ENERGY METABOLISM, RANGING BEHAVIOUR

AND

HAEMATOLOGICAL STUDIES

WITH

ROMNEY MARSH AND CHEVIOT SHEEP

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DIVISION "A"

BACKGROUND TO PROJECT

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A-I INTRODUCTION

Youatt (1776-1847 a) in commenting on British breeds of sheep, writes:-

> "In all the different districts of the Kingdom we find various breeds of sheep beautifully adapted to the locality which they occupy. No one knows their origin; they are indigenous to the soil, climate and pasturage, the locality on which they graze; they seem to have been formed for it and by it."

Some present day students of animal husbandry are now examining the characteristics of these various breeds in the light of the particular environment in which each originated. Their object is to discover what characteristics can fairly be ascribed to particular sets of conditions, or in other words, what possible functional adaptations to environment can be revealed by study of this unique collection of soil stable breeds.

Interest in the background of the development of these breeds and its possible influence on them is not however limited to the United Kingdom as British breeds of livestock have been taken to all the corners of the world in the wake of the migratory movements of the British people. For example, in New Zealand, at the time of writing, attention is being focused on the Romney-Cheviot crossbred ewe which is competing against the Romney Marsh for certain hill country and this has prompted consideration of the parent stocks (Plates 1 and 2) from the standpoint of their original habitats. This project was undertaken to augment what has already been done in New Zealand on this subject.

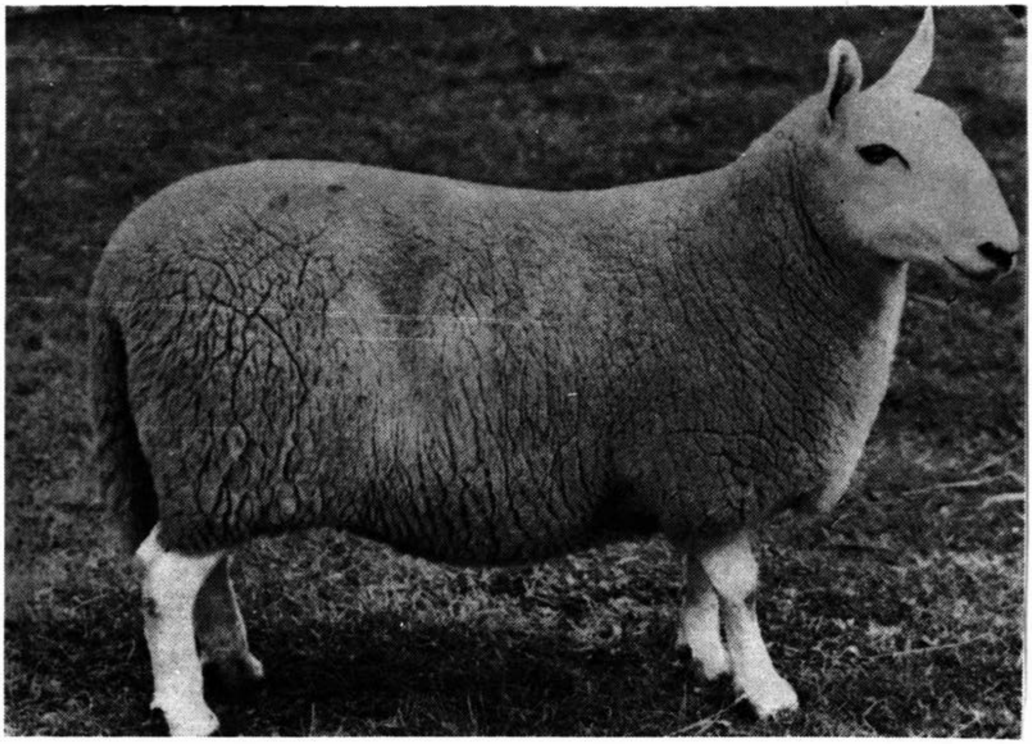


Plate 1. Typical Border Cheviot ewe.

Plate 2. Typical Romney Marsh ewe.

A-II REVIEW OF LITERATURE AND SOME DISCUSSION OF IT

von Borstel (1951) studied the forequarter anatomy of samples of ten animals from each of the Romney Marsh and Cheviot breeds. He found that the Cheviot has comparatively sharp, pointed withers and rather sloping shoulders and that, while the shoulder muscles believed to be concerned with the flight phase of locomotion were very much the same in both breed types, those believed to be concerned with the work phase (producing locomotive power) were significantly heavier in the Cheviot group. von Borstel views these breed differences as having possibly been brought about through the Cheviot, a hill breed, developing shoulders for active hill work that the Romney, a lowland breed, would not require. He contends that locomotion studies, linked with behaviour investigations, would enlighten the subject of anatomical form as related to adaptation.

Unfortunately however, for the student of functional anatomy, the agricultural literature abounds with circumstantial--but nonetheless concrete--evidence to the effect that sheep of many British breeds have had their body conformation changed to the breeders' concept of what it should be in place of what it was. Bakewell (1725-1795) pioneered modern alterations in sheep breeds and his disciples have been numerous, to say the least of it, the yardsticks of desirability being supplied by the wool merchants and the butcher and his customers. Thus it would appear that lowland breeds as well as hill types may have originally possessed high, and/or light shoulders.

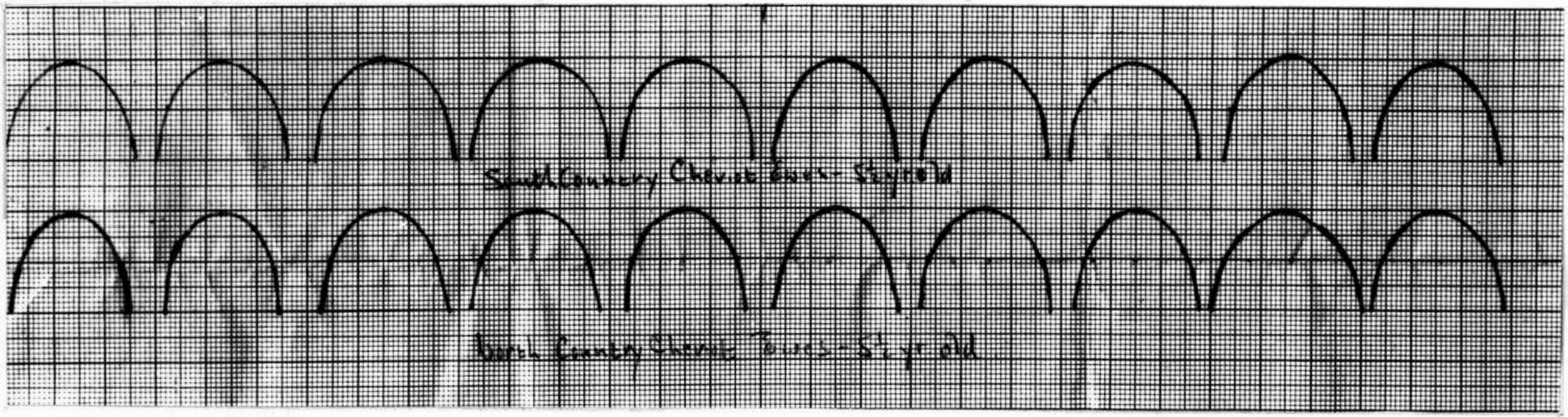
That high shoulders in sheep should at the present time be indicative of an active disposition is also questioned by Wannop (1957 a) who writes:-

> "The early breed society (Cheviot) statements on type said that the withers should be high enough to give style but not so high that there was any indication of slackness of back. Nowadays, little if any reference is made to this feature and there is certainly no special emphasis placed on the high withers or any desire to accentuate them. They occur in the breed, but the desire to avoid slackness in the back would, if anything, tend to reduce the wither height. Re. our newly shorn North Country and South Country (Border) Cheviots run together on the same hirsel* on Sourhope. Both are equally prominent in the withers, but the South Country tends to have a more rounded shoulder and the North Country a more pointed shoulder. From this one would expect the North Country to be more active whereas in practice it is the South Country which ranges more freely to the top of the hill and, unless herded, the North Country would keep to the lower slopes. The Scotch Blackfaced sheep tends to be more level from neck to tail. In practice it has to be more agile than the Cheviot, grazing steeper, higher and more rugged hills."

Wannop(1957 a) confirmed the more pointed nature of the North Country Cheviot's shoulder by making a number of shoulder moulds according to the method of von Borstel (1951). Scaled down by Wannop, these shoulder moulds are presented in Figure I. They show that the South Country Cheviot does tend to have the more rounded shoulder. Attempts to relate present day anatomy to the particular environments of British sheep breeds are therefore beggared from the very start by the unrivalled enthusiasm with which the United Kingdom animal breeder has unquestionably remoulded the native stocks. For this reason the writer

* Pasture divisions.

Figure I. The shoulder profiles of 10 South Country (Border) Cheviot and 10 North Country Cheviot ewes at Sourhope hill research station, Scotland (Wannop 1957a).



decided to look for some other approach to the question of how ancestral background may still affect New Zealand Romney Marsh and Cheviot sheep. In seeking for clues to what may be basic differences, other than conformation, between the two breeds recourse was had to their breed histories.

A-III BREED HISTORIES

(a) The Romney Marsh or Kent Sheep

Romney Marsh occupies the South East corner of Kent. The district includes not only Romney Marsh proper, 24,000 acres; but also the adjoining and similar areas of Walland Marsh, 15,000 acres, the New Romney Level, 1,500 acres, and Denge Marsh, 9,000 acres, making altogether roughly 50,000 acres in the County of Kent. There are also approximately 9,000 acres in the county of Sussex, a total of 59,000 acres. 'The Marsh' is a marsh in name only. Drainage has made the land fit to graze and plough, and it has become a farming area of first class value although the bulk of it lies below the high water level of spring tides. It is pre-eminently a sheep grazing area and carries some of the best sheep pastures in the world; but there has always been some arable land, the amount varying with the prosperity or otherwise of arable farming. The Marsh is isolated but has a present day population of 50 to 500 people per square mile (Bartholomew 1953 a). Generally speaking, the land is flat, large areas being almost treeless and without hedges to break the force of the wind.

Fields in the Marsh are divided by water dykes which carry off the drainage water into sewers, the sewers conveying the water either into the Royal Military Canal or into the sea at low tide. The tendency is for the fields to be rather larger than in most parts of Kent. A fair average figure may be fifteen acres with very many in the 15 - 20 - 30 acre range whereas on the South Downs the divisions would be in the five to fifteen acre range and on the North Downs seven to ten acres (Wyatt 1957).

Taken as a whole the Marsh is inherently fertile and capable of producing not only excellent grazing but also arable crops comparable with those obtained in any other part of Great Britain. In summer the Marsh is very heavily stocked with sheep--eight to ten ewes per acre. At the end of August or the beginning of September it is customary to relieve the pastures of some of the sheep by sending most of the lambs away, either to be sold in the autumn lamb sales or to be wintered until the following April on the uplands of Kent, Surrey, and Sussex or farther afield. Nevertheless the breeding ewes and wether tegs and some of the lambs remain in the Marsh. Even in winter, therefore, the Marsh pastures are not really being rested from sheep--they are stocked up to capacity, usually at the rate of two and a half sheep per acre. The Marsh grazier likes to have a fair covering of grass on his pastures in the autumn in order that he may have sufficient winter food for his ewe and wether tegs which find their own sustenance on the grass throughout the year, generally without the help of hay.

Romney Marsh is the home of the Romney Marsh or Kent breed of sheep, several other breeds having been tried in the area but without success. The breed has possibly one of the longest traceable histories of sheep in the United Kingdom for the isolated position of Romney Marsh (it was in earlier days separated from the other parts of the Kingdom by the vast Kent Wealden forest), must have assisted in maintaining the local breed pure and untainted from outside strains until comparatively modern times.

In making particular reference to the Romney Marsh or Kentish sheep, Youatt (1776-1847 b) says that a long wooled and highly valuable breed of sheep has been kept on Romney Marsh from time immemorial. This breed demanded a pasture of unusual richness and found it on these Marshes. It was not uncommon for six or seven or eight fattening wethers to be placed on one acre.

Evidence of interference with the original conformation of the breed through the introduction of the Leicester is also given by the same authority (Youatt 1776-1847 c). He writes that the pure Leicester would not be sufficiently hardy for the Marsh lands but they would affect some valuable service in producing greater depth and roundness, symmetry of form, earlier maturity, and greater propensity to fatten.

The 'Romney' is not only an inhabitant of the Marsh but, as its other name implies, was and is one of the main breeds of the whole county of Kent. The Kent Sheep as the Romney is known in that county generally, was bred essentially for grazing pastures and the line of improvement chosen by the old Kentish flock masters was to hold grazing contests rather than to parade the sheep for judging at a show. During the earlier part of the nineteenth century many flock masters turned their attention to careful selection, rams from the best flocks being let out to hire (Garrard 1954).

