a hip site and the four lean cuts (ham, loin, picnic, and Boston butt). They also obtained a correlation of 0.61 between average live probe and fat yield (total carcass trim fat plus leaf fat).

It seems from the above work that the live probe is quite highly related to back fat thickness measurements and that these are well related to total fatness. High negative correlations are obtained between probes on the live animal and measures of leanness.

(3) The Lean-meter.

Banfield and Callow (1935) showed that the electrical resistances of muscle and fat differ markedly. They used an electrical probing device which made use of this principle in determining the back fat thickness of unsplit carcasses. More recently this principle has been used by Andrews and Whaley (1954) who developed an instrument which is available commercially known as the "Lean-meter" for use in determining the back fat thickness of live animals. They made Lean-meter and carcass measurements on 200 pigs using three probe sites: first rib, last rib and last lumbar vertebra. Two measurements were made at each site, one on either side of the midline. The correlations of average back fat thickness of the live animal and chemical components of the carcass were 0.585 for per cent fat, -0.075 for per cent protein, and -0.593 for per cent moisture.

Berg and Bowland (1956) compared the average of three Lean-meter measurements with the average of three back fat measurements and found a correlation of 0.80.

Pearson et al. (1957) compared the live probe and Lean-meter for predicting various carcass measurements on 99 swine. They obtained a correlation between live probe and Lean-meter of 0.78. The methods were found equally accurate for measuring back fat, with correlations of 0.70 and 0.71 for the live probe and Lean-meter respectively. They also found that the live probe was the better indicator of leanness.

Walker - Love et al. (1958a) used the Lean-meter on 72 split bacon carcasses. They found no statistical differences between Lean-meter and carcass back fat measurements. However the Lean-meter over estimated slightly the depth of fat. These workers (Walker - Love et al., 1958b) also used the Lean-meter on live pigs. They compared Lean-meter readings taken at the same site on the live animal and on the carcass. The carcass readings were six to eight m.m. higher than those on the live pig. Readings taken at the loin site were more repeatable than those at the shoulder site.

All the work described so far has been conducted on pigs. The only account in the literature of the use of the Lean-meter on ruminants is that of Temple et al. (1956). These workers attempted to estimate fat thickness in live cattle. The Lean-meter was used on 11 live animals but due to the effort involved, the lack of variability between readings, and the haemorrhage caused by the needle, it was not continued. The correlation between Lean-meter estimate of fat thickness and carcass fat thickness was -0.16. However, when used on 25 steer carcasses, the correlation between Lean-meter measurement and caliper measurement was 0.87.

It seems that while the Lean-meter gives a reasonably accurate estimate of the back fat thickness of live pigs, its value on other animals has yet to be determined.

(4) Other Measures.

(a) X-ray Measurements. Keys and Brožek (1953) review the literature on the measurement of subcutaneous fat with X-rays for humans.

Harrington (1958) has reviewed the literature dealing with the estimation of body fatness and bone content in domestic animals using X-rays. He concludes that it is difficult to measure the subcutaneous fat of domestic animals with X-rays because it is necessary to take slightly under-exposed photographs. When full exposure time is used the respiratory movements of the animal blur the photograph.

(b) Ultrasonic Measurements. Wild and Reid (1952) first proposed the use of echo-ranging techniques for determining the structure of biological tissues. They were interested mainly in detecting cancerous growths. Howry and Bliss (1952) also used ultrasonic means to visualize the soft tissue structures of the body in humans. They were also interested in medical applications. Temple et al. (1956) appear to be the first workers to use an ultrasonic device on domestic animals when they attempted to measure the back fat thickness of cattle. They obtained a correlation of 0.63 between the ultrasonic measurement and actual fat thickness. Dumont (1957) used the method to measure the back fat of pigs and obtained good agreement with carcass back fat measurements. Since this work, many investigators have used the method in studying various aspects of body composition (Claus, 1957; Kliesch et al., 1957; Lauprecht et al., 1957; East et al., 1959; Stouffer et al., 1959; Hazel and Kline, 1959; Campbell et al., 1959). The method appears to be most promising.

4. SPECIFIC GRAVITY

(1) The Constancy of the Fat-Free Mass.

The use of specific gravity (S.G.) in the prediction of carcass and/or body composition is based on the concept of a fat-free mass of constant composition, and hence constant density, and a variable amount of fat. Fat has a lower density than the fat-free mass (Keys and Brožek, 1953) and so the larger the amount of fat present the lower will be the density of a carcass. Therefore some relation should be expected between the level of fatness of an individual and its density, or, at any given temperature, its specific gravity. The specific gravity of a substance being the ratio of its density to the density of water at a given temperature. Fidanza et al. (1953) present data giving the fat density of many mammalian species.

Ever since a relative constancy of composition of the mature fat-free mass was demonstrated by Murray (1922) and Moulton (1923) much work has been devoted to enlarging and checking the concept. Behnke (1941-42) and Behnke et al. (1942) working with humans introduced the idea of a "lean body mass" of constant composition and density. This concept is not the same as the fat-free body because the lean body mass was assumed to contain 10 per cent of its weight as "essential lipids". Later Behnke (1953) amended this to approximately two per cent "essential lipids". Although Behnke was a pioneer in the use of S.G. for determining body composition his idea has confused the issue and some workers (Rathbun and Pace, 1945; Kraybill _et al._, 1952) do not distinguish between fat-free mass and lean body mass.

A large body of literature has accumulated on the constancy of the fat-free composition of many species. Thus Pace and Rathbun (1945), Callow (1947), Pitts (1951), and Babineau and Pagé (1955) support the concept of constancy in guinea pigs, sheep, cattle, pigs, humans and rats. Against this, many workers have produced evidence showing that due to various causes the fat-free composition is not constant after maturity. Chatfield (1926) stated that the composition of fat-free beef is variable. Spray and Widdowson (1950) present data on the changes in the chemical components of the fat-free bodies of many species with age. Hopper (1944), Reid _et al._ (1955) and Kirton _et al._ (1959_a_) have shown that water per cent decreases and protein per cent increases with age in cattle, pigs and sheep on a fat-free basis. Keys and Brožek (1953) state that the fat-free composition of the body is not independent of the amount of fat in it. They found that fat and water are correlated in the body and tend to change together. As fatty tissue is increased so too is a certain amount of water, protein and mineral. So the proportion of the fat-free mass represented by water is neither absolutely constant nor is it independent of the total body weight or its fat content. At low levels of fatness increased hydration has been noted in sheep by Mitchell et al. (1928b) and Kirton et al. (1959a), and in the pig by Clawson et al. (1955).

Thus it can be seen that the composition of the fat-free mass is not constant in the mature animal and therefore its density is also not constant. It is clear from the above that any analysis based on the concept of a theoretically constant fat-free mass is an oversimplification which could lead to error.

(2) Specific Gravity as a Measure of Carcass Composition.

Specific gravity determines primarily the proportion of fat in a carcass. Its big advantage over other methods is that it does not involve destroying any part of the carcass.

The initial work in this field was done using humans and small laboratory animals. Behnke (1941-42) pioneered the subject with his concept of lean body mass. This work was followed by the papers of Rathbun and Pace (1945), and Pace and Rathbun (1945) on the S.G. of guinea pigs. Along with Da Costa and Clayton (1950) they found that the relation between fatness and S.G. was close enough for predictive purposes. Da Costa and Clayton (1950) with rats established an inverse relationship between carcass fat per cent and water per cent, and a direct relationship between water per cent and S.G. Morales *et al.* (1945), by means of theoretical investigations showed that the relationship between S.G. and fat per cent is hyperbolic. Therefore a linear relationship is to be expected between fat per cent and $\frac{1}{\text{S.G.}}$ Kirton and Barton (1958*b*), using sheep, found that this was so and also found that the relationship between S.G. and fat per cent was curvilinear but that it curved in the opposite direction to the theoretical curve of Morales *et al.* (1945). No possible reasons are forwarded by them for this.