A-III (b) The Cheviot Breed of Sheep

The Cheviot Hills are part of an elevated and extensive range which extends from Galway through Northumberland and occupies a space of approximately 112,000 acres.

If Romney Marsh can be referred to as "isolated" the Cheviots can be described as extremely remote. Roman rule was never permanently extended beyond Hadrian's Wall which lies some 30 to 40 miles south of Cheviot and, from the recall of the Legions to the seventeenth century, the area knew relative peace only under the Northumbrian branch of the Saxon heptarchy. William's Doomsday recorders (1086) did not enter Northumberland as, subsequent to his harrying of the North (1068), the area lay a desert* for upwards of two centuries. After this both England and Scotland tacitly

* An apt description used by early historians.

encouraged the Border warfare which raged unceasingly between clan and clan, family and family, until the Act of Union (1707). This family warfare resulted in little intercourse between the outside world and the Border peoples. It can thus be reasonably assumed that the sheep stocks of the area were free from extensive external influences until quite modern times. Some idea of the remoteness of the district is gained from the fact that Scott (1771-1832) was the first man to take a wheeled carriage into Liddlesdale, a large centre of Cheviot stock. At the present time the human population is in many places less than one per square mile with a maximum of fifty in the vicinity of small villages and townships (Bartholomew 1953 b).

Sir John Sinclair (Youatt 1776-1847 d) described as follows the native sheep of the Cheviot Hills as they were in 1792 before the admixture of Leicester blood:-

> "Perhaps there is no part of the Island where, at first sight, a fine wooled breed is less to be expected than among the Cheviot Hills. Many parts of the sheep walks consist of nothing but peat bogs and deep morasses. During winter the hills are covered with snow for two, three, and sometimes four months and they have an ample proportion of bad weather during the other seasons of the year, and yet a sheep is to be found that will thrive in the wildest part of it. Their shape is excellent and their forequarter in particular is distinguished by such justness of proportion as to be equal in weight to the hind one. Their limbs are of a length to fit them for travelling and enable them to pass over bogs and snows, through which a shorter legged animal could not penetrate. They are excellent snow travellers and are accustomed to procure their food by scraping snow off the ground with their feet, even when the top is hardened by frost."

Mr. Culley (Youatt 1776-1847 e) reports the breed as, "Forequarter wanting depth in the chest and breadth both there and on the chine." Youatt comments, "This might be correct as to the Cheviot of that day but the system of crossing with the Leicesters has remedied this defect." Here again is evidence of alterations in the external conformation of a native sheep.

Conditions in the Cheviot Hills have changed little since Sir John Sinclair's time. Winter is still harsh with many long weeks of snow and ice and easterlies which blow across the North Sea from Siberia often continuously from December to May. Hirsels are still large, ranging from 100 to 600 acres (Richards 1957), and the true hill pasturage can in no way compare in quality, quantity and length of growing season with Romney Marsh. The average stocking per acre in the Cheviot area is one ewe : two acres (H.F.R. 1951 a). Ewe lambs are wintered on lowland farms the mature sheep being left to face semi-starvation for a period of some months. The doubtful quality of much hill herbage, the lack of arable crops, adequate shelters, buildings and enclosures, harsh climate and the remoteness of many farms therefore all continue to militate against the less suited types of sheep.

The modern Cheviot is described by Thomas (1945 a) as being one of the most important breeds in Britain. Not only has it a great regional importance in the English/Scottish Border country, but in Northern Scotland it is prominent, and in many English counties it is found to such an extent that it can claim to be more cosmopolitan than any other breed within the United Kingdom. Vast numbers of Cheviots invaded the chalk lands of Southern England when the reduction in ploughed land between the wars caused the giving up of Down breeds kept in arable flocks; they have even invaded Wales and a colony has been established on Exmoor. Within the breed a strain possessing a bigger body, a larger head, a more open coat, and a requirement for more and better food has been evolved in Caithness (Thomas 1945 b; H.F.R. 1951 b).

A-IV TOPOGRAPHY, GENERAL ASPECT AND CLIMATE OF ROMNEY MARSH AND THE ENGLISH/SCOTTISH BORDER

Plates 3, 4, 5, and 6* illustrate the great difference in topography and general aspect between typical sections of Romney Marsh and the Cheviot Hills in winter and summer.

Unfortunately there are no meteorological stations located exactly in these areas but Table 1 summarizes the information on temperature, frost, snow, rain, sunshine, and wind for the stations nearest to the required districts (G.B. Meteorological Office 1957). In each case the station nearest to Romney Marsh is given first and the station nearest to the Cheviots is second.

This table clearly demonstrates the severity of climatic conditions on the English/Scottish Border in comparison with those of

*By courtesy of the Royal Air Force.

Plate 3 - Cheviot Hills 20/6/46

Plate 4 - Romney Marsh 31/8/54

Plate 5 - Cheviot Hills 16/10/45

Plate 6 - Romney Marsh 19/4/55

Table 1. G. B. Meteorological Office weather data (average figures) for the recording stations nearest+ to Romney Marsh and the Cheviot Hills.

DATES OF FIRST AND LAST SCREEN FROSTS

	First Frost	Last Frost
Folkstone*	19th Nov.	21st March
Kelso**	6th Oct.	7th May

Mean Temperature °F

	Jan.	Feb.	Mch.	Apl.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Folkstone	40.0	40.3	43.1	46.8	52.7	57.3	61.4	61.6	58.9	52.8	45.5	41.7	50.2
Kelso	37.8	38.3	40.5	44.2	50.1	54.9	58.3	57.5	53.2	47.4	40.3	38.4	46.7

Extremes of Temperature °F

Maximum

	Jan.	Feb.	Mch.	Apl.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Folkstone	56	58	67	76	83	85	88	90	86	75	63	59	90
Kelso	59	59	71	74	81	86	88	86	88	79	62	57	88

Minimum

	Jan.	Feb.	Mch.	Apl.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Folkstone	17	15	12	27	32	38	42	44	36	29	27	12	12
Kelso	1	-3	6	15	24	31	37	35	28	18	10	12	-3

Rainfall in inches

	Jan.	Feb.	Mch.	Apl.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Folkstone	2.25	2.03	2.17	1.66	1.68	1.99	2.10	2.39	2.37	4.03	3.25	3.21	29.13
Kelso	1.75	1.70	1.95	1.57	1.93	2.11	2.63	2.95	1.90	2.91	2.31	2.32	26.03

	Jan.	Feb.	Mch.	Apl.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Folkstone	16	14	15	13	11	11	11	12	11	16	15	18	13.6
Kelso	17	15	18	15	14	13	15	18	13	18	16	17	15.7

Average Sunshine (Total Hours per Month)

	Jan.	Feb.	Mch.	Apl.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Folkstone	56	82	138	167	224	236	231	216	164	119	67	53	146.1
Eskdalemuir	37	60	97	126	167	171	137	125	99	80	54	36	99.1

Number of Days Snow Falling and Lying

Snow Falling

	Jan.	Feb.	Mch.	Apl.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Lympne	3.8	4.7	2.8	1.8	0.1					0.1	1.0	3.2	17.5
West Linton	7.7	6.9	8.3	5.7	1.7					1.2	3.8	6.4	41.7

Snow Lying

	Jan.	Feb.	Mch.	Apl.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Lympne	1.9	2.4	1.4	0.1	0.0					0.0	0.3	1.6	7.7
West Linton	9.5	8.7	7.6	1.8	0.1					0.8	3.6	7.2	39.3

Average Wind Speed
M.P.H.

	Jan.	Feb.	Mch.	Apl.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Dover	16.6	15.6	12.5	13.5	12.1	11.9	11.6	10.6	11.8	13.7	14.1	14.7	13.2
Eskdalemuir	12.6	13.6	13.2	11.3	10.2	10.8	9.7	8.5	9.7	11.0	12.4	12.0	11.2

+ The Station nearest to Romney Marsh is given first under each sub-heading
* Height 128'
** Height 193'

Southern Kent. Derived from Table 1, the following facts are of particular interest:

(1) Both districts have approximately the same rainfall and number of rainy days but snow lies in the North on an average for 39.3 days and only 7.7 days in Kent.

(2) The mean yearly temperature for the Borders is only 4°F. below that of Kent but the mean minimum temperatures show a wide difference, temperatures at Kelso dropping to below zero and showing only July and August free of frost. Kelso is at approximately the same height as Folkstone, Lympne, and Dover. The Cheviots range 2000 feet higher than Kelso and therefore must have an even more severe climate.

(3) The hours of sunshine total for the year at Folkstone is 1753 whereas in Eskdalemuir there are only 1189 hours.

A-V DISCUSSION

An examination of the backgrounds of the two breeds reveals a number of basic differences. On the one hand is the Romney, a long-wooled, south-country, lowland sheep, accustomed to rich pasturage on land which will carry up to ten sheep per acre in summer and two and a half sheep per acre in winter. On the other hand is the Cheviot, a medium length-wooled, north-country hill and moorland sheep accustomed to tough living conditions on land which at its best will carry no more than one sheep per acre in summer, while for a sheep to survive Border winter conditions it must be able to withstand body wastage which may run from ten to forty-six percent of its Autumn live weight (Cresswell 1951; Wannop 1957 b).

> "At the present juncture it seems that it is the extent to which body wastage can be tolerated by the sheep that decides most of the problems concerned with the successful running of a hill flock." (Jones 1945 a).

The rate of stocking of the Cheviot Hills and Romney Marsh indicates that the Cheviot may require to cover a great deal more country in search of food than the Romney. It must be admitted though that the system of husbandry followed in the Border hill country may force the Cheviot to range more freely than is necessary. The Cheviot's pastures are large, running up to 600 acres, and the instinct of the flocks makes them move to the lowest point in the early part of the day and from there work their way back to the highest point by evening. Thus the sheep may cover quite high mileages per day just moving to a preordained pattern. Hunter (1954) makes some interesting observations on this type of phenomenon in hill sheep. The average size of the fields of Romney Marsh (15 - 20 - 30 acres) is certainly large enough to give opportunity for raking* but the conditions are not comparable to the Border sheep walks.

These differences in the backgrounds of the breeds suggest that they may be endowed with differing physiological mechanisms related to their ability to survive in their respective environments and which the breeders may not have radically altered in their selective breeding

* Walking and grazing.

for carcass improvement as Jones (1945 b) in writing on sheep and their environments comments, "It is well known that it spells ruin every so often if the demands of the breed or type are bigger than the capacity of the land at its lowest;" and Nichols (1928) wrote:-

> "The two chief classes of British sheep which can be distinguished are the mountain and lowland types, the latter cannot successfully contest for the natural habitat of the former, while owing to the development of the flying flock, the former, frequently and in large numbers encroach upon the habitat of the latter. The distinction in type is complicated and embodies physiological and genetical differences which at the present time cannot be expressed in strict terms and therefore cannot be subjected to definite analysis."

The analysis of breed characteristics has still not yet proceeded far, and evidence is still lacking as to the precise nature of the breed adaptations to environment; but in the present project the animals and their backgrounds indicated three lines of approach which would be suitable for intensive study:-

1. Energy Metabolism:

That characteristic which enables one animal to live where another may die due to its inability to gather and to make good use of limited food of possibly poor quality, is a factor which is obviously connected with the over-all metabolic processes of the animal as for example:- Herbivorous animals differ in their ability to survive on the toughened desiccated vegetation of the desert. "The burro of the desert and the llama of the arid puna thrive on provender which the cow and the horse are unwilling to eat and possibly unable to digest" (Dill 1938).

The Cheviot has been evolved in an area where the winter and even summer climate and pasturage can be classed as desert when compared with Southeast England and the breed is therefore recognized as being able to make adequate use of a comparatively poor food supply.

This may be accomplished in one of two ways:

(i) By an adaptation in the metabolic rate;

(ii) By an increased efficiency in the manner in which the digestive system deals with the food available.

The last mentioned possibility was beyond the training of the author to deal with but the first was deemed to hold some promise and was examined further.

Keyes et al. (1950) define "adaptation" as a useful adjustment to altered circumstances. When the total metabolic rate decreases in starvation, as it indubitably does, it is certainly a favourable change in that it reduces the caloric deficit as compared with what it would be in the absence of such changes in the basal metabolism. To the starving individual the reduced metabolic rate means that, at a given caloric intake, his rate of loss of strength and endurance is diminished and thus he will survive longer.

The present day Cheviots' ancestors were subjected to comparatively severe seasonal starvation each and every year and so far as it and the Romney are concerned it was therefore felt reasonable to look for a possible breed difference in the effect of starvation on their energy metabolism. However, the Cheviots' ancestral standard of living being at the best of times comparatively poor, it was felt to be reasonable to also look for a differential between the metabolic rates of the breeds on adequate rations.

2. Ranging behaviour

Ranging behaviour studies were initiated because the following points indicate that the Cheviot is a much more active animal than the Romney.

(i) The difference in field size between Romney Marsh and the Cheviot Hills.

(ii) The possible need of the Cheviot to cover more ground in search of sustenance.

(iii) The comparatively more dynamic, nervous and intelligent disposition of the Cheviot as opposed to the Romney Marsh sheep.

3. Haematology

As it was hoped to show that one of the breeds (Cheviot) was more active than the other it was thought it may be useful to include a study based on some accepted measures of muscular work capacity, e.g. blood volume and haemoglobin.

Brody (1945) states that:-

"Muscular-work capacity is dependent on many factors such as soundness of limbs and muscles, on body build and strength, on skill and intelligence, on temperament and ambition and

> so on. These factors are more or less judgeable externally by inspection. There are however other factors and aptitudes which are not externally evident, measurable only functionally. These are concerned mostly with the oxygen supply to the tissues by the cardio-respiratory system."

Stamina, reserve power, endurance, appear to be directly proportional to factors such as pulmonary ventilation, blood circulation, quantity of haemoglobin (quantity of blood), oxygen capacity of the blood, and so on.

In discussing factors causing physiological variations in plasma and red cell volume, Reeve (1948) mentions muscular activity. He states that he knows of little work on the effects of prolonged muscular training on the blood volume but his impression is that physically fit men such as front line soldiers have a greater blood volume, particularly red cell volume, than civilians.

The inclusion of haematological studies was also of value from another viewpoint. Haematological data are used in everyday clinical medicine whether with the human being or farm animal as an indication of the physical well-being or otherwise of subjects believed to be under physiological stress.

Between the Cheviot and the Romney sheep on certain areas of hill country in New Zealand it is the Romney which is exposed to the less favourable environment when the breeds are considered from the viewpoint of their ancestral habitats. Under these conditions the Romney is performing in a disappointing manner particularly in lamb production (Peren et al. 1951), and it was hoped that this would be reflected in the haematological picture of the breed.

These three natural divisions of the project, energy metabolism, ranging behaviour, and haematological studies are now dealt with in turn.

DIVISION "B"

ENERGY METABOLISM STUDIES

CONTENTS

B-I INTRODUCTION AND REVIEW OF LITERATURE

The main aim of this division of the project was to compare the energy metabolism of Cheviot with Romney Marsh sheep under standardized conditions of environment and feed over a period of approximately one year. Incidental studies which were added as the study proceeded and opportunity presented are reported in the Addendum to this Division "B."

Benedict (1938 a) writes:- "Within a few animal species striking racial differences in metabolism have been noted." This author presents a comprehensive summary of available knowledge on the subject. Brody (1945 a) found statistically significant differences between the resting metabolism of some Holstein and Jersey heifers. Unfortunately Brody did little work with sheep and then only on a few Merinos prior to 1940 (Brody 1956).

Prosser *et al*. (1952) present a review of intra-specific differences in oxygen consumption which includes Drosophila and humans. However, as the present project is primarily concerned with sheep, only the position as regards the sheep is to be elaborated on.

Cited from Benedict (1938 b) the data presented in Fig. II represent two races of sheep, those in Australia being the Merino and those at Durham, U.S.A., a cross between the Southdown and the Rambouillet breeds.

Benedict argues that the pronounced lability in the basal metabolism of these animals might well explain the scatter of the data above

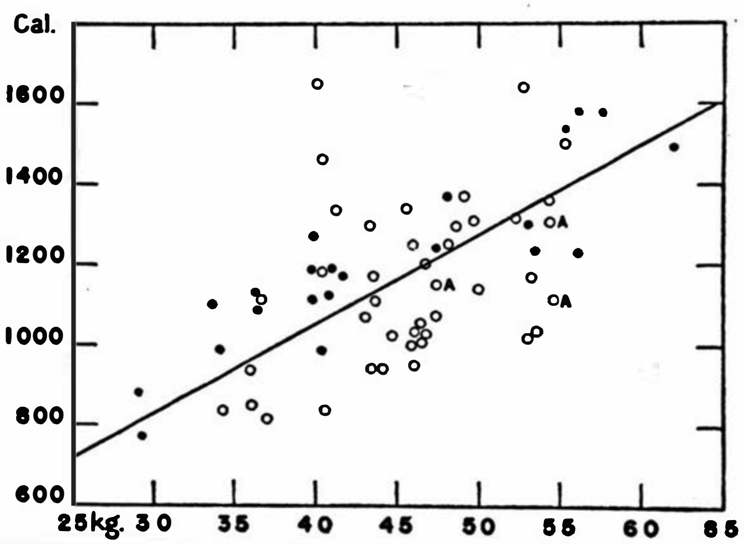


Figure II. Total 24-hour basal heat production referred to body weight - sheep. The solid dots represent a U. S. A. cross between the Southdown and Rambouillet and the hollow circles Australian Merinos (Benedict 1938b).

and below the average curve, but it cannot explain the difference in the two groups of sheep as a whole. Consequently he writes, "It appears that there is a distinct racial difference in that the energy metabolism of the Australian race may be thirteen percent lower than the Durham." However, Marston (1948 a) feels that there was no reason for Benedict to assume a distinct racial difference.

The problem in the comparison of the data from Australia with that in America is that the metabolism of the Australian sheep was measured after a 48 hour fast and the American sheep after a 24 hour fast. Also Marston argues that both bases for reporting the metabolism of these sheep are unacceptable and insecure in the absence of a complete definition of the previous level of feeding and the nature of the fodder.

B-II TECHNIQUES FOR MEASURING ENERGY METABOLISM

(a) Principles

The two major biocalorimetric techniques are designated as direct and indirect. Both direct and indirect methods were originated by Lavoisier in 1777. Lavoisier demonstrated that living involves oxidation; he defined life as a chemical process and introduced the essentially modern nomenclature especially as it relates to oxygen in life processes.

Direct calorimetry involves the measuring of the heat output of an organism confined in a suitable chamber (calorimeter).

This chamber commonly takes the form of a well insulated box, the interior of which is kept at a constant temperature by water circulating through pipes attached to the lining. The heat absorbed by the water is computed from the amount of water flowing per unit time and from the temperature differences between incoming and outgoing water.

A current of air is drawn through the chamber to provide the subject with fresh air to breathe. This air is warmer when it comes out than when it enters, and consequently carries heat away with it. The amount of heat thus removed is calculated by multiplying the volume of air drawn through the chamber by its density, by the difference in temperature between the entering and issuing air and the specific heat of air.

A certain amount of heat is also carried out of the chamber in the issuing air in the form of latent heat of the water vapour exhaled by the subject. The weight of water vapour thus removed multiplied by the latent heat of vaporisation of water gives the amount of heat removed from the chamber in this form. These three quantities of heat added together give the total amount of heat lost by the subject.

Other methods of direct calorimetry are reported by Benedict and Lee (1937) and Murlin and Burton (1935). The former authors placed the subject in one chamber while another similar chamber had electric-resistant wires made to produce exactly the same amount of heat as that emitted by the subject in the other chamber. The latter authors used a Pyrex glass cylinder for the respiration chamber.

Indirect calorimetry is based on the fact that the heat output of some organisms can be calculated from their O_2 consumption, or CO_2 production, and the caloric values of those gases.

The commonly adopted procedures in indirect calorimetry are therefore:-

(1) To connect the subject to an oxygen spirometer and measure its oxygen consumption.

(2) To collect and analyse the air expired by the subject.

However, the caloric equivalent of O_2 consumed and CO_2 produced varies with the nature of the substance being oxidised. It is therefore theoretically necessary to know the composition of the fuel mix (carbohydrate, fat, protein) being oxidised. The relative amounts of fat and carbohydrate oxidised are determined from the non-protein respiratory quotient (R.Q.).

The respiratory quotient is a term applied by Pfluger (Cantarrow and Trumper 1949 a) to the ratio of the volume of carbon dioxide expelled to the volume of oxygen inspired during the same interval of time. The value of the respiratory quotient varies with the nature of the foodstuffs metabolised, the determining factor being their relative content of hydrogen and oxygen.

In considering the relative values of direct and indirect calorimetry, Cantarrow and Trumper (1949 b) write to the effect that direct calorimetry, though the most accurate, is too costly and impracticable for routine clinical use but indirect calorimetry is sufficiently accurate to meet the exacting requirements of clinical tests in man.

Brody (1945 b) considers that direct and indirect calorimetry are equally simple in principle but since the direct method in practice is much more expensive and complicated it is comparatively rarely used for farm and other animals.

In addition to high cost and complicated procedure, direct calorimetry has the following disadvantages:-

(1) The long period required to put each animal through the respiration chamber procedure.

(2) With ruminants, the heat of fermentation in the rumen cannot be distinguished from true body heat.

(3) The lack of control of the animal.

(4) Possible physiological upsets stemming from the psychological shock of confinement in a totally enclosed chamber.

Indirect calorimetry offers the advantages of simplicity, speed of operation, low cost, ease of control of the subject, lack of psychological upsets, lack of complication from the heat of fermentation and adaptability to a variety of studies. However, indirect calorimetry (which for the above reasons was the method adopted in this investigation) also has its difficulties which must be understood or surmounted. e.g.:-

Brody (1945 c) argues that it is not necessary and often not even advisable to employ the R.Q. for estimating the metabolism of ruminants by indirect calorimetry because it does not always have the fundamental significance given it in human medicine. Thus cattle and other ruminants produce huge quantities of CO_2 in the digestive tract by anaerobic bacterial fermentation and by the liberation of CO_2 from bicarbonates. This extra metabolic CO_2 cannot be distinguished from the respiratory metabolism CO_2. Under these conditions the R.Q. has no metabolic significance and of course the quantity of CO_2 production cannot be taken as a measure of metabolism.

Nevertheless Brody (1945 d) points out that although the range in caloric equivalent of CO_2 is relatively wide, from 5.0 to 6.7 Cals. per litre, the range of caloric equivalent of O_2 is relatively narrow, from 4.7 to 5.0 Cals. per litre, and is within the limits of experimental error in metabolism measurements. Furthermore, since the average R.Q. of protein is 0.82 which corresponds to the average caloric value of O_2 of 4.825 Cals. per litre no correction need be made for protein metabolism when measuring energy metabolism from oxygen consumption.

Within indirect calorimetry the measurement of oxygen consumption is more easily accomplished than the measurement of CO_2

production. In view of the above, the measure of metabolism adopted for this investigation was oxygen consumption.

B-II (b) Technique Development

For the purpose of connecting animals to oxygen spirometers Brody (1930 a) developed a face mask and others including Dougherty et al. (1955) have used cuffed rubber or metal endotracheal tubes.

The face mask suffers from the disadvantage that although eructated and exhaled CO_2 is easily removed from a closed circuit* by a reagent such as soda lime methane is not. In addition, the production of methane varies within wide limits and is particularly voluminous when the ruminant is on full feed (Pilgrim 1948). Brody (1930 b) overcame part of this problem by firstly starving the animals for twelve hours, when methane production had fallen to a low level, and sidestepped the remainder of the problem by simply discarding those graphic records which showed the liberation of such gases. In this project it was desired to measure the O_2 consumption of sheep on full feed. The face mask was therefore ruled out because of the methane problem. Later events were to indicate that this was a correct decision as, when the sheep were on full feed, eructation took place very frequently during metabolism recordings. In addition the length of time required for dealing with a number of animals made it practically impossible to carry out many repeat runs.

*As opposed to an open circuit where the expired gases do not re-enter the spirometer.

Connection of the pulmonary system direct to an oxygen spirometer overcomes the methane problem in that it prevents the contamination of pulmonary by rumen gases, and it was therefore decided to approach the technique problems from this angle. The use of cuffed rubber or metal tubes was, however, rejected because the author was advised that over long periods they were most inconvenient pieces of equipment to manage. (Colonna 1956) .