Since 1950 much work has been done in establishing relationships between S.G. and various measures of carcass composition and the formulation of prediction equations. Brown *et al.* (1951) using the pig found correlations between S.G. and area of loin eye, per cent primal cuts and per cent lean cuts that were positive and highly significant. Highly significant negative correlations were found between S.G. and average back fat thickness, per cent fat cuts, and chilled carcass weight. They concluded that S.G. could be used to estimate carcass fatness just as accurately as those methods involving the cutting of the carcass. S.G. was found to be almost as good as chemical analysis for estimating fatness. Kraybill *et al.* (1951) found a good relationship in cattle between carcass fat per cent (as estimated from the 9 - 11 rib cut by chemical analysis and physical separation) and fat per cent as determined from S.G. Kraybill et al. (1952) using cattle found an inverse relationship between body fat and body S.G. whereas there was a direct relationship between body water and body S.G. They obtained a correlation of 0.989 between the S.G. of the carcass and the S.G. of the whole body. Whiteman et al. (1953) found that S.G. was more closely associated with several measures of carcass leanness than was back fat thickness in the pig. Whiteman and Whatley (1953) found the area of the loin eye muscle to be significantly correlated with S.G. in the pig. A good relation between the separable fat of the 9 - 11 rib cut and S.G. was found by Lofgreen and Garrett (1954) using Hereford steers. De Pape and Whatley (1954) compared live hog probes at various sites with S.G. Stouffer (1955) using 16 lambs obtained a correlation of -0.622 between S.G. and the ether extract of the boneless meat of the right side. This seems to be the first work on sheep with S.G. appearing in the literature. Fredeen et al. (1955) found that S.G. was not as good an indicator of ham quality in pigs as the percentage area of the lean at the surface where the ham is cut off the body. Clawson et al. (1955) found that the correlation between S.G. and water per cent in the pig carcass ($r = 0.89$) was higher than the same correlation for the whole empty body ($r = 0.63$). Good correlations between $\frac{1}{S.G.}$ and various measures of fatness in the carcass and in sample joints of the sheep were found by Barton and Kirton (1956). Pearson et al. (1956) obtained high correlations between total carcass S.G. and the S.G's. of the ham (r = 0.94), the loin (r = 0.96) and the shoulder (r = 0.92). The S.G. of the ham or whole carcass proved superior to back fat as a measure of leanness. However, the authors noticed that carcass length and back fat thickness were found to be superior to S.G. on the leaner carcasses. This observation is important because other workers (Kelly et al., 1959) have found that S.G. is not reliable in carcasses of low fat content. Price et al. (1957) also found that carcass S.G. was a very good estimator of leanness. Kirton and Barton (1958b) present correlations and regression equations between S.G. and fatness for the 9-11 rib cut, the loin, and the leg of sheep. Pearson et al. (1958) found that S.G. was probably the best indicator of leanness in pigs. A diversion from the above applications of S.G. is made by Orme et al. (1958) who use it to estimate marbling in the eye muscle of the 9-11 rib cut in beef. A correlation of -0.81 was obtained and the authors conclude that S.G. is a useful objective measure of marbling. Garrett et al. (1959) used S.G. extensively as an indicator of carcass composition both in beef cattle and in sheep. They obtained a correlation of -0.90 between carcass S.G. and carcass fat per cent in the sheep. This compares with the correlation of -0.8417 obtained by Kirton (1957).

Certain general points emerge from the literature cited. First, S.G. determinations have been carried out on most domestic animals but particularly on the pig. Secondly, S.G. seems to be a very good measure of leanness as well as fatness. Most of this work has been conducted in America on pigs and in many cases S.G. has been found a better indicator of the leanness of the various commercial cuts than several measures of leanness. Thirdly, most of the relationships between S.G. and fatness are high but there are indications that S.G. might not have a good relationship with fat over the entire range of fatness found in animal bodies. Several workers have found that at low levels of fatness the results are variable. Keys and Brŏzek (1953) present evidence which indicates that body composition is abnormal at low levels of fatness -

> ....with decreasing fatness more and more cellular matter is lost and this is replaced or filled in by extracellular fluid.

This agrees with the increased hydration of the fat-free mass at low levels of fatness found by Mitchell et al. (1928b), Clawson et al. (1955) and Kirton et al. (1959a).

Throughout the literature various workers have given possible factors that could lead to errors in S.G. determinations. Below are listed some of the main ones extracted from Whiteman et al. (1953), Keys and Brŏzek (1953), Walters (1953) and Kirton (1957):

(a) Water temperature variations within 20°F are of no particular consequence but beyond this range they could lead to errors.

(b) The weight of the carcass or body in water must be read as quickly as possible. This is related to the volume of the carcass, especially if the water and carcass are at different temperatures. The S.G. of a carcass is lessened the longer it is left in water. This is all part of the problem concerning the effect of temperature on the carcass, Kline et al. (1955) conducted a trial on this problem. S.Gs. of the carcasses determined after 0, 24, 48 and 72 hours of chilling ~~and the S.Gs.~~ were 0.9965, 1.0214, 1.0249, and 1.0276 respectively. Correlations between fatness and S.G. changed significantly with time of chilling. This points to the necessity for making S.G. determinations after a uniform chilling time.

(c) S.G. has been noticed to decrease with storage. Explanations that have been given for this are first that gas develops in the carcass as it ages, and secondly that shrinkage causes a reduction in volume.

(d) Differences in water purity can markedly affect results if the density of the water is altered.

(e) The validity of the assumption of constancy of composition of the fat-free mass is under doubt. The composition has been shown to change with age, degree of fatness and body weight.

CHAPTER III

MATERIALS AND METHODS

1. A COMPARISON OF CHEMICAL AND DISSECTION ANALYSES

Chemical and dissection methods were described in detail in Part I and so will not be repeated here. Data obtained from the sheep described in Part I were suitable for examining relationships between the chemical and dissectible components of the carcass. These relationships were examined between corresponding joints on either side of the carcass. This was done on a bandsaw joint basis so it was necessary to bulk dissection data for the neck, shoulder and thorax to make up the "rest", and also for the anatomical leg and pelvis to make up the bandsaw leg (see Fig. 3). The relationships between chemical and dissection components within these joints were evaluated using a simple regression and correlation analysis.

2. A COMPARISON OF TWO METHODS OF ESTIMATING PROTEIN

In the chemical analysis described by Barton and Kirton (1956) protein is estimated by difference. Therefore an effort was made here to determine how closely this method agrees with the standard Kjeldahl analysis. Duplicate samples were taken for this purpose from the crude residues of each side sample. A factor of 6.25 was used to convert the nitrogen per cent as determined by Kjeldahl, to protein per cent. This is standard procedure although Bate-Smith (1942) claims that a factor of 5.6 should be used for meat.