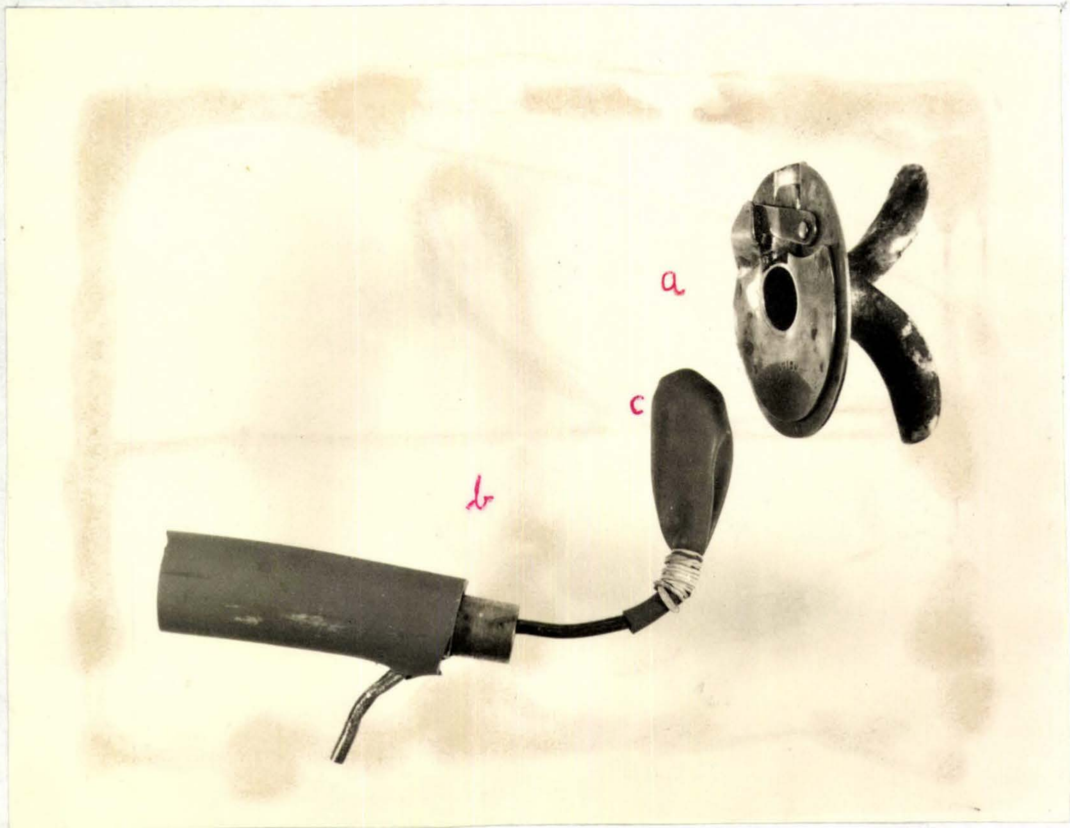
It was therefore decided that before any long term experiments could be planned it would be advisable to devise a new technique for making direct contact between an oxygen spirometer and the pulmonary system via the trachea of an animal.

Subsequently the experiments were started (27/7/56) by fitting two sheep* with 'Field' pattern tracheotomy tubes (Plate 7a) and devising a piece of supplementary equipment to make this type of tube usable for such work (Plate 7b).

The tubes were worn permanently and kept plugged except when recordings were to be made. The solid plug was the replaced by a hollow (half inch lumen), soft brass, machine tapered plug linked to the spirometer. The hollow plug carried with it a 2mm., hard brass, by-pass tube which, extending some 6cm. beyond the plug itself, was bent in an arc corresponding to the curvature of the upper tongue of the tracheotomy tube so that the free end of the by-pass located within the lumen of the upper trachea when the plug was inserted into the tracheotomy tube.

* Under a general anaesthetic.

Plate 7. 'Field' pattern tracheotomy tube (a), with introducer (b) and rubber balloon (c).



A deflated rubber balloon securely attached to the free end of the by-pass tube (Plate 7c) was then gently inflated and clamped off after the insertion of the hollow plug.

By this device (quickly and with a minimum of disturbance to the animal) it was possible to completely occlude the upper trachea. Plate 8, an X-ray print in which the inflated balloon has been visualised in situ by means of radiopaque contrast medium clearly demonstrates the effective manner in which the upper trachea is blocked. To reduce irritation to a minimum the deflated balloon was lightly smeared with a non-oily analgesic jelly prior to insertion. Throughout the course of the investigation the analgesic factor used was a one percent mixture of Amethocaine in a mucilage jelly. The insertion of the hollow plug with its attached by-pass tube and balloon was never in any way resented by the sheep. Its placing took only a few seconds and caused no more than an occasional cough due to irritation of the tracheal mucosa. Plates 9 and 10 illustrate the complete indifference of the sheep to this procedure. Note that in plate 10 the pilot balloon 'a' is inflated indicating that the animal is breathing through the connection tube 'b' which was used to link the subject with a spirometer. As soon as the balloon was inflated the animals resumed feeding or rumination if these processes were interrupted. Various types of balloon were tried. The most satisfactory proved to be the upper two inches of an ordinary latex condom which was

Plate 8.

X-ray plate showing inflated balloon occluding the upper trachea of a sheep.

Plate 9. Sheep before the insertion of a tracheal balloon (a).

Plate 10. Sheep after the insertion and inflation of a tracheal balloon. Note - pilot balloon (a) connection tube (b).

gathered and bound to the tip of the capillary with an elastic band. A condom has an advantage over toy balloons in that its exceedingly thin but tough latex is easily inflated and it immediately bonds itself to the mucous membranes of the trachea, thus forming a perfect seal.

However, it was not sufficient to produce an air tight stopper within the trachea for the design of the 'Field' pattern tracheotomy tube meant that there was no air tight joint between the stem of the tube itself and the sheep's neck. The problem of obtaining an air tight seal in this location was only overcome after a considerable period of experimentation.

The wounds originally healed snugly round the tracheotomy tubes and thus made a firm joint which in the case of the first two animals was effectively supplemented by a supporting sponge rubber pad having a rubber ring behind it which pressed onto the sheep's shaven neck. Wool growth and the relaxing of the walls of the wound away from the cannula, however, very shortly brought a great deal of leakage trouble. Pads coated with temperature resistant grease were almost ineffective and their use possibly led to one case of pneumonia from grease contamination of the lungs.

Three rings cut from one inch internal diameter corrugated rubber tubing (Plate 11) and sprung between the cannula and the neck of the animal were most effective in preventing leaks for a number of weeks. Unfortunately this seal eventually caused more

Plate 11. Tracheal cannula with corrugated rubber cuff (a).

trouble than it was worth for it led to physiological pressure adaptations which sooner or later caused failure of the seal.

Finally, a long-wearing air tight seal was produced between the base plate of the tracheotomy tube and the neck by using a commercial rubberised putty smeared onto a sponge rubber pad. The rubberised putty made an air tight bond between the sponge rubber pad and the sheep's neck (Plate 12a). A sheet of rubber cut from a car tyre inner tube assisted the sealing process. The sponge rubber pad tended to slacken its grip on the stem of the cannula but the inner tube rubber (placed against the sponge rubber) fatigued in its grip only after comparatively very long periods. The inner tube rubber was an indispensible part of the seal. The oxygen spirometer used (Plate 12b) was a McKesson* closed circuit Metabalor designed for human usage, which was secured on loan from the Palmerston North General Hospital.

With this instrument a measurement is taken of the amount of oxygen consumed during a five or six minute period. The essential feature of the apparatus is a four litre oxygen container (a rubber bellows) geared to a kymograph. As the oxygen in the reservoir is exhausted the kymograph automatically records its consumption on a quantity - time chart. Thus on one graph are recorded the O_2 consumption in litres and tenths of litres and the time period in minutes and tenths of minutes. Respiration rate and depth are also recorded. Being a closed circuit apparatus it

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* McKesson Appliance Co., Toledo, Ohio, U.S.A.

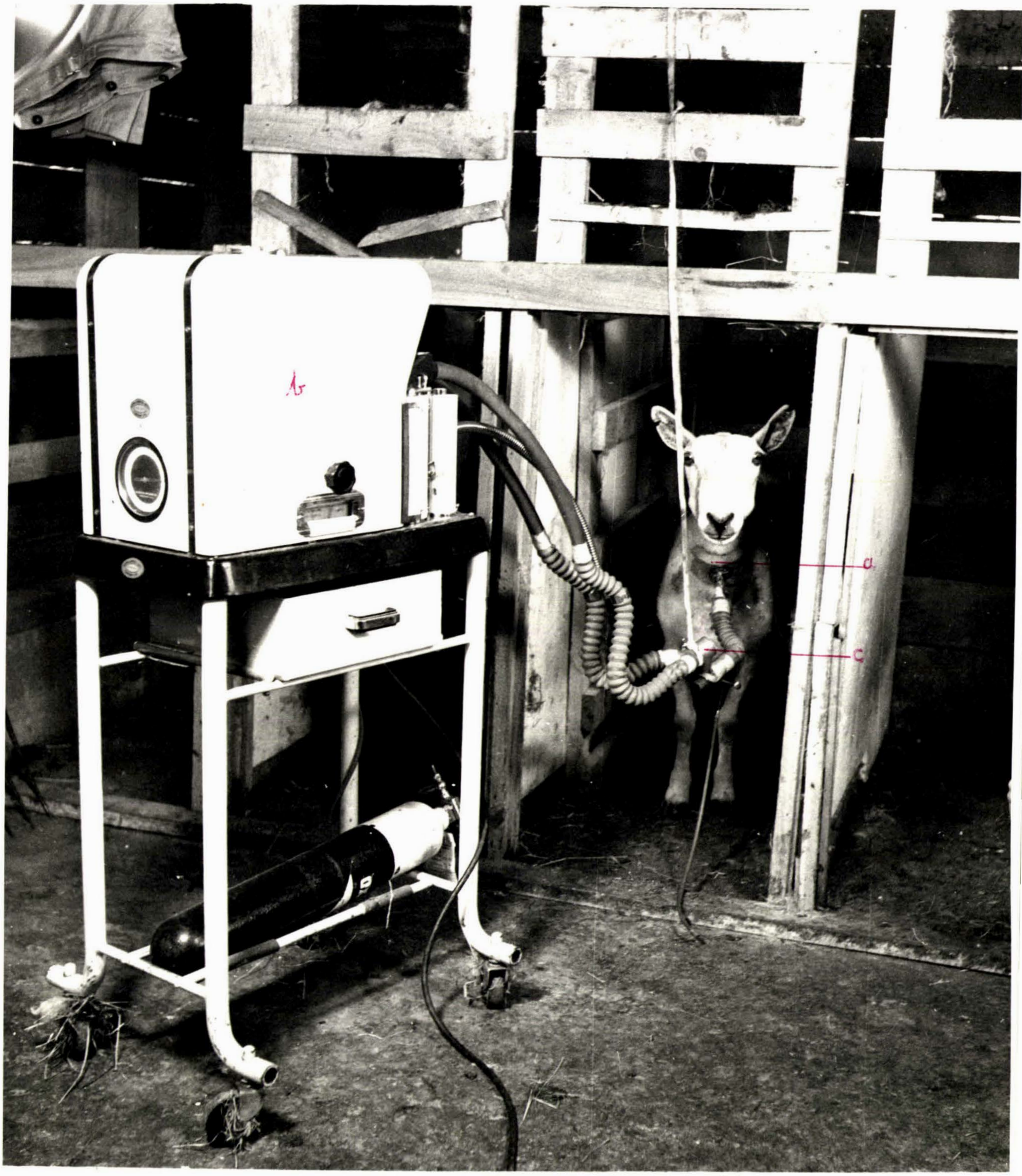


Plate 12. A spirometer recording in progress using the modified 'Field' pattern tracheal cannula. (a) External sealing pads, (b) Spirometer, (c) Two way valve corresponding to the animal's nostrils.

included a soda lime container. When the machine was in operation the charge of soda lime absorbed the exhaled CO_2 for approximately forty runs before it needed changing. Re-charging was carried out at this point even though the sheep may not have indicated the need for this by overbreathing. The metabalor had a built-in thermometer and barometer.

The efficiency of the seal between a tracheotomy tube and a sheep's neck was checked before and after each spirometer recording by placing the thumb over the open end of the tube used to connect the tracheotomy tube with the machine. If the seal was perfect the animal was unable to draw breath. A leak manifested itself as a hiss of inrushing or outrushing air. The test was, by its very severity, able to detect a weakening seal, i.e., one which had given a perfectly normal run but which would almost certainly leak the next time if the rubberised putty was not changed.

Good service was obtained from this arrangement and, in fact, almost all of the calorimetry work to be reported was obtained by its use.

A weakness of the 'Field' tube which only became apparent after the subject had been intubated for several weeks was a tendency for the cartilagenous rings of the trachea to collapse. Merillat (1921) gives a description of this type of occurrence in intubated horses.

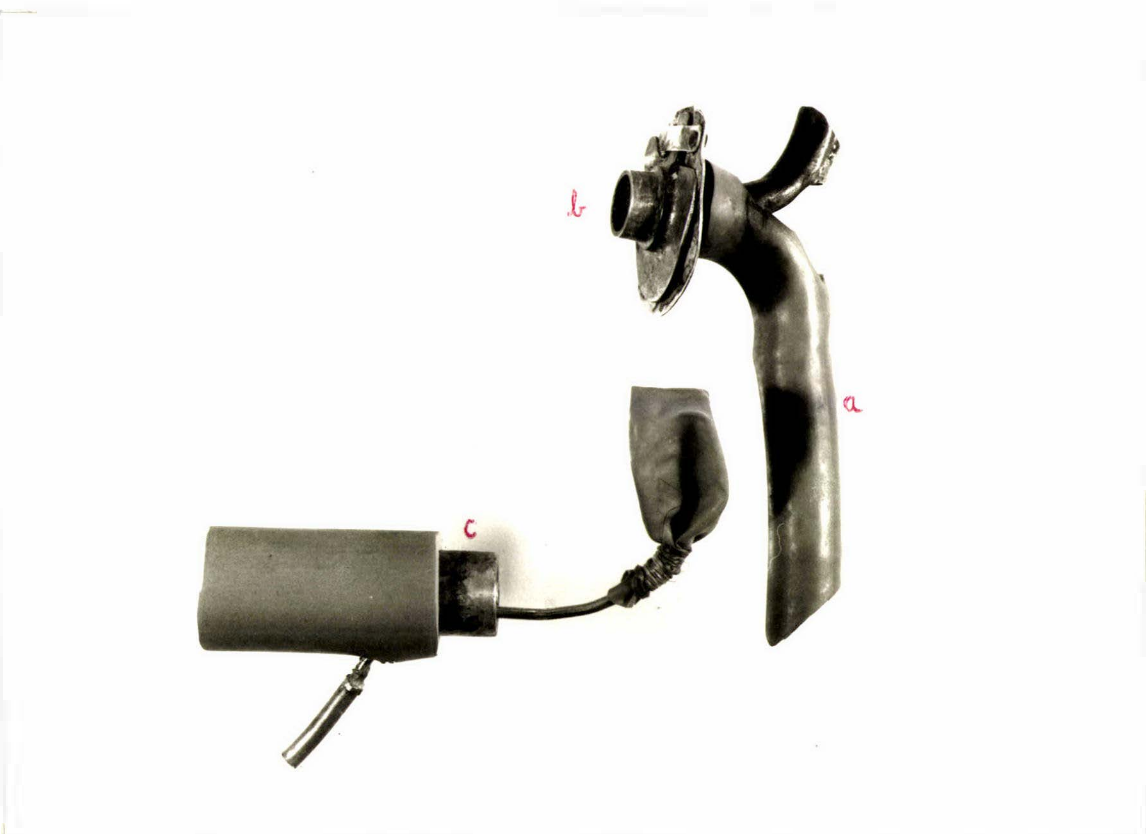
The tracheotomy tubes were therefore modified by soldering onto their tongues half sections of copper tubing (Plate 13 a,b). These half sections completed the ring shape of the tracheotomy tube tongues and gave support to the upper and lower edges of the wound.

It also transpired that, after the 'Field' pattern tubes had been fitted for some weeks, the tracheas showed a marked tendency to close due to an edematous condition of the mucous membranes just below the lower tongue of the tracheotomy tube. This was undoubtedly brought about by the irritating effect of the unprotected edge of the tracheotomy tube working on the wall of the trachea whenever the sheep bent its head. A contributing factor was possibly the increased negative pressures exerted within the trachea to enable the animal to draw air past the partial obstruction formed by the edematous tissues.

To overcome this problem the lower section of the tracheotomy tube was sheathed with a half inch internal diameter soft rubber tube (Plate 14a). The rubber edge still gave trouble but only after some long time had elapsed. However, when the closing of the trachea becomes obvious to the operator, it is a simple matter to slip on a slightly longer piece of rubber tubing. It is of some advantage to feather the lower end of the rubber tubing to produce a softer edge.

Plate 13. Modified 'Field' pattern tracheotomy tube with tracheal supports (a) and (b).

Plate 14. Modified 'Field' pattern tracheotomy tube with rubber-sheath (a) and introducer cones (b) and (c).



Again in connection with the 'Field' pattern cannula, the technique for connecting the sheep to the oxygen spirometer ultimately led to another modification of this piece of equipment.

The requirements were for a smooth and rapid connection so that the sheep were disturbed as little as possible, normal breathing was permitted and the time for dealing with each animal was no more than ten minutes which included the spirometer recording.

As previously described, the smooth connection was originally obtained by using a machine tapered, hollow, brass plug which was easily inserted into the lumen of the cannula. The taper and the soft metal of the plug gave an air tight junction without the exertion of more than light finger pressure on the mating of the two pieces. Unfortunately, however, there was a drawback to this arrangement in that the tapered plug (when fitted into the lumen of the cannula) severely reduced the diameter of the tube through which the sheep drew its breath.

Time devoted to this point resulted in a greatly improved technique. To the outer face of the cannula was soldered a precision turned, hollow, soft brass cone (Plate 14b). The introducer cone (Plate 14c) was machined to fit exactly over the cannula cone so that an air tight joint was obtained with only a slight twist of the fingers. The lumen of the cannula was thereby left free of all obstruction other than the fine, hard, brass capillary carrying the tracheal balloon.

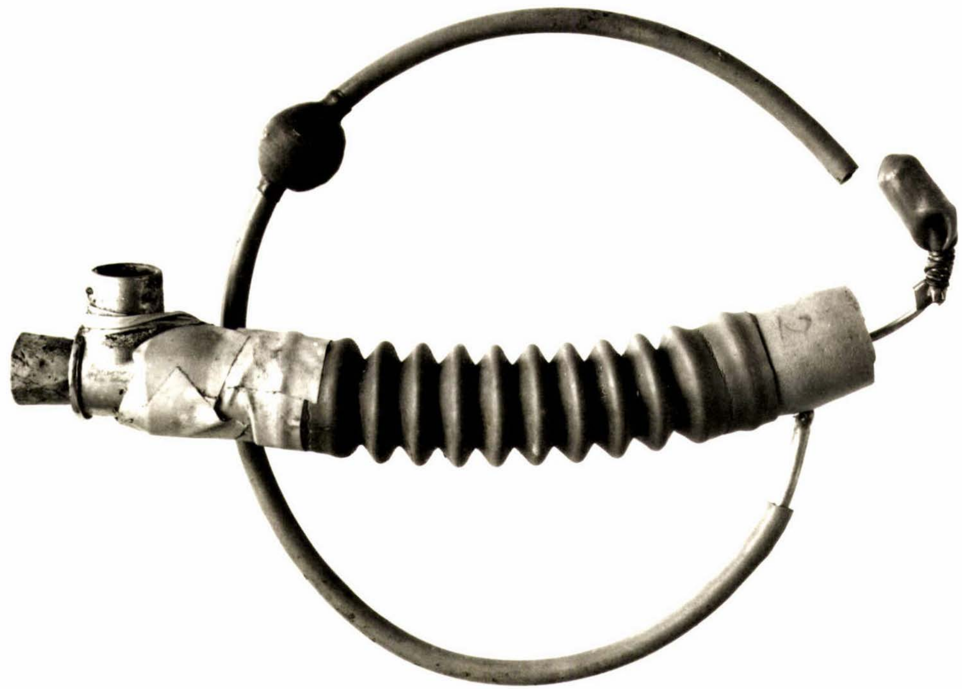
The rapidity with which it was possible to connect up sheep after sheep to the oxygen spirometer owed much to the simple linking devices.

In linking up the sheep to the spirometer another factor had to be taken into account. This was the question of "dead" space between the trachea and the two-way valve (Plate 12c) which corresponded to the animal's nostrils. The problem of dead space is directly related to the necessity of avoiding a build-up of exhaled CO_2 in the tube between the sheep and the two-way valve. Such a build-up of CO_2 results in overbreathing.

Soft rubber tube of half inch internal diameter was originally used to link the sheep to the spirometer. The slight resistance to breathing created by the narrow bore of the tube however tended to produce an overbreathing effect with some sheep no matter what length was used as an estimate of the dead space. A most satisfactory solution to the problem was obtained through the use of one inch internal diameter, corrugated soft rubber tubing as used with anaesthetic machines (Plate 15). This tube was 8 inches long and had an internal capacity of 80 ml.

All of the indirect calorimetry work in this project was carried out using the modified 'Field' pattern tracheotomy tube. However, the fact that a technique so potentially useful for indirect calorimetry work should be complicated by the likelihood of leaks led to the final development of this section of

Plate 15. Connection tube for linking sheep to oxygen spirometer.



the project--a tracheotomy tube designed specifically for indirect calorimetry work.

This tracheotomy tube (Plates 16 and 17) consists of three main parts, the upper and lower sections and a rubber extension with roll-on inflatable cuff.

The lower section which is inserted first has five main features:-

A deeply grooved edge (Plate 16a) and a capillary tube (Plate 16b) which allows the roll-on rubber cuff (Plate 16c) to be inflated after the cannula has been inserted into the trachea. The reason for making the inflatable cuff (Plate 16c) of a roll-on type is one of economy, it being necessary to lengthen the rubber extension of the tracheotomy tube (Plate 16d) whenever edematous thickening of the tracheal mucosa treatens to close the trachea. The rubber extension tube (Plate 16d) fits over and is welded to the metal tube by means of a commercial bonding paste. A pilot balloon always within sight of the operator (Plate 16 e) indicates the state of inflation of the cuff which forms a seal against the inner wall of the trachea.

The upper section of the tracheotomy tube has two main features: a deep cutting edge (Plate 16f) which makes an air tight joint with the grooved edge of the lower section (Plate 16a) when the cannula is closed (Plate 17); and a chamfered tube (Plate 16g).

Plate 16. "T" cannula open--showing

(a) Grooved edge
(b) Capillary tube
(c) Roll-on rubber cuff
(d) Rubber extension tube
(e) Pilot balloon
(f) Cutting edge to fit groove (a)
(g) Chamfered tube.

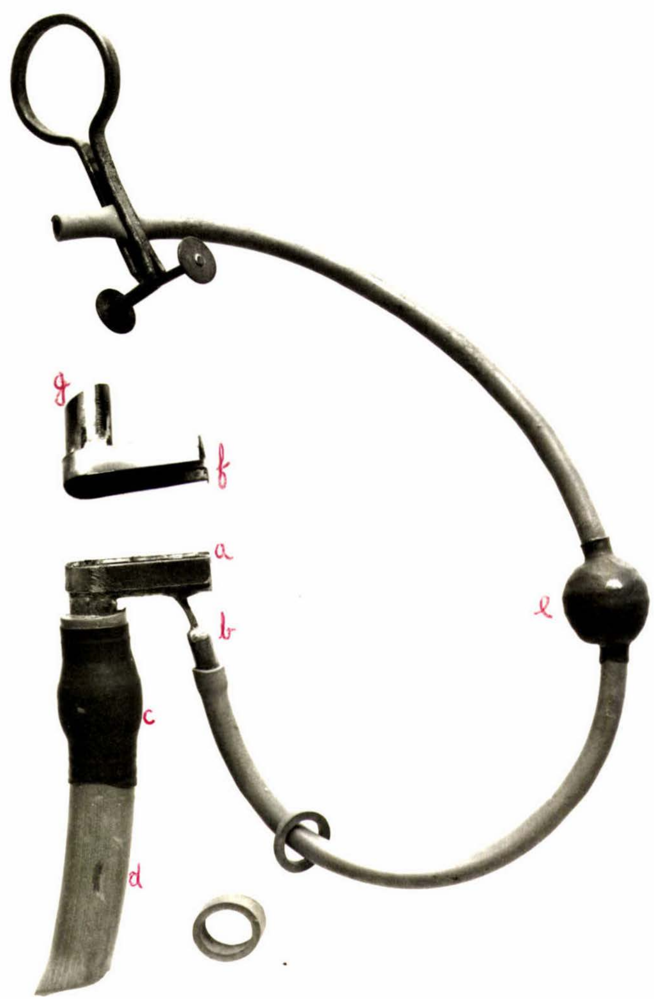


Plate 17. "T" cannula closed.

The chamfer facilitates the fitting of the upper section of the cannula into position in the trachea.

It is proposed to refer to this tube as a "T" cannula and it is intended to develop its use in future work for it obviates the need for elaborate, costly, and time consuming seals between the base plate of the tracheotomy tube and the neck of the animal.

Plates 12 and 18 illustrate the Field pattern and "T" cannulae in use. Note the lack of external sealing pads on the neck of the sheep in plate 18.

During the course of the metabolism experiments it occasionally became necessary to insert 'Magill' pattern cuffed rubber endotracheal tubes into the tracheas of some animals. At times a bent metal tube was used. The difficulties in the use of these tubes as forecast by Colonna (1956) were confirmed. When in use both tubes needed continual cleaning, there being no flow of tracheal mucus to keep the lumen clear. It was also difficult to prevent the open end of the tubes from becoming closed by a stopper of wool, hayseeds and mucus, especially as they had to be taped into position on the exterior of the sheep's neck. In addition, there was firstly a marked tendency for quantities of fluid to accumulate in the lower half of the trachea when a tube had been in place more than twelve hours and secondly the tracheal rings above the fistula collapsed within a few days. Long metal tubes had an additional disadvantage over the rubber tube. Continual

Plate 18. A spirometer recording in progress using the "T" cannula. Note the lack of external sealing pads on the sheep's neck.

neck bending by the sheep rapidly leads to abrasion of the wall of the trachea by the edge of the lower tongue of metal tracheotomy tubes. This results in edematous thickening of the tracheal membranes followed by fibrosis and consequent narrowing of the lumen.