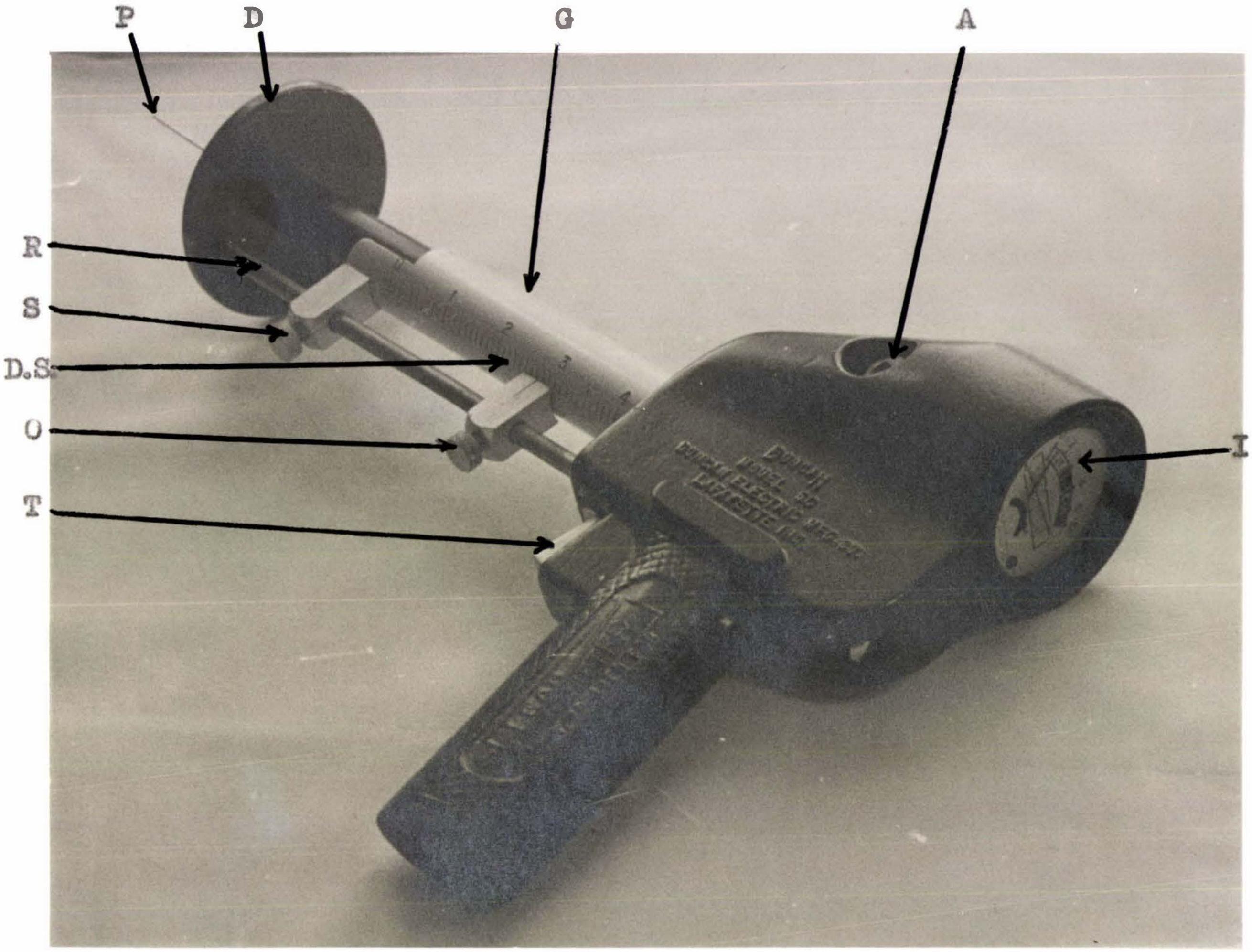
3. LEAN-METER MEASUREMENTS

The Lean-meter is an electronic probing device manufactured commercially by the Duncan Electric Manufacturing Company, Lafayette, Indiana (See Fig. 5). It operates on the principle of difference in electrical conductivity between fat and muscle; fat is a relatively poor conductor while muscle and blood are good conductors. The probe on the instrument consists of a fine central element which is insulated from an outer sleeve. These electrodes are connected to an indicator with a scale graded from fat to lean. Flashlight batteries provide electrical power. When readings are being taken the disc is placed on the animals back and pressure is applied with the trigger being squeezed until the indicator flicks over showing that the tip of the probe has contacted muscle. The trigger is then released thereby clamping the probe in this position, and the instrument withdrawn. The depth of probe can then be read off the guide tube scale.

In the present work all Lean-meter measurements were taken on the morning of the day of slaughter. A difficulty in this type of work is the problem of accurately locating the site for probing. In the present study three sites

FIG. 5

THE LEAN-METER



Key

D.S. = Direct Scale
O = Scale Pointer
G = Guide Tube
D = Disc
P = Probe
A = Indicator Adjustment
I = Indicator
R = Rod
S = Rod Support
T = Trigger

were chosen: loin, shoulder and rump. All measurements were taken two inches away from the midline on the left side of each animal. The loin measurement was taken at the level of the last rib and because this position is easy to identify it was used as a reference point. The shoulder site was 15 cm. anterior and the rump 25 cm. posterior to the loin site. Once the sites for probing had been established the wool was removed to the skin for an area of approximately two inches radius to each site. Observer A then made a probe at each site while Observer B restrained the animal. The observers then changed positions and repeat probings were carried out. The sheep did not require much restraining. It was noticed that they objected most when the skin was broken with the probe. In an effort to reduce pain to the animal the probe was pre-set at about a quarter of an inch. The probe was pushed through the skin with a quick jab, then the trigger was released and the depth of fat determined. This procedure caused the animal little discomfort and made the probing much easier and quicker.

At the time of jointing of the carcass in the Meat Laboratory the depth of subcutaneous fat at each probe site was measured. In most cases identification of sites was easy because of the presence of small bruises caused by the Lean-meter probe. However, when these were not present the last rib was used as a reference point and the other sites located from it. At each site the subcutaneous fat was cut away down to the underlying muscle and the depth of fat measured with calipers.

4. SPECIFIC GRAVITY

On the morning following slaughter the cold carcasses were weighed first in air and then when immersed in water. Water and carcass temperatures were recorded. Specific gravity was calculated from the following equation:

$$\text{S.G.} = \frac{\text{Wt. in Air}}{\text{Wt. in Air} - \text{Wt. in Water}}$$

CHAPTER IV

RESULTS

1. A COMPARISON OF CHEMICAL AND DISSECTION ANALYSES

(1) Whole Carcass

The carcasses had a mean weight of 62.2 lb (range 25.8 - 92.0 lb). Means, standard deviations and ranges of the chemical and dissectible components of the carcass are presented in Tables 17 and 18 respectively. Table 19 sets out the correlation coefficients, and regression equations with their standard errors of estimate, for some variables. In all cases the independent variate is the chemical component.

TABLE 17

Chemical Components of the Carcass. Means, Standard Deviations and Ranges (lb)

Item	Number	Mean	S.D.	Range
Fat	39	27.22	10.38	5.5 - 45.4
Water	39	25.36	4.11	14.8 - 34.2
Protein	39	7.39	1.30	4.1 - 9.9
Ash	39	2.23	0.50	1.3 - 3.3

TABLE 18

Dissectible Components of the Carcass. Means, Standard Deviations and Ranges (lb)

Item	Number	Mean	S.D.	Range
Fat	39	27.63	10.83	4.9 - 46.6
Muscle	39	26.10	4.42	14.9 - 36.2
Bone	39	5.76	0.77	4.0 - 7.8
Tendon + Waste	39	1.81	0.01	1.3 - 2.4

TABLE 19

Relationships Between Chemical and Dissectible Components

Dependent Variate	Independent Variate	No. of Pairs	Correlation Coefficient	Regression Equation	$S_{y.x}$
Fat Wt. (Dissectible)	Fat Wt. (Chemical)	39	0.9964**	$Y = 1.04X - 0.68$	0.93
Muscle Wt.	Protein Wt.	39	0.9655**	$Y = 3.29X + 1.79$	1.17
Muscle Wt.	Water Wt.	39	0.9694**	$Y = 1.04X - 0.27$	1.10
Bone Wt.	Ash Wt.	39	0.7243**	$Y = 1.11X + 3.28$	0.54
Bone Wt.	Fat Wt. (Chemical)	39	0.5776**	$Y = 0.04X + 4.67$	0.64
Bone Wt.	Water Wt.	39	0.8376**	$Y = 0.16X + 1.70$	0.43
Bone Wt.	Protein Wt.	39	0.8370**	$Y = 0.49X - 2.14$	0.43

The most variable component in the carcass is fat weight. This applies to both chemical and dissectible fat. Indeed these two components are very similar with respect to the statistics presented in Tables 17 and 18. Dissectible and chemical fat weights are highly correlated and the regression equation has a low standard error of estimate.

Muscle weight is well correlated with water and with protein weights. However the correlation with water is higher and its regression equation has a lower standard error of estimate. A possible reason for this high correlation may be seen in Tables 17 and 18 where water and muscle have very similar means, standard deviations, and ranges. Also, water comprises approximately 70 per cent of muscle (Ulyatt, unpublished data) and so a high relationship between the two is to be expected.

The high correlation between muscle and protein weights can also be explained on a part-whole basis, for nearly all the protein in the animal body occurs in the muscle.

None of the chemical components gives a really good estimate of bone weight. In all cases the correlations are low and the standard errors of estimate of the regression equations high. It was hoped that there might be a large correlation between ash and bone weights on the grounds that most of the mineral matter in the ash comes from bone. However, the relationship was not satisfactory.

A possible reason for this is a lack of homogeneity, with respect to bone, of the mince samples taken for chemical analysis. It was thought that as bones contain large amounts of fat, bone weight might be highly correlated with fat weight. However this was not the case. The components best related to bone weight were protein and water weights. Reasons for this are obscure; however it is possible that the explanation of these high relationships may be that muscle, which is composed mainly of protein and water, varies in a similar manner to bone on the different planes of nutrition present in this trial.

The fourth dissectible component of the carcass, tendon plus waste, poses a problem as it is subject to much variation between dissectors. Correlations between tendon plus waste and fat weight ($r = 0.4000^{*}$), muscle weight ($r = 0.5025^{**}$) and bone weight ($r = 0.6844^{**}$) were obtained. These relationships, although statistically significant, are not high enough for purposes of prediction. On this evidence it was thought that if any high relationships were established between chemical components and tendon plus waste, they would be purely fortuitous and of little predictive value.

(2) Leg.

Leg weight had a mean value of 8.53 lb and a range of 4.00 to 11.82 lb. Means, standard deviations and ranges of the chemical and dissectible components of the leg are detailed in Tables 20 and 21. On a joint basis, with one exception, only those relationships which were high on a carcass basis were used. The exception was the relationship between ash and bone. It was decided that although none of the correlations of chemical components with bone weight was high, an attempt should be made to estimate bone on a joint basis. Ash weight was chosen as the chemical component because it is probably more related biologically to bone weight than any of the other chemical components. For statistical justification differences on

TABLE 20

Chemical Components of the Leg. Means, Standard Deviations and Ranges (lb)

Item	Number	Mean	S.D.	Range
Fat	39	2.92	0.95	0.81 - 4.88
Water	39	4.31	0.68	2.58 - 5.74
Protein	39	1.22	0.25	0.69 - 1.87
Ash	39	0.38	0.078	0.22 - 0.59

TABLE 21

Dissectible Components of the Leg. Means, Standard Deviations and Ranges (lb)

Item	Number	Mean	S.D.	Range
Fat	39	2.87	0.90	0.58 - 4.56
Muscle	39	4.48	0.74	2.51 - 5.98
Bone	39	0.86	0.12	0.62 - 1.15

TABLE 22

Some Relationships Between Chemical and Dissectible Components in the leg.

Dependent Variate	Independent Variate	No. of Pairs	Correlation Coefficient	Regression Equation	$S_{y.x}$
Fat Wt. (~~Dissectible~~)	Fat Wt. (Chemical)	39	0.9069 **	Y = 0.86X + 0.36	0.38
Muscle Wt.	Water Wt.	39	0.9467 **	Y = 1.02X + 0.08	0.24
Muscle Wt.	Protein Wt.	39	0.9136 **	Y = 2.74X + 1.14	0.30
Bone Wt.	Ash Wt.	39	0.7638 **	Y = 1.13X + 0.43	0.08

a carcass basis between the correlation of ash with bone, and the higher correlations of protein and water with bone, were tested using Fisher's Z-transformation (Snedecor, 1957). This showed that there were no significant differences between the three correlations. Therefore ash weight was then correlated with bone weight on a joint basis.

Relationships between the chemical and dissectible components outlined above are presented in Table 22.

As in the carcass, fat weight is the most variable component. In Tables 20 and 21 dissectible and chemical fat weights are very similar in mean, standard deviation and range, although chemical fat is slightly larger in each case. The correlation between chemical and dissectible fat weights is not as high as for the carcass, however it is still quite good.

There is more muscle than fat in the leg. The leg is the only joint where this is so. Both water and protein weights are highly correlated with muscle weight, although the water correlation is better and its regression has the lower standard error of estimate.

The correlation between ash and bone weights is higher than the corresponding one for the carcass.

(3) Loin.

The mean weight of the loin is 5.51 lb and the range is from 1.63 to 9.80 lb. Means, standard deviations and ranges of chemical and dissectible components are presented

TABLE 25

Some Relationships Between Chemical and Dissectible Components in the loin

Dependent Variate	Independent Variate	No. of Pairs	Correlation Coefficient	Regression Equation	$s_{y.x}$
Fat Wt. (Dissectible)	Fat Wt. (Chemical)	39	0.9905 **	$Y = 1.06X + 0.12$	0.22
Muscle Wt.	Water Wt.	39	0.8545 **	$Y = 0.88X - 0.23$	0.19
Muscle Wt.	Protein Wt.	39	0.7556 **	$Y = 2.03X + 0.77$	0.24
Bone Wt.	Ash Wt.	39	-0.0011 NS.	$Y = 0.03X + 0.24$	0.10

in Tables 23 and 24, and relationships between some of them in Table 25.

Again fat weight shows the largest variation of all the components. The loin is the fattest joint and shows the greatest variation in this respect. Dissectible fat has the higher values for the statistics presented in Tables 23 and 24. The correlation between chemical and dissectible fat weights is very high and the standard error of estimate of the regression equation is low. In these respects the loin is very similar to the whole carcass.

TABLE 23

Chemical Components of the Loin. Means, Standard Deviations and Ranges (lb)

Item	Number	Mean	S.D.	Range
Fat	39	3.07	1.48	0.40 - 6.95
Water	39	1.69	0.34	0.96 - 2.32
Protein	39	0.47	0.13	0.25 - 0.79
Ash	39	0.12	0.033	0.06 - 0.19

TABLE 24

Dissectible Components of the Loin. Means, Standard Deviations and Ranges (lb)

Item	Number	Mean	S.D.	Range
Fat	39	3.37	1.59	0.41 - 7.28
Muscle	39	1.72	0.36	0.98 - 2.49
Bone	39	0.24	0.095	0.07 - 0.53

TABLE 28

Some Relationships Between Chemical and Dissectible Components in the rib cut

Dependent Variate	Independent Variate	No. of Pairs	Correlation Coefficient	Regression Equation	$S_{y.x}$
Fat Wt. (Dissectible)	Fat Wt. (Chemical)	39	0.9876**	$Y = 1.06X - 0.06$	0.10
Muscle Wt.	Water Wt.	39	0.9083**	$Y = 0.85X + 0.10$	0.06
Muscle Wt.	Protein Wt.	39	0.8388**	$Y = 2.21X + 0.25$	0.08
Bone Wt.	Ash Wt.	39	0.3333*	$Y = 0.73X + 0.12$	0.03

The correlations of water and protein weights with muscle weight are relatively low for the loin. In this case water weight is clearly better related to muscle weight than is protein weight.

There is no relationship between ash and bone weights in the loin.

(4) Rib Cut

The mean weight of rib cut was 2.29 lb (range 0.64 to 4.26 lb). Means, standard deviations, and ranges for the chemical and dissectible components of the rib cut are set out in Tables 26 and 27. The relationships being studied are presented in Table 28.

TABLE 26

Chemical Components of the Rib Cut. Means, Standard Deviations and Ranges (lb)

Item	Number	Mean	S.D.	Range
Fat	39	1.31	0.60	0.16 - 2.79
Water	39	0.72	0.15	0.40 - 1.11
Protein	39	0.21	0.055	0.12 - 0.35
Ash	39	0.06	0.016	0.03 - 0.10

TABLE 27

Dissectible Components of the Rib Cut. Means, Standard Deviations and Ranges (lb)

Item	Number	Mean	S.D.	Range
Fat	39	1.33	0.64	0.11 - 2.90
Muscle	39	0.71	0.14	0.40 - 1.09
Bone	39	0.16	0.015	0.09 - 0.25

TABLE 31

Some Relationships Between Chemical and Dissectible Components in the "Rest".

Dependent Variate	Independent Variate	No. of Pairs	Correlation Coefficient	Regression Equation	$s_{y.x}$
Fat Wt. (Dissectible)	Fat Wt. (Chemical)	39	0.9883 **	$Y = 1.04X - 0.43$	0.36
Muscle Wt.	Water Wt.	39	0.9497 **	$Y = 0.97X + 0.34$	0.31
Muscle Wt.	Protein Wt.	39	0.6778 **	$Y = 1.51X + 3.46$	0.73
Bone Wt.	Ash Wt.	39	0.6184 **	$Y = 1.16X + 0.96$	0.17

The relationships are very similar to the other joints previously detailed. Fat weight again accounts for most of the variation in composition. All correlations are lower than the corresponding ones for the carcass. In the case of chemical against dissectible fat this reduction is not marked.

Water weight is again correlated more highly than protein weight with muscle weight.

The correlation between bone weight and ash weight is also low and is only significant at the five per cent level of probability.

(5) "Rest".

The mean weight of the "rest" was 14.45 lb with a range of 6.43 to 21.43 lb. Tables 29 and 30 show means, standard deviations, and ranges of the chemical and dissectible components of the joint. Relationships between some of these components are presented in Table 31.

A similar picture to the other joints is seen here. The correlation between chemical and dissectible fat is quite good although not as high as for the carcass. Water weight is clearly superior to protein weight for predicting muscle weight.

The correlation between ash weight and bone weight, while not as high as for the carcass, is reasonably large.

TABLE 29

Chemical Components of the "Rest". Means, Standard Deviations and Ranges (lb)

Item	Number	Mean	S.D.	Range
Fat	39	6.31	2.24	1.52 - 10.89
Water	39	5.87	0.96	3.45 - 7.96
Protein	39	1.70	0.44	0.97 - 2.49
Ash	39	0.55	0.11	0.32 - 0.82

TABLE 30

Dissectible Components of the "Rest". Means, Standard Deviations and Ranges (lb)

Item	Number	Mean	S.D.	Range
Fat	39	6.13	2.36	1.30 - 11.03
Muscle	39	6.03	0.98	3.44 - 8.42
Bone	39	1.60	0.21	1.14 - 2.03

(6) Discussion.