Reference must now be made to the tracheotomy wounds. Quite unnecessarily, as it turned out later, the first two tubes were removed and the wounds dressed daily until healing was complete; a period of about two weeks.

The next group of animals had their tubes left in place until the stitches were removed. This proved a great success. Healing was rapid and no sloughing took place. The final policy which was adopted was to leave the tubes in place until the stitches were removed. A minimum of discomfort and risk of infection is thus obtained and this practice or preferably the use of dissolving sutures is recommended to others who may contemplate work along the lines of this investigation.

A point of note is that the first two patients had the corks omitted from their tubes for the first week or so to facilitate drainage of blood and any discharge from the trachea. What occurred instead was a copious flow of slimy mucus which coated the breasts of the animals with a noxious mess in about twelve hours.

This flow of mucus is probably the trachea's answer to the creation in it of an opening direct to the outside world. Presumably the flow is intended to prevent the entry of dust and other irritants to the lungs and to provide material to close the wound until normal healing takes place.

After all further operations the cork was inserted into the cannula within two hours of a sheep regaining consciousness and this proved to be a satisfactory procedure.

It was noticed at an early stage that if a tracheal cannula was removed for more than fifteen minutes or so it was very difficult indeed to replace owing to the powerful constriction of the muscles through which the fistula was made. Where a cannula was accidentally lost out during the night--as could happen if a fastening catch caught in the wire of the hay racks--the tracheal fistula was completely closed by morning and proved to be impossible to reopen without the use of considerable instrument leverage.

With the facilities available in the shed allocated for this project it was difficult to maintain a high standard of asepsis--in fact the standard was quite low. Fortunately troubles from infected tracheas were not met with until the last two weeks the bulk of the animals were alive. A bloody mucus then formed in large quantities in the tracheas of six animals. This condition was unresponsive to treatment possibly due to the fact that it had long been the writer's practice to bolster the hygiene of the laboratory by greasing the rubber sheathing of the tracheotomy tubes with a suspension of antibiotics in an aqueous base. Incidentally, this also overcame the need for lubricating the rubber tubes before insertion, otherwise they would not slide easily down the trachea.

B-III PRE-REQUISITES FOR METABOLISM MEASUREMENTS

Not only the mechanics of calorimetry are of importance in metabolism studies, as for example, the psychological effects of unwonted interference with the subject may produce profound changes in the metabolic rate. Also, when an animal is being regularly fed and the stimulating influence of food plays a large role, studies in metabolism must be carried out over a sufficient period of time so that the result corresponds to an entire representative day or succession of days of normal feed.

Ritzman and Benedict (1938 a) devote a great deal of space to dealing with the pre-requisites for metabolism measurements. In discussing the pre-requisites for energy metabolism studies with ruminants, Ritzman and Benedict express their opinion that:-

> "In spite of the large number of studies on other animals, in which comparable conditions of muscular repose and cessation of digestive activity were fairly readily obtained, analysis of the literature on the metabolism of the ruminant, both early and late, shows that the pre-requisite conditions for measurements on the ruminant have been little understood by most investigators and the variable factors affecting such measurements have seldom been completely eliminated or standardised."

In carrying out this project the writer made every possible attempt to follow and to add to the principles laid down by these authors. These principles are aimed at eliminating or standardising:-

(1) The activities connected with the consumption of food.

(2) Extremes of environmental temperature.

(3) Muscular and nervous tension.

(For this project the following additional variables were considered):-

(4) Time of day.

(5) Position in the recording sequence.

B-IV EXPERIMENTAL ARRANGEMENTS

In the human, basal metabolism (otherwise standard metabolism or post-absorptive metabolism*) is an expression used to designate the energy (heat) output of the body at complete mental and physical rest, twelve to sixteen hours after the last meal.

In the ruminant, however, it may be argued that a similar post-absorptive state possibly does not occur for days after the last feed (Forbes et al. 1926; Ritzman and Benedict, 1938 b; Marston, 1948 b). In any case sheep on the hill or any type of normal pasture are not on a restricted diet--they have food before them at all hours of the day and night. The oxygen requirements of the animal on full feed is therefore one of some practical interest and so it was decided that this project should be based on continuously fed animals.

This project being concerned with hill country Cheviot and Romney Marsh ewes the experimental animals were selected at random from stock carried on Tua Paka, one of the hill farms attached to Massey Agricultural College.

Mature ewes were chosen in order that growth effects could be eliminated from consideration. Pregnant animals were all that were

* The state attained when the effects of the last meal have ceased to register in increased metabolic activity.

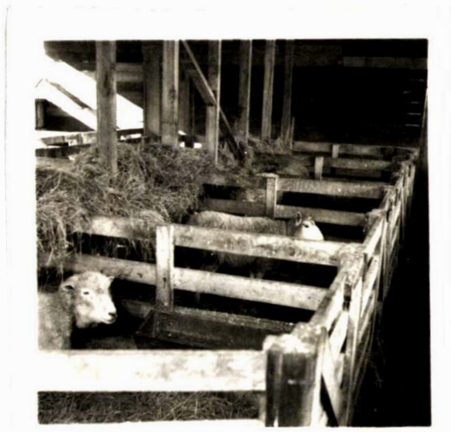
available but it was hoped it would be possible to pick up the effect of lambing and lactation on the oxygen consumption of these sheep. All of the ewes were in-lamb to the Southdown ram.

The first ewes were moved to Massey Agricultural College on 5/7/56. These sheep (five of each breed) were housed one to a pen (Plate 19) and were offered a diet of good quality hay ad libitum and one pound per head of a concentrate in nut form. The Cheviots settled down immediately and ate hay and cake voraciously, but of the Romneys one starved herself to death while the other four came only slowly to eat their rations. Romney No. 5 did not eat cake until the third day of Block II energy metabolism experiments and this was possibly reflected in her records which were below the general run of all the other sheep to this point (Appendix A, tables 1 and 2).

The general management of these animals was quite simple, the aim being to interfere with them as little as possible. Fresh hay was put in the racks at 9:00 a.m. every morning and the cake was fed at the same time. Feeding of a concentrate sheep cake was soon abandoned. The sheep ate it well for three or four weeks and then grew tired of it and left the major portion of their ration.

In place of the cake it was found that one pound of crushed oats with a handful of kibbled peas were eaten avidly. The latter were particularly welcome to the animals who would refuse to touch their oats without the sprinkling of peas. This diet of hay ad libitum, crushed oats and kibbled peas was maintained throughout the investigation.

Plate 19. Interior of sheep shed.



At no time did the animals show lack of interest in it until the aftermath of a ten day period of complete starvation. Water was always available in each pen. No attempt was made to measure water consumption but hay was consumed at the rate of approximately three to four pounds per head per day.

Environmental variations within the shed due to the sun rising on one side and setting on the other, a leaky roof and wind-driven rain were compensated for by randomising the sheep within the shed.

The ewes all lambed without assistance between 24/8/ and 13/9/56 and both they and their lambs took quite kindly to their living conditions.

Foot rot presented virtually no problem during the entire period of confinement which in some instances extended to eleven months. Attention was paid to each foot individually as and when it was observed to be balled up with a mixture of hay and dung.

From the very beginning the writer set out to win the confidence of the animals in order that they might be completely relaxed when being handled for recordings with the oxygen spirometer. All figures, graphs and statistical analyses in this division of the project depend for their final accuracy on the degree to which success was achieved in this matter. The sheep soon came to accept the necessary handling as part of the routine of living.

On 27/7/56, one Cheviot (No. 10) and one Romney (No. 5) were each fitted with a "Field" pattern tracheal cannula. Each wound healed snugly round the stem of the cannula, the stitches being removed about the fifth day after the operation. During the second post-operative week the technique of using a tracheal balloon and the method for connecting the sheep to the oxygen spirometer were tested.

The first tests were successful, neither of the sheep seriously objected to being handled and every indication was given that the technique was likely to prove worthy of development. The first two sheep (which survived until they were slaughtered on 8/5/57) were used for a period of approximately three weeks before any further sheep were cannulated. Technique development having proceeded to a point at which it could be decided to continue with the project, four more each of Cheviot and Romney ewes were cannulated on 30/8/56.

Recordings on the oxygen spirometer were made in a small room at one end of the sheep barn. Against one wall of this room small pens were constructed as illustrated in plate 12. These recording pens were of approximate dimensions 20" x 42" and held one sheep comfortably. Later experience showed that they would have been improved by being several inches narrower to prevent the sheep from turning their heads away from the operator. Each pen was closed by a sliding gate which could be operated smoothly with one hand while the other was busy with the oxygen spirometer.

The sheep were quickly trained to walk quietly out of their pens and to the recording room where they were backed into the small pens. So used to this procedure did the sheep become that they soon turned themselves round and backed into the recording pens with only slight guidance. This cooperation was regarded as being of the utmost importance to the work.

From 5 to 19/9/56, the ten sheep were subjected to a period of training to the oxygen spirometer. This lengthy training was abandoned for all future animals brought into the experiment as it was found that four days at the most were needed before the animals were completely relaxed in the recording pens. They all regularly started chewing the cud immediately after the gate was dropped to fasten them in the recording pen. Sometimes they would continue cud chewing throughout the recording runs. In the case of these records it was found that a second run could be obtained free of the interruption of cud chewing if given immediately after the first. Although no claim is made that all animals behaved themselves at all times, it is submitted on the basis of the cud chewing phenomenon that recordings were obtained with the animals in the maximum attainable state of relaxation. As will be seen from plate 12, during the recording period the gate was in the raised position.

Plates 20 and 21 illustrate typical spirometer recordings, their straight line nature, repeatability, and eructation blips.

The recording period was originally fixed to commence at 1:00 p.m. every day but after the first four days of Block I experimental recordings (Appendix A, table 1) the policy was altered to one of making all records before 9:00 a.m., commencing as nearly as possible at daybreak.

Plate 20. Typical oxygen spirometer graph. Note the downward blips "X" produced during eructation. These blips are due to cessation of breathing and not to the entry of eructated gas into the spirometer.

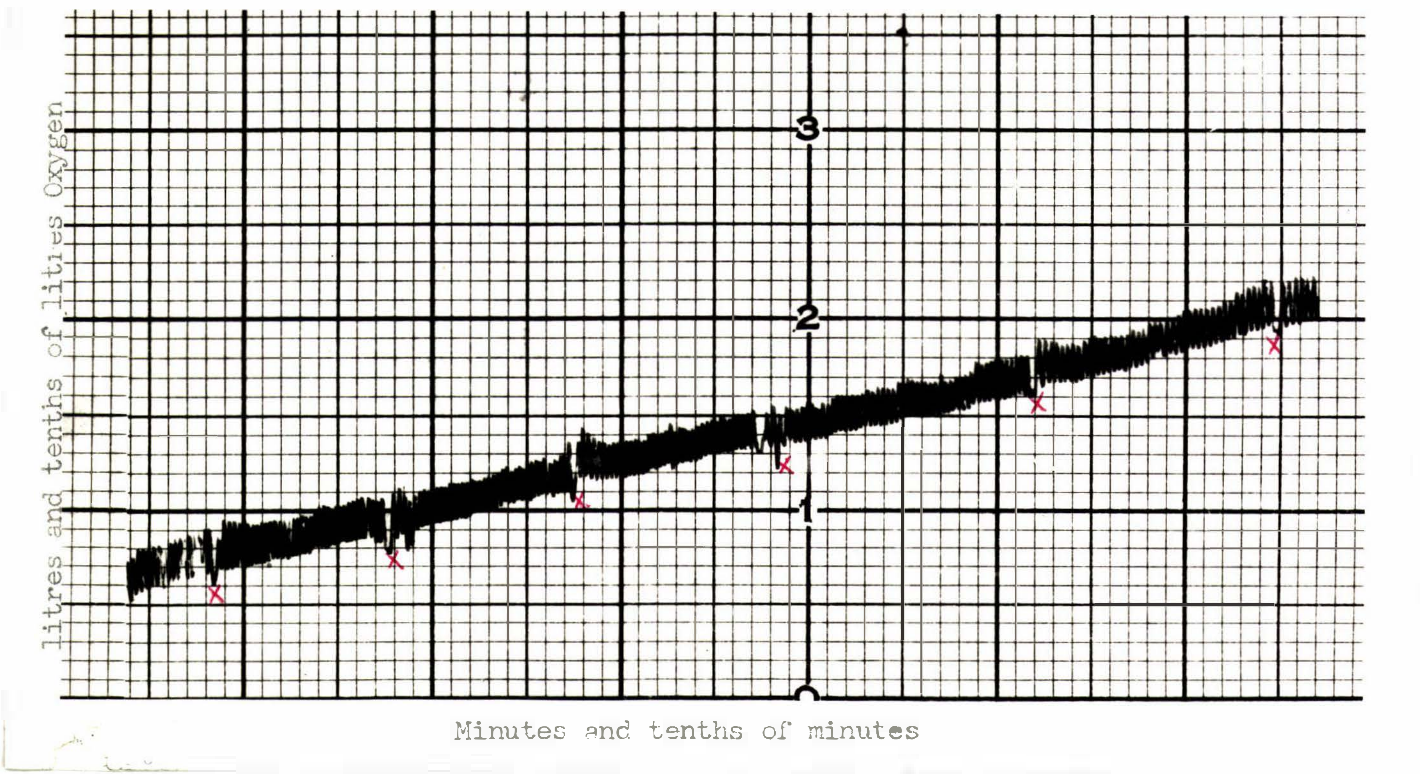
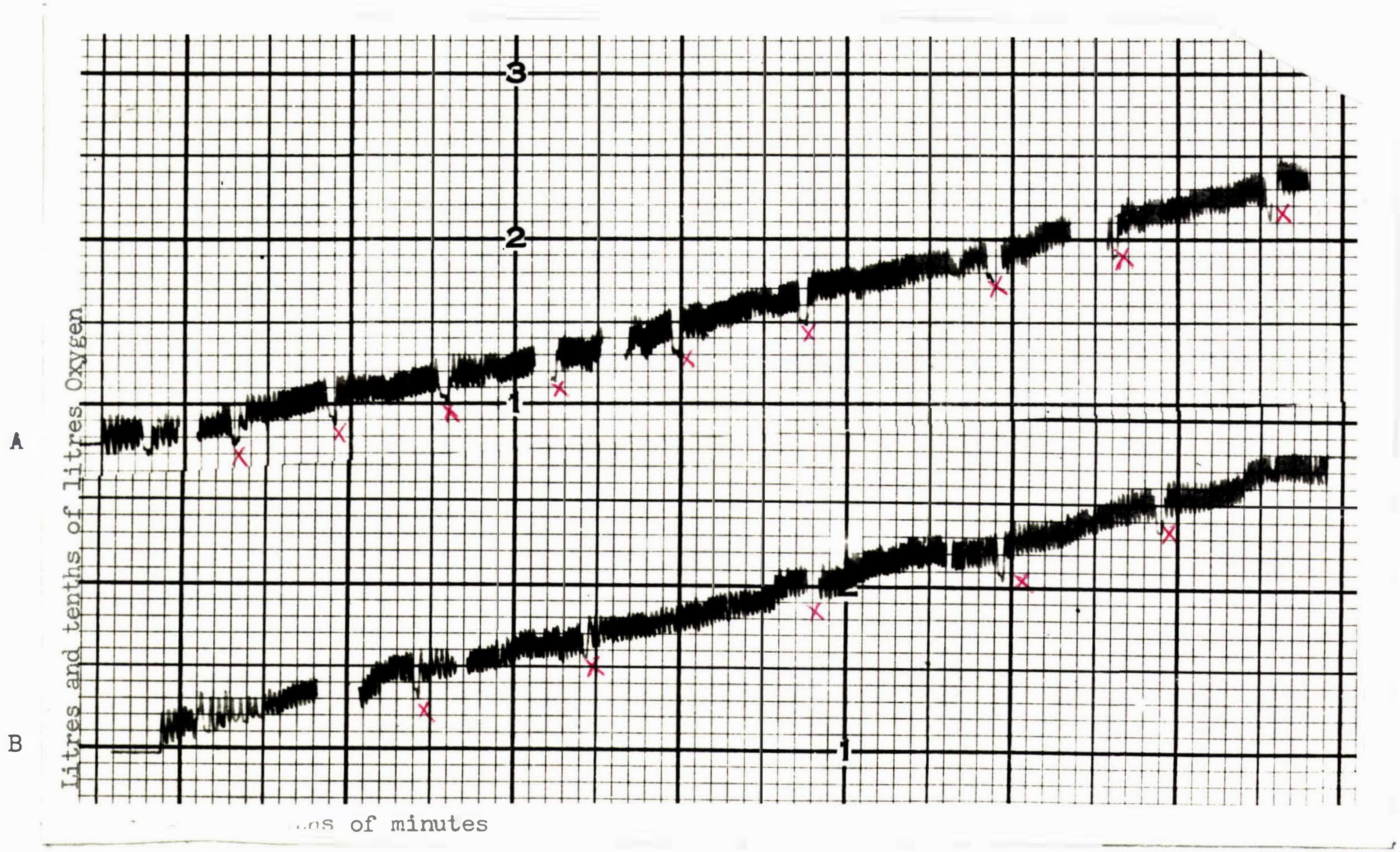


Plate 21. Metabolism charts illustrating:-



1. The lack of effect of prolonged metabolism recordings on the respiratory pattern and rate of oxygen consumption.

2. The repeatability of recordings; chart B was made 8 minutes after chart A.

3. Eructation blips "X".

At this time of day temperature and barometric pressure were almost static and except during midsummer there was no accelerated breathing due to the effects of heat.

B-V EXPERIMENTAL DESIGN

In choosing the experimental design for the energy metabolism experiments account had to be taken of the aim to study the animals on full feed at different periods during the year and the effect on them of prolonged fasting.

It was also necessary to recognise the possible existence of fluctuations in ruminant metabolism such as were indicated by the work of Ritzman and Benedict (1938 c) and Benedict (1938 c). Further, since the total time required to record 10 sheep was between two and three hours, a consistent bias could be introduced if each animal occupied the same position in the recording sequence from day to day. In addition, the sheep were moved to the recording pens in batches of three (except the tenth which was brought in immediately after the seventh had been recorded); hence there was a possibility that the recent muscular exercise might be an unbalancing factor if the recording plan was not designed to even out any such influence.

The above considerations suggested the use of a Latin square design in which the oxygen consumption of each sheep was recorded daily in the early morning, each of the sheep appearing once in each of the ten possible positions in the recording sequence over a ten day period, these ten day periods occuring over the year.

B-VI CHRONOLOGICAL EVENTS 19/9/56 - 8/8/57

Table 2 presents in chronological order the events from the commencement of the first routine energy metabolism recordings on 19/9/56 to the slaughter of the last sheep on 8/8/57. Also in chronological order, a detailed discussion of the listed events follows below:-

19/9/56

Block I of routine energy metabolism recordings was commenced (Appendix A, table 1). The ewes had all lambed and the sheep were in the early stages of lactation. Three of the Cheviots were unavoidably five to six days closer to their parturition dates than the Romneys. This block of work went reasonably smoothly being complicated only by the main defects in the technique at this stage--leaks between the cannula and the neck of the animal. These occurred in fourteen (eight Romneys and six Cheviots) out of the total of one hundred recordings.

To rule out the effect of separation of ewes from lambs, during the recording period the lambs were placed in the recording pens with their mothers. Having been previously trained to this routine the lambs would in many cases voluntarily follow their respective dams into the recording room and then into the small pens.

7/10/56

Block II of routine energy metabolism recordings was commenced (Appendix A, table 2).

Table 2. Chronological events--energy metabolism sheep--19/9/56 to 8/8/57.

Date	Events
19/9 - 4/10/56	Experiment (Block (I); Appendix A, table 1) to compare the energy metabolism of Romney Marsh and Cheviot ewes on full rations shortly after lambing in the spring of the year.
7 - 17/10/56	Experiment (Block (II); Appendix A, table 2) to compare the energy metabolism of lactating Romney Marsh and Cheviot ewes on full rations. Also to ascertain the effect of 72 hours starvation on their energy metabolism.
19/10/56	All ewes turned out to grass in an attempt to improve their condition.
2/11/56	All ewes returned to sheep barn - lambs weaned.
23/11 - 28/12/56	Experiment (Addendum a) to investigate the effect of shearing and drenching with simulated rain on the respiratory exchange and respiratory pattern of sheep.
5/1/57	Experiment (Addendum b) to ascertain the effect on their metabolic rates of feeding one pound oats to each of three sheep after twelve hours starvation.
23/1 - 3/2/57	Experiment (Block (III); Appendix A, table 3) to compare the energy metabolism of Romney Marsh and Cheviot ewes on full rations in mid-summer.
28/1/57	Experiment (Addendum c) to ascertain the effect of 1 thyroxine on the oxygen consumption, respiratory rate and body weight of one Romney Marsh ewe.
8/2 - 12/2/57	Experiment (Block (IIIa); Appendix A, table 4) to compare the energy metabolism of Romney Marsh and Cheviot ewes on full rations in mid-summer.
14/3/57	Experiment (Addendum d) to investigate methane exhalation in sheep.
29/3 - 7/4/57	Experiment (Block (IV); Appendix A, table 5) to compare the energy metabolism of Romney Marsh and Cheviot ewes on full rations in autumn.
8/4 - 17/4/57	Experiment (Block (V); Appendix A, table 6) to compare the energy metabolism of Romney Marsh and Cheviot ewes over a ten day period of total starvation in autumn.
18/4 - 27/4/57	Experiment (Block (VI); Appendix A, table 7) to compare the energy metabolism of Romney Marsh and Cheviot ewes with full rations offered after a ten day period of total starvation.
7/5/57	All ewes photographed. Blood samples taken for haematological studies.
8/5/57	Six ewes slaughtered. Carcass data and skin areas obtained.
8/5 - 8/8/57	Remaining two sheep used for tracheal cannula development (one died 4/6/57).
8/8/57	Last ewe slaughtered and the necessary carcass and skin area data recorded.

This consisted of seven daily records taken under normal conditions. The eighth and ninth day records were obtained after twenty-four and forty-eight hours of complete starvation, respectively. Tenth day records (72 hours starvation) were not taken due to a breakdown in the writer's health. Of Block II, seven records (two Romneys and five Cheviots) were spoiled by leaks.

19/10/56

The ewes were turned out to grass. They had all recently lost condition. It was believed that their lambs were bearing heavily on them in the comparatively confined space of the pens.

During the period at grass one Cheviot (No. 9) died of maggot fly strike in the trachea and one Romney (No. 1) died of suffocation following the loss of her cannula which sprung its fastening catch. One Cheviot (No. 10) was very sick due to the thickening of the mucous membranes below the lower tongue of her cannula. It was at this stage that a method for dealing with this type of situation was discovered, i.e. by simply lengthening the cannula with a rubber tube. The Cheviot (No. 10) made a splendid recovery.

2/11/56

The ewes were returned to the sheep shed, the lambs being weaned at this time.

23/11 to 28/12/56

The opportunity was taken at this stage of investigating the effect of shearing and drenching with simulated rain on the respiratory exchange and respiratory pattern of the animals. (Addendum a)

5/1/57

Three of the ewes, two Cheviots and one Romney, were used to ascertain whether or not the technique could be used for plotting the effects on their metabolic rates resulting from feeding each sheep one pound of oats after twelve hours starvation (Addendum b).

Unfortunately towards mid-January hot weather with shed temperatures rising to almost 90°F. brought great discomfort to the sheep which, showing the symptoms of a pasteurella type infection, began to respire very rapidly. It was then found to be essential to leave the corks out of the tracheotomy tubes to compensate for the slight resistance offered to rapid breathing by the presence of a tube within the trachea. Rapid passage of warm air in and out of the stem of a tracheal cannula leads to a build-up of dried mucus on its lower tongue. Under these conditions it was necessary to remove the cannulae for scraping twice or thrice daily. An inordinate amount of time and attention was required at this stage. Only rapid breathing produced the effect for at all other times the cork could be left out with impunity.

23/1/57

Block III metabolism recordings commenced (Appendix A, table 3).

At this time the early morning temperatures were moderate and in the ten day period only two recordings were spoiled by leaks.

28/1/57

One sheep (Romney No. 2) was allocated to a cooperative study of the effects of 1 thyroxine on its metabolic rate, respiration rate, and live weight (Addendum c).

8/2/57

A further block of recordings, Block IIIa (Appendix A, table 4), was brought to a close after the fifth day because high temperatures and humidity were maintained throughout this day and continued for some weeks after. One recording was spoiled by leaks.

During the hot weather period it was found of benefit to the animals to thoroughly spray down the shed about noon hour.

More clement conditions arrived towards the end of March when night temperatures started to fall and mild hoar frosts occurred.

14/3/57

In view of the statements made by Brody (1945)* Blaxter (1954)* and Ritzman and Benedict (1938)*to the effect that the ruminant exhales methane in considerable quantities, it was deemed necessary to investigate the amount of methane, if any, which accumulated in the oxygen spirometer during recordings. This was done as soon as appropriate arrangements could be made for gas analyses to be carried out by the Dominion Physical Laboratory at Wellington (Addendum d).

* These references appear in the bibliography for Addendum d--Methane exhalation in sheep.