Throughout this work the relationships studied within joints between chemical and dissectible components are not as good as the corresponding relationships on a carcass basis. However the correlations within joints are of similar relative magnitude to those on the carcass. Some interesting trends were noticed between joints. Chemical and dissectible fat weights were very similar within each joint with respect to mean, standard deviation and range. With the exception of the leg, dissectible fat weight was larger than chemical fat weight. This fact may explain why the correlation between the two estimates of fat was lowest in the leg. It was noticed that the correlation between chemical fat weight and dissectible fat weight was highest in the fattest joint (loin) and lowest in the leanest joint (leg). The reason for this is not clear.

The correlations between water weight and muscle weight were better than the protein - muscle weight correlations in each joint. Therefore it was concluded that water weight is better than protein weight for estimating muscle weight. The correlations with muscle weight were highest in the lean joint (leg) and lowest in the fat joint (loin). This trend is opposite to that noticed when comparing chemical and dissectible fat between joints.

The ash - bone correlation was very variable between joints. In the leg it was higher than that for the carcass, while in the loin there was no relationship at all. The poor relationships between ash and bone in the rib and loin are probably related to the precision with which the carcass was divided down the backbone. Both these joints contain small amounts of bone and any accidental deviations from the midline when the carcass was split could cause large variations in the amounts of bone contained in these two joints.

2. A COMPARISON OF TWO METHODS OF ESTIMATING PROTEIN

In the present work protein was estimated by difference, following the method of Barnicoat and Shorland (1952). This was crude residue minus ash and minus a fat correction factor determined by Soxhlet extraction.

Barnicoat and Shorland (1952) compared this method against the standard Kjeldahl protein analysis for muscle samples and found that the two methods did not differ by more than 1.1 per cent. They used a conversion factor of N x 6.25 and found that the difference method gave slightly higher values. Apart from this work no effort appears to have been made to check the accuracy of the difference method on minced meat samples. Accordingly this was done with the present data. The standard multiplier of 6.25 was used in converting nitrogen per cent, as determined by Kjeldahl, into protein per cent. Bate-Smith (1942) claims that the nitrogenous substances in meat comprise approximately 89 per cent only of true protein. He therefore proposed that a factor of N x 5.6 be used for meat. However, Bate-Smith (1942) was working with pure muscle. We are concerned here with analysing whole meat, not just muscle and so will conform to tradition and use 6.25. The factor 6.25 probably does over-estimate the amount of protein present as can be seen from Table 32 where protein, fat and ash, make up the whole of the crude residue and do not allow for the presence of constituents

TABLE 32

Percentage Composition of the Crude Residue

Item	Number	Mean	S.D.	Range
Protein per cent	39	67.96	3.47	59.25 - 74.88
Fat per cent	39	12.49	3.29	6.74 - 20.52
Ash per cent	39	20.13	1.67	15.94 - 23.83

such as carbohydrates, lactic acid, pigments and vitamins. Most of the variation in the composition of the crude residue is related to fat content as can be seen in Table 32. The reason for this is that the amount of fat removed in the first decantations with ether is very variable. Soxhlet extraction of a homogeneous sample of each residue is thus essential in order to estimate accurately the weight of chemical fat in each carcass.

Table 33 presents means, standard deviations and ranges of protein in the carcass as estimated by the two methods. It can be seen that they are very similar with the Kjeldahl method giving slightly higher values, which is opposite to the findings of Barnicoat and Shorland (1952). The correlation coefficient between the two methods of estimation was 0.9480 ** and the regression equation as follows:

$y = x - 0.07$; $S_{y.x} = 0.14$ lb protein.

Where y = Kjeldahl method and x = the residual method

TABLE 33

Means, Standard Deviations and Ranges of Protein Wt. (lb). Estimated by Two Methods.

Item	Number	Mean	S.D.	Range
Protein Wt. (Kjeldahl)	39	7.46	1.37	4.1 - 10.7
Protein Wt. (Difference)	39	7.39	1.30	4.1 - 9.9

The equation shows that there is little difference between the two methods and thus is borne out by the analysis of variance (Table 34) which shows a non-significant difference between them.

TABLE 34

Analysis of Variance Between Two Methods of Estimating Protein

Source	d.f.	S.S.	M.S.	F	
Between Methods	1	0.09	0.09	0.05	N S
Error	76	135.83	1.79		
Total	77	135.92			

Thus it is concluded that in the present type of work the difference method of estimating protein is sufficiently accurate.

3. RELATIONSHIPS BETWEEN LEAN-METER MEASUREMENTS, SUBCUTANEOUS FAT DEPTH AND CARCASS COMPOSITION

Data from only 35 of the 39 sheep were used in this section. The four sheep omitted (Nos. 25, 26, 74 and 114) bled profusely at one or more of the probe sites making it impossible to get an accurate reading.

In Table 35 are set out means, standard deviations and ranges of both average Lean-meter measurement and average depth of subcutaneous fat at the Lean-meter probe sites. Mean Lean-meter depth is almost twice that of subcutaneous fat depth although the latter has a wider range. Skin thickness would account for some of this difference in mean depth, but not all. It seems therefore, that the Lean-meter probe extends into the underlying muscle to some degree and this over-estimates the depth of subcutaneous fat. The reason for this may be that the meter does not register until the probe contacts blood.

TABLE 35

Average Lean-meter and Subcutaneous Fat Depths. Means, Standard Deviations and Ranges (in.)

Item	Number	Mean	S.D.	Range
Av. Lean-meter depth	35	0.80	0.20	0.23 - 1.19
Av. Subcutaneous Fat depth	35	0.45	0.24	0.10 - 1.20

An analysis of variance of Lean-meter measurements is presented in Table 36. The only sources contributing significantly to the variability are between sheep and between sites. The between observers and all the interaction terms do not contribute significantly. This type of result with large differences between sheep, small differences between sites, and no differences between observers is very good and points to the usefulness of the Lean-meter. The lack of any significant difference between observers means that results obtained by other workers should be comparable.

TABLE 36

Analysis of Variance of Lean-meter Measurements

Source	d.f.	S.S.	M.S.	F	
Between Sheep	34	8.460	0.2488	12.02	**
Between Sites	2	0.195	0.0975	4.71	*
Between Observers	1	0.005	0.0050	0.24	N.S.
Sheep X Sites	68	1.948	0.0286	1.38	N.S.
Sheep X Observers	34	0.542	0.0159	0.77	N.S.
Observers X Sites	2	0.001	0.0005	0.02	N.S.
Error	68	1.409	0.0207		
Total	209	12.560			

TABLE 37

Relationships Between Lean-meter Measurements and Subcutaneous Fat Depth (in.)

Independent variate (Lean-meter Measurement) = X
Dependent variate (Depth of subcutaneous fat
at site of Lean-meter Measurement) = Y

Site	No. of Pairs	Correlation Coefficient	Regression Equation	$S_{y.x}$
Shoulder	35	0.6490 **	$Y = 0.68X - 0.15$	0.14
Loin	35	0.8440 **	$Y = 0.98X - 0.33$	0.14
Rump	35	0.7979 **	$Y = 0.85X - 0.19$	0.17
Average of all sites	35	0.7972 **	$Y = 0.95X - 0.31$	0.15

Correlations between Lean-meter and subcutaneous fat measurements at the three probe sites are presented in Table 37. They are best correlated at the loin site which also has the lowest standard error of estimate of the regression equations. The relationship at the rump site is not much lower but has a slightly higher standard error of estimate, while the shoulder site has the poorest relationship between the two methods. The average of all Lean-meter sites is also quite highly correlated with average subcutaneous fat depth though not as well as the loin site. The significance of the differences between the correlation coefficients shown in Table 37 were tested using Fisher's Z - transformation (Snedecor 1957) which showed that there were no differences. Thus, although the loin site gave the best relationship in this case, in the long run it would be better to use the average of all sites. In accordance with this the remaining relationships have been calculated on an average basis.

The Lean-meter essentially measures depth of subcutaneous fat at the probe sites. Therefore it is necessary to know the relationships between both Lean-meter measurements and subcutaneous fat depths, and various measures of body composition to be able to evaluate the technique. Some of the more important relationships in this connection are presented in Table 38. It can be seen from the table that average subcutaneous fat depth is better related to fat weight (both chemical and dissectible) than Lean-meter depth.

TABLE 38

Relationships Between Average Lean-meter Measurement, Average Depth of Subcutaneous Fat, and some Components of Body Composition

Dependent Variate	Independent Variate	No. of Pairs	Correlation Coefficient	Regression Equation	$s_{y.x}$
Fat Wt. (Dissectible)	Av. Depth Subcutaneous Fat	35	0.8973 **	$Y = 41.60X + 8.51$	5.02
Fat Wt. (Chemical)	Av. Depth Subcutaneous Fat	35	0.8956 **	$Y = 39.71X + 8.99$	4.84
Fat Wt. (Dissectible)	Av. Lean-meter Depth	35	0.8197 **	$Y = 45.23X + 8.95$	6.51
Fat Wt. (Chemical)	Av. Lean-meter Depth	35	0.8292 **	$Y = 43.76X - 8.15$	6.08
Fat Percentage (Dissectible)	Av. Depth Subcutaneous Fat	35	0.8705 **	$Y = 31.66X + 28.18$	4.39
Fat Percentage (Chemical)	Av. Depth Subcutaneous Fat	35	0.8603 **	$Y = 29.09X + 28.94$	4.22
Fat Percentage (Dissectible)	Av. Lean-meter Depth	35	0.8239 **	$Y = 35.66X + 13.90$	5.06
Fat Percentage (Chemical)	Av. Lean-meter Depth	35	0.8324 **	$Y = 33.50X + 15.23$	4.70
Muscle Wt.	Av. Depth Subcutaneous Fat	35	0.5621 **	$Y = 10.67X + 20.95$	3.61
Muscle Percentage	Av. Depth Subcutaneous Fat	35	-0.8829 **	$Y = 53.03 - 21.85X$	2.85
Muscle Wt.	Av. Lean-meter Depth	35	0.6898 **	$Y = 14.95X + 13.79$	3.23
Muscle Percentage	Av. Lean-meter Depth	35	-0.7725 **	$Y = 61.40 - 22.75X$	3.85

The standard errors of estimate of the regression equations are also lower for average fat depth. There is not much difference between the two methods of estimating fat weight although in each case the chemical method has a slightly lower standard error of estimate.

Subcutaneous fat depth is also better related to both chemical and dissectible fat percentages than is the Lean-meter measurement. Again the chemical fat is slightly better related to both the Lean-meter measurement and average fat depth than the dissectible fat, as can be seen by comparing the standard errors.

Muscle weight is better predicted by the Lean-meter while muscle per cent is more closely related to average subcutaneous fat depth. Unlike fat where there was not much difference in the magnitude of the correlations between percentage and weight components, there is quite a large difference for muscle. The percentage correlations are negative and of appreciably greater magnitude than those with the weight component. The negative sign was to be expected in view of the high negative correlation between muscle and fat percentages (r = -0.9777 **).

Although the standard errors of estimate of the regression equations shown in Table 38 have been used in comparisons it should be noted that they are large. These large standard errors remove somewhat the value of the relatively high correlations found in Table 38. The

TABLE 39

Relationship of Specific Gravity to Some Measures of Carcass Composition

Dependent Variate	Independent Variate	No. of Pairs	Correlation Coefficient	Regression Equation	$s_{y.x}$
Fat Percentage (Chemical)	Specific Gravity	39	-0.9475 **	$Y = 704.71 - 643.86X$	2.53
Fat Percentage (Dissectible)	Specific Gravity	39	-0.9399 **	$Y = 749.10 - 686.54X$	2.90
Water Percentage	Specific Gravity	39	0.9357 **	$Y = 472.44X - 444.17$	2.07
Muscle Percentage	Specific Gravity	39	0.9165 **	$Y = 453.50X - 423.54$	2.30

size of these correlations is probably due more to the variability of the data than to biological causes.

4. SPECIFIC GRAVITY AS A MEASURE OF CARCASS COMPOSITION

The specific gravity (S.G.) determinations were made at water temperatures of 65 to 66°F. Mean S.G. was 1.029 with a range of 1.013 to 1.055.

High negative relationships were obtained between S.G. and both chemical and dissectible fat percentages. However the correlation with chemical fat is higher and the standard error of its regression equation is lower than with dissectible fat. This is reasonable on the grounds that S.G. is influenced by total carcass fat. This total fat is estimated better by chemical means than by dissection which does not account for many fats such as intramuscular fat and bone fat.

High positive correlations are shown between S.G. and water and muscle percentages as seen in Table 39.

CHAPTER V

GENERAL DISCUSSION

Three methods of determining composition have been studied; one on the live animal and two on the carcass. Pace and Rathbun (1945) and Kraybill *et al.* (1952) have demonstrated a very high relationship between whole body and carcass composition. So the practice used in the present work of relating all measurements to carcass composition would seem valid in terms of body composition.

The results have shown that the Lean-meter will give an indication of the level of fatness of a group of live sheep. The correlations are much better than those obtained by Temple *et al.* (1956) for beef cattle and as good as, or better than, the relationships found by several workers on the pig. However the relationships in the present study have large standard errors of estimate for the regressions. The relationships are not good enough to give an accurate appraisal of the fatness of an individual animal. As fat is the most variable component of the body and therefore an important determinant of body composition, any method which will accurately measure the fat content of the live animal is of great practical importance. Herein lies the value of the Lean-meter. As yet the technique is imperfect and has many faults, but due to the fact that promising results were obtained, further work on the technique would appear to be warranted. The present results indicate the type of approach needed:

(a) Easy identification of probe sites at the same relative anatomical position on each animal. The method used in the present work, where constant distances were measured from the last rib, was not satisfactory because no allowance was made for variation in animal length.

(b) The depth of subcutaneous fat at the site of probing must be highly related to the fat content of the animal. In the present case this relationship was quite high and back fat thickness was in fact better related to total fatness than Lean-meter depth. However, apart from the depth of fat along the backline little systematic work has been done measuring the relationship between subcutaneous fat depth and total fat at other sites on the body. There might be some other site where the relationship is higher than for back fat.

(c) As with Temple _et al._ (1956) bleeding was found to be a source of trouble and the data from four sheep was discarded because of this. A site needs to be found which, taking into account (a) and (b) above, is not prone to bleeding. Most of the work with the Lean-meter has been conducted on the pig. The subcutaneous fat in this animal is different anatomically to that of the ruminant. It is closely adherent to the skin, is not markedly interspersed with muscle layers, and does not have a vascular supply equal to that of the sheep. These factors make it much easier to obtain accurate Lean-meter measurements on the pig.

(d) The Lean-meter itself requires improving. It is not easy with the sheep to locate the point where muscle is first encountered. The indicator needle flickers all the time and a definite end-point is not certain. As in the case of Walker-Love et al. (1958a) it was found that the Lean-meter over-estimated the depth of subcutaneous fat.

It is thought that if the problems outlined above could be solved the Lean-meter approach to determining live animal body composition could be very rewarding.

Results from the comparison of chemical and dissection analyses show that it is possible to estimate accurately dissectible fat from chemical fat, and muscle from either protein or water; on both a whole carcass and joint basis. The relationships between chemical and dissectible fat are as good as those found by Hopper (1944) and Hankins and Howe (1946). The results in the present work showed, however, that in general dissectible fat and muscle could not be predicted as accurately from chemical data within joints as on a whole carcass basis.

It was not found possible to estimate bone or tendon plus waste accurately from chemical data. However the correlation between ash and bone weights in the carcass was higher than that found by Hopper (1944). Cannon bone weight has been suggested as an independent variate for estimating total bone weight (McMeekan, 1941; Hughes, 1957). In the present work the correlation between these two variables was 0.8329 and the standard error of estimate of the regression equation was 0.44 lb bone. While these figures are better than those between bone and ash, they are still not good enough for useful prediction. It seems that a better method of chemically estimating bone is required. It is suggested therefore, in work of this type, that dissectible fat and muscle be estimated from the appropriate chemical components while bone plus tendon plus waste be calculated by difference as a single component. This procedure would be far quicker than carrying out dissection. It takes approximately 24 man hours to dissect one half-carcass and approximately four man hours to chemically analyse six side samples. In actual practice the time taken to increase the number of chemical analyses would not be large because there is an overhead of work that must be done and the addition of extra samples involves little extra time. The findings of Kirton et al. (1960) that the chemical composition of a side can be estimated accurately from two samples is of pertinence here. The chemical analysis of carcasses can be speeded up threefold because of this.

A great deal of work on many species of animals has been conducted on the relationship of S.G. to body composition.

Reports of the efficiency of S.G. are most varied. The relationship between fat per cent and S.G. for sheep in the present work is higher than those found by Stouffer (1955), Kirton (1957), or Garrett et al. (1959). The high relationship between S.G. and muscle per cent bears out the findings in the literature. Although many factors can cause variations in S.G. values the method must not be depreciated. Its value lies in the fact that it is quick and that it does not involve destroying any part of the carcass. Therefore in work where it is not possible economically to determine chemical composition directly, S.G. may provide a useful indirect assessment of composition.

CHAPTER VI

SUMMARY AND CONCLUSIONS

1. Data from the 39 Romney ewe carcasses studied in Part I were used to evaluate three methods of determining composition.

2. High relationships were found between chemical and dissectible fat weights ($r = 0.9964$), water and muscle weights ($r = 0.9694$), and protein and muscle weights ($r = 0.9655$) for the whole carcass. Correlations were similarly calculated on a joint basis, but these were generally slightly lower. Relationships between chemical component weights and bone weight were not considered high enough for predictive purposes. It is suggested that in work of the present nature dissectible fat and muscle be estimated from the appropriate chemical components while bone plus tendon plus waste be calculated by difference as a single component.

3. Protein estimated by the standard Kjeldahl analysis using a conversion factor of 6.25 was compared with protein as estimated by difference using the method of Barnicoat and Shorland (1952). There were no significant statistical differences between the two methods and the correlation between them was 0.9480. The regression was:

$$y = x - 0.07; \quad s_{y.x} = 0.14 \text{ lb protein}$$

where y = Kjeldahl method and x = the difference method of

Barnicoat and Shorland. It was concluded that the difference method was sufficiently accurate in the present type of work.

4. The Lean-meter was used to determine composition of the live animal. Data from four sheep had to be discarded because of haemorrhage at the probe sites. An analysis of variance showed highly significant differences between sheep, significant differences between probe sites and non significant differences between observers. The mean of the three probe sites (shoulder, loin and rump) had a correlation of 0.7972 with the average depth of subcutaneous fat at the same sites on the carcass. Both average Lean-meter measurement and average depth of subcutaneous fat were correlated with several measures of fatness and leanness. In all cases, except muscle weight, average depth of subcutaneous fat gave a better estimate. However, the correlations with average Lean-meter depth were only slightly lower and may be detailed as follows: weight of dissectible fat (r = 0.8197), weight of chemical fat (r = 0.8292), dissectible fat per cent (r = 0.8239), chemical fat per cent (r = 0.8324), muscle weight (r = 0.6898), muscle per cent (r = -0.7725). These results show that the Lean-meter will give an indication of the level of fatness of a group of live sheep. However, standard errors of estimate for the relationships studied were large. Further work on improving the technique appears to be warranted.

5. High correlation coefficients were estimated between carcass specific gravity and chemical fat per cent ($r = -0.9475$), dissectible fat per cent ($r = -0.9399$), water per cent ($r = 0.9357$) and muscle per cent ($r = 0.9165$). The usefulness of S.G. in determining carcass composition is discussed.

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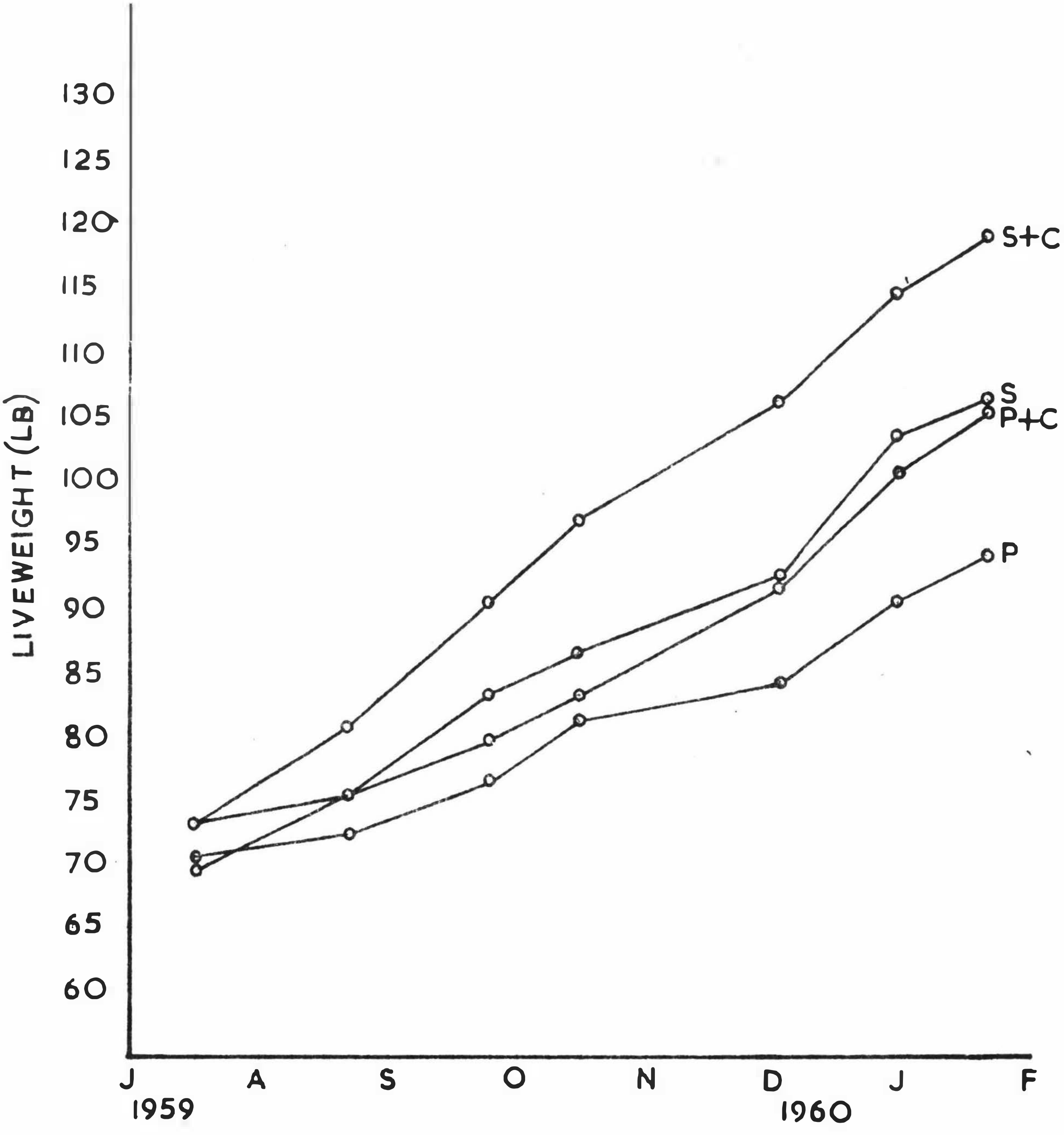
APPENDICES

A copy of all the data used in this thesis has been lodged with the Sheep Husbandry Department, Massey Agricultural College.

APPENDIX I. GROWTH CURVES (SECOND TRIAL)



APPENDIX II

Analyses of Variance from Part I

1. Liveweight at 10 May 1957 (lb)

Source	d.f.	S.S.	M.S.	F	
Pasture	3	117.09	39.03	1.78	N.S.
Error	35	765.99	21.89		
Total	38	883.08			

2. Liveweight at 10 July 1957 (lb)

Source	d.f.	S.S.	M.S.	F	
Pasture	3	446.15	148.72	5.42	**
Error	35	960.52	27.44		
Total	38	1406.67			

3. Liveweight (Final) at 17 December 1958 (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	1908.49	238.56	1.07	N.S.
Birthrank	3	1413.70	471.23	2.12	N.S.
Pasture	3	6275.08	2091.69	9.40	**
Error	24	5340.90	222.54		
Total	38	14,938.17			

4. Frozen Carcass Weight (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	1666.33	208.29	1.97	N.S.
Birthrank	3	503.95	167.98	1.59	N.S.
Pasture	3	2510.42	836.81	7.92	**
Error	24	2534.50	105.60		
Total	38	7215.20			

5. Chemical Fat Weight in Carcass (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	187.29	23.41	0.57	N.S.
Birthrank	3	1060.33	353.44	8.67	**
Pasture	3	1423.50	474.50	11.64	**
Error	24	978.38	40.77		
Total	38	3649.50			

6. Water Weight in Carcass (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	96.56	12.07	1.17	N.S.
Birthrank	3	12.49	4.16	0.40	N.S.
Pasture	3	251.57	83.86	8.13	**
Error	24	247.63	10.32		
Total	38	608.25			

7. Protein Weight in Carcass (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	8.65	1.08	0.96	N.S.
Birthrank	3	3.09	1.03	0.92	N.S.
Pasture	3	23.27	7.76	6.93	**
Error	24	26.77	1.12		
Total	38	61.78			

8. Ash Weight in Carcass (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	0.95	0.12	0.54	N.S.
Birthrank	3	0.72	0.24	1.09	N.S.
Pasture	3	1.93	0.64	2.90	N.S.
Error	24	5.32	0.22		
Total	38	8.92			

9. Chemical Fat Percentage in the Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	148.30	18.54	0.55	N.S.
Birthrank	3	447.33	149.11	4.46	*
Pasture	3	661.67	220.56	6.59	**
Error	24	802.75	33.45		
Total	38	2060.05			

10. Water Percentage in the Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	75.66	9.46	0.51	N.S.
Birthrank	3	266.60	88.87	4.83	**
Pasture	3	352.96	117.65	6.40	**
Error	24	441.41	18.39		
Total	38	1136.63			

11. Protein Percentage in the Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	10.16	1.27	0.70	N.S.
Birthrank	3	20.82	6.94	3.81	*
Pasture	3	30.40	10.13	5.57	**
Error	24	43.71	1.82		
Total	38	105.09			

12. Ash Percentage in the Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	2.19	0.27	1.42	N.S.
Birthrank	3	0.44	0.15	0.79	N.S.
Pasture	3	2.56	0.85	4.47	*
Error	24	4.63	0.19		
Total	38	9.82			

13. Dissectible Fat Weight in the Carcass (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	574.24	71.78	1.49	N.S.
Birthrank	3	769.24	256.41	5.34	**
Pasture	3	1119.57	373.19	7.77	**
Error	24	1152.36	48.02		
Total	38	3615.41			

14. Muscle Weight in Carcass (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	95.56	11.95	1.00	N.S.
Birthrank	3	10.88	3.63	0.30	N.S.
Pasture	3	307.32	102.44	8.54	**
Error	24	287.65	11.99		
Total	38	701.41			

15. Bone Weight in Carcass (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	6.45	0.81	2.38	*
Error	24	8.14	0.34		
Total	32	14.59			

16. Tendon and Waste Weight in the Carcass (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	1.05	0.13	3.36	*
Error	24	0.94	0.04		
Total	32	1.99			

17. Dissectible Fat Percentage in the Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	166.04	20.76	0.50	N.S.
Birthrank	3	483.77	161.26	3.87	*
Pasture	3	1377.76	459.25	11.02	**
Error	24	1000.66	41.49		
Total	38	3028.23			

18. Muscle Percentage in Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	89.76	11.22	0.62	N.S.
Birthrank	3	284.93	94.98	5.28	**
Pasture	3	299.97	99.99	5.56	**
Error	24	431.95	18.00		
Total	38	1106.61			

19. Bone Percentage in the Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	8.16	1.02	0.34	N.S.
Birthrank	3	21.46	7.15	2.39	N.S.
Pasture	3	52.00	17.33	5.80	**
Error	24	71.82	2.99		
Total	38	153.44			

20. Tendon and Waste Percentage in Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	1.61	0.20	0.27	N.S.
Birthrank	3	1.02	0.34	0.46	N.S.
Pasture	3	7.83	2.61	3.55	*
Error	24	17.67	0.74		
Total	38	28.13			

21. Feet Weight (gm)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	108688	13586	1.06	N.S.
Birthrank	3	7291	2430	0.19	N.S.
Pasture	3	261261	87087	6.78	**
Error	24	308333	12847		
Total	38	685573			

22. Skin Weight (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	13.79	1.72	0.56	N.S.
Birthrank	3	8.50	2.83	0.92	N.S.
Pasture	3	68.27	22.76	7.37	**
Error	24	74.25	3.09		
Total	38	164.81			

23. Head Weight (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	2.04	0.26	2.00	N.S.
Birthrank	3	0.04	0.01	0.10	N.S.
Pasture	3	2.37	0.79	6.08	**
Error	24	3.13	0.13		
Total	38	7.58			

24. Empty Weight of Stomach plus Oesophagus (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	2.50	0.31	4.23	**
Error	24	1.78	0.07		
Total	32	4.28			

25. Empty Weight of Large and Small Intestines (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	1.82	0.23	1.21	N.S.
Birthrank	3	1.04	0.35	1.84	N.S.
Pasture	3	0.84	0.28	1.47	N.S.
Error	24	4.49	0.19		
Total	38	8.19			

26. Heart Weight (gm)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	13399	1675	1.68	N.S.
Birthrank	3	723	241	0.24	N.S.
Pasture	3	6422	2141	2.15	N.S.
Error	24	23886	995		
Total	38	44430			

27. Lungs plus Trachea Weight (gm.)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	27187	3398	0.17	N.S.
Birthrank	3	24133	8044	0.41	N.S.
Pasture	3	439454	146485	7.49	**
Error	24	469087	19545		
Total	38	959861			

28. Spleen Weight (gm.)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	1024	128	1.08	N.S.
Birthrank	3	1064	355	2.98	N.S.
Pasture	3	4110	1370	11.51	**
Error	24	2857	119		
Total	38	9055			

29. Liver Weight (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	0.30	0.04	1.00	N.S.
Birthrank	3	0.01	0.003	0.08	N.S.
Pasture	3	0.51	0.17	4.36	*
Error	24	0.93	0.04		
Total	38	1.75			

30. Caul Fat Weight (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	9.26	1.16	0.69	N.S.
Birthrank	3	29.00	9.67	5.76	**
Pasture	3	43.04	14.35	8.54	**
Error	24	40.40	1.68		
Total	38	121.70			

31. Gut Fat Weight (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	0.92	0.12	0.86	N.S.
Birthrank	3	0.51	0.17	1.21	N.S.
Pasture	3	0.97	0.32	2.31	N.S.
Error	24	3.26	0.14		
Total	38	5.66			

32. Kidneys' Weight (gm.)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	3559	445	1.91	N.S.
Birthrank	3	482	161	0.69	N.S.
Pasture	3	4710	1570	6.74	**
Error	24	5584	233		
Total	38	14335			

33. Genital Tract plus Bladder Weight (gm.)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	33579	4197	1.12	N.S.
Birthrank	3	6394	2131	0.57	N.S.
Pasture	3	30069	10023	2.67	N.S.
Error	24	89959	3748		
Total	38	160001			

34. Stomach Content Weight (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	23.13	2.89	1.48	N.S.
Birthrank	3	21.72	7.24	3.71	*
Pasture	3	17.94	5.98	3.07	*
Error	24	46.85	1.95		
Total	38	109.64			

35. Intestinal Content Weight (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	1.83	0.23	1.21	N.S.
Birthrank	3	1.94	0.65	3.42	*
Pasture	3	2.03	0.68	3.58	*
Error	24	4.45	0.19		
Total	38	10.25			

36. Stomach plus Intestinal Contents Weight (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	24.49	3.06	1.37	N.S.
Birthrank	3	33.30	11.10	4.96	**
Pasture	3	29.32	9.77	4.36	*
Error	24	53.69	2.24		
Total	38	140.80			

37. "Fat-Free" Carcass Weight (lb)

Source	d.f.	S.S.	M.S.	F	
Interaction	8	177.10	22.14	1.38	N.S.
Birthrank	3	17.83	5.94	0.37	N.S.
Pasture	3	446.51	148.84	9.31	**
Error	24	383.87	15.99		
Total	38	1025.31			

38. Percentage Muscle in the "Fat-Free" Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	8.07	1.01	0.21	N.S.
Birthrank	3	9.81	3.27	0.67	N.S.
Pasture	3	47.22	15.74	3.24	*
Error	24	116.62	4.86		
Total	38	181.72			

39. Percentage Bone in the "Fat-Free" Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	4.41	0.55	0.35	N.S.
Birthrank	3	4.76	1.59	1.03	N.S.
Pasture	3	23.94	7.98	5.15	**
Error	24	37.27	1.55		
Total	38	70.38			

40. Percentage Tendon plus Waste in the "Fat-Free" Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	1.91	0.24	0.31	N.S.
Birthrank	3	0.13	0.04	0.05	N.S.
Pasture	3	3.14	1.05	1.35	N.S.
Error	24	18.75	0.78		
Total	38	23.93			

38. Percentage Muscle in the "Fat-Free" Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	8.07	1.01	0.21	N.S.
Birthrank	3	9.81	3.27	0.67	N.S.
Pasture	3	47.22	15.74	3.24	*
Error	24	116.62	4.86		
Total	38	181.72			

39. Percentage Bone in the "Fat-Free" Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	4.41	0.55	0.35	N.S.
Birthrank	3	4.76	1.59	1.03	N.S.
Pasture	3	23.94	7.98	5.15	**
Error	24	37.27	1.55		
Total	38	70.38			

40. Percentage Tendon plus Waste in the "Fat-Free" Carcass

Source	d.f.	S.S.	M.S.	F	
Interaction	8	1.91	0.24	0.31	N.S.
Birthrank	3	0.13	0.04	0.05	N.S.
Pasture	3	3.14	1.05	1.35	N.S.
Error	24	18.75	0.78		
Total	38	23.93			