29/3/57

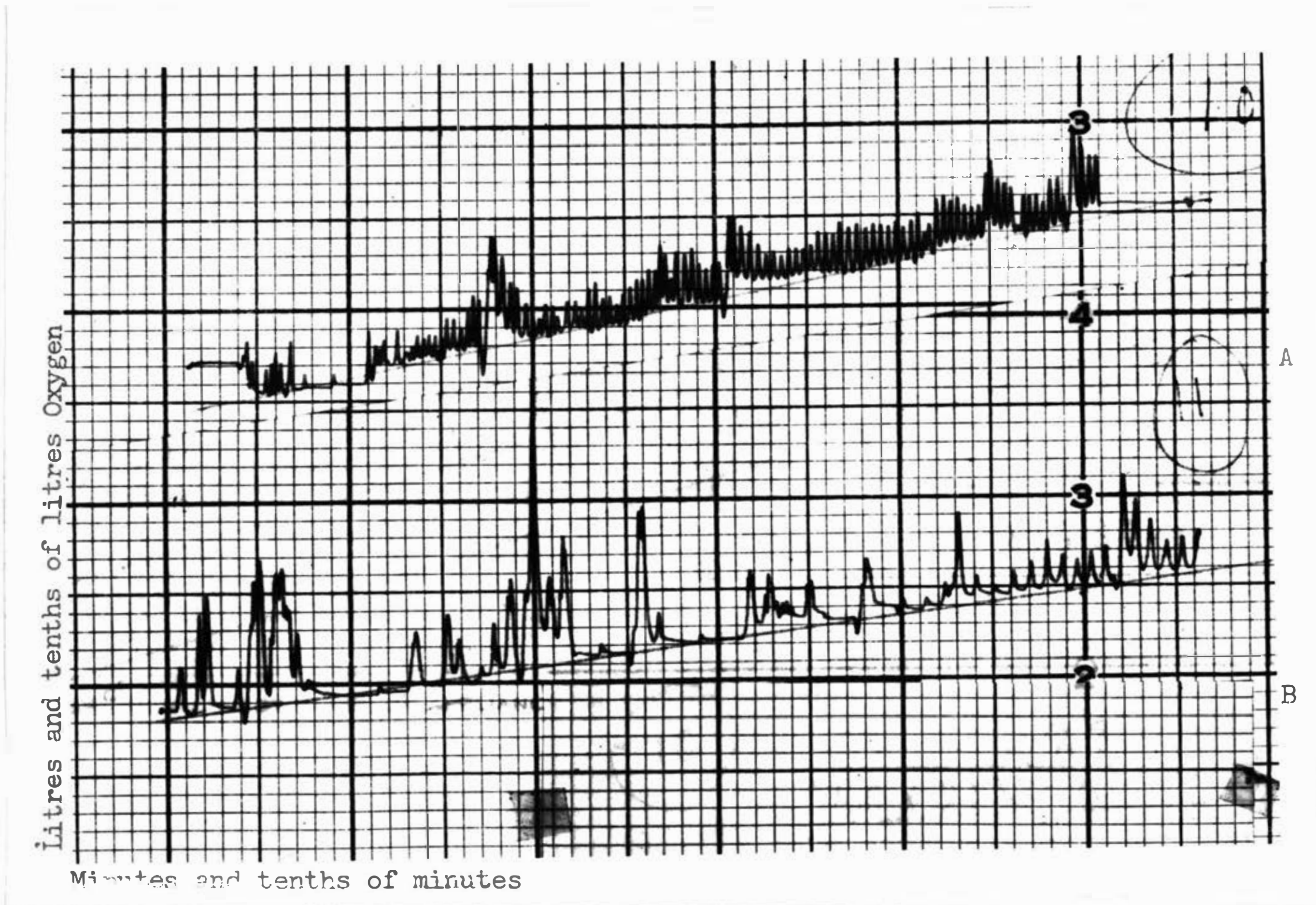
Experiment Blocks IV, V, and VI followed a preliminary two or three days reaccustoming the animals to the routine. Block IV (Appendix A, table 5) was run off with the sheep under normal feed conditions and Block V (Appendix A, table 6) followed with the animals completely deprived of food although water was allowed *ad libitum*. For the starvation period all bedding was removed and only a handful of scattered sawdust was used to soak up the urine. The sheep made no attempt to eat the sawdust.

From the management viewpoint the ten days of complete starvation were of great interest. At no time did the sheep fail to hunt for food on the journey from the recording room to their pens, or fail to show interest when the feed room door was opened. The animals showed no signs of weakness and spent no undue length of time lying down. Water consumption, though not measured, fell quite appreciably. Respiration rates fell most markedly (Plate 22).

For Block VI (Appendix A, table 7) the animals were again offered full rations. Initially, they were in all cases only partially consumed. In fact, it took three to four days before the sheep regained their appetites. Two weeks after the completion of Block VI it was decided to abandon further energy metabolism work owing to the onset of a tracheal infection in six animals.

7/5/57

The experimental animals were photographed. These photographs



A 24 hour starvation point

B 240 hour starvation point

Plate 22. The effect of starvation on the respiratory pattern of a Cheviot ewe.

are presented in plate 23 as evidence of the general well being of the sheep despite the tracheal infection and the fact that they had been subjected to many months of constant handling.

An attempt was made to obtain estimates of blood volume, packed red cell volume (P.C.V.) and haemoglobin values. This work was incompleted through poor artificial lighting and the extraordinary elusiveness of the jugular in some animals.

8/5/57

Eight of the metabolism sheep were slaughtered. At slaughtering the animals were most carefully skinned and the following weights recorded:- dressed carcass, heart, adrenals, thyroids, and ovaries. The dressed carcasses were put into cold storage for future reference and the ovaries were examined. A permanent record of each skin area was obtained by laying the skins on sacking which was then carefully cut to shape.

8/5 to 8/8/57

The remaining two animals (one Romney and one Cheviot) were used for cannula development purposes. The Romney died of pneumonia on 4/6/57. The skin, heart, adrenals, thyroid, and ovaries were removed immediately following death. So fresh was the carcass that it bled quite freely under the knife. This animal was in a very fat condition. The lone Cheviot was used for further developmental experiments until 8/8/57 when it was slaughtered and the necessary measurements recorded.

Plate 23. The energy metabolism experiment sheep 7/5/57 (prior to slaughter on 8/5/57).

Y

5

15

8

10

16

X

20

7

17

Plate 23. (cont.) The energy metabolism experiment sheep 7/5/57 (prior to slaughter on 8/5/57).

B-VII BASES FOR THE PRESENTATION OF THE RESULTS OF ENERGY METABOLISM EXPERIMENTS

The bases for the presentation of the results of energy metabolism studies have apparently been argued over since such studies were initiated. So complicated have some authors made their computations and theories that Benedict (1938 d) felt obliged to hope that the progress of studies in animal metabolism would not be deterred by such complicated techniques and methods of calculation. Benedict (1938 e) and Brody (1945 e) devote a large section of their published works to the possible relationships existing between heat production and the following biologic factors:-

(1) Surface Area

The method of expressing energy metabolism as a function of surface area was introduced by Rubner (1883). Based upon a series of observations on dogs of greatly differing weight, Rubner came to the conclusion that the surface area calculation equalised the heat production of these animals. This concept was subsequently applied by Rubner and notably Voit (Benedict 1938 f) to animal species in general and is today generally accepted as applicable to all warm blooded animals with few exceptions. Benedict and Brody, in general, criticise the use of this method of presentation as follows:-

Representing metabolism as a function of external surface area would imply that the surface area is the cause of the metabolic rate, whereas heat production is merely incidental to metabolism as the animal's body does not, within the zone of thermal neutrality, metabolise because it must produce heat but produces heat because it metabolises; the immediate causative mechanism being resident in the neuroendocrine system and not in the external surface area. In addition, the surface area of a living animal is not constant and cannot be measured in such a manner that the results can be checked by different investigators. Further, an animal's surface area, as it relates to heat loss, changes with environmental temperature not only by its skin contracting in cold weather and spreading out in hot weather but also by its developing heat conserving and heat dissipating devises, e.g. wool in sheep.

(2) Body Weight

Reporting energy metabolism upon the basis of heat production per unit of body weight is according to Benedict, a time honoured custom; however, the same author argues that there is little basis for the belief that the expression of the heat production per kilogram of body weight can equalise either intraspecifically or interspecifically animals of varying sizes.

(3) Body Weight \ 0.73

Brody argues that basal energy metabolism does not vary directly with simple body weight or surface area but varies directly with what can be called metabolically effective body weight. Brody found that this value was about $W^{0.73}$ for animals ranging in weight from mice to elephants. In 1935 the Committee on Animal Nutrition of the National Research Council* (U.S.A.) had recommended that this figure $W^{0.73}$ be adopted for metabolism work. Benedict expresses some dissatisfaction with it. In considering the futility of attempts to discover a unifying principle in metabolism, Benedict reaches a conclusion that:- "The more one thinks over the factors known today as influencing basal metabolism, the more one realises that basal metabolism in many species is not a constant and that with many races there are differences in metabolism. It seems therefore unjustifiable to apply mathematics to the pooled end result of the activities of millions of cells, each highly differentiated with different energy potentialities and actuated by different stimuli."

However, Kleiber (1947 a) in a review of body size and metabolic rate remarks that, "If this is the way Benedict feels, one cannot help but wonder how he ever became interested in conducting a respiration trial and why, furthermore, he even calculated the means of groups of several of these pooled end results, which indeed is applying mathematics!" Kleiber (1947 b) goes on to eventually put forward his own recommendation that the three-fourths power of the body weight is representative of metabolic body size for comparison purposes.

* Report of conference in energy metabolism held at State College, Pa., under auspices of Committee on Animal Nutrition, Nat. Research Council, June 1935 : 7 (cited from Benedict, F. G. (1938) Carn. Inst. Wash. Bul. 503 : 177).

Both Benedict (1938 g) and Kleiber (1947 c) support the possibility of blood measurements being of value as an alternative to carcass factors in expressing energy metabolism measurements.

Marston (1946 c) adopted the function $W^{0.73}$ as a parameter to relate the heat productions of sheep of different body weights and as a basis for comparing their behaviour with cattle. In considering Marston's work, however, Hellberg (1949 a) comments that "The correction for the very wide variation in weight was carried out in a manner that is probably not correct. It also seems as though certain systematic errors are inherent in the material." Hellberg (1949 b) puts forward an argument that so far as possible the variation in body weight ought to be analysed with reference to its causes and that the different items ought to be treated differently in the way of correction.

For this investigation the problems of reporting are to a certain extent sidestepped by the presentation of the oxygen consumption data corrected to Standard Temperature and Pressure and the data as related to:-

(1) Animal.

(2) Kilograms body weight.

(3) Sq. metres computed surface area.*

(4) Kilograms body weight $^{0.73}$

The presentation of the basic data in litres O_2/5 minutes is a departure from the usual practice of expressing metabolism in

---

* Brody 1945 f

Cals./5 mins. or Cals./24 hours. Benedict (1938 h) puts forward a powerful argument against the use of the 24 hour period in so much as it seems illogical to him to report results on the basis of the 24 hour period when the measurements are almost never continued for 24 hours. Benedict states that the results could be expressed as cubic centimetres consumption of O_2 per minute.

The writer considers that since his measurements were made as O_2 consumption per five minute periods, then the results should be reported on that basis. For purposes of comparison the multiplication of the figures by the appropriate factors will give Cals. per 5 minutes, 1 hour, 12 hours, or 24 hours. There is some risk in doing this, however, for the multiplication by K. results in increasing the error variance by K^2; also in starvation periods the caloric value of the oxygen consumed may change drastically.

Simply expressing the metabolic rates in oxygen consumption per five minutes avoids all argument about caloric values and time periods; therefore, that is how the data are presented, although on one occasion the Calories per 24 hours presentation is used when it is desired to compare standards.

B-VIII RESULTS

(a) Statistical Procedures.

Missing values for Block I, Block II and Block IIIa (Appendix A, tables 1, 2, 4) were calculated by standard statistical procedures for randomised blocks (Cochran and Cox 1957) and the tables were analysed on a randomised block basis. Block III (Appendix A, table 3) was completed by the standard procedure for two missing values in Latin squares (Snedecor 1946). Blocks III, IV, V, VI (Appendix A, tables 3, 5, 6, and 7) were analysed as Latin squares.

B-VIII (b) Introduction of New Animals

The introduction of new animals during the period of this project makes it necessary to interpret all results with caution. However, it is a striking fact that whenever replacement animals were introduced they responded in the same general manner as the remaining animals in each group (Tables 3 and 4; appendix A, tables 3 to 7 inclusive).

For the changes by way of the introduction of new animals (four Romneys and three Cheviots) it should be noted that no sheep were brought in during an energy metabolism experiment. Of the ones that fell by the wayside, No. 1 died of suffocation following the loss of her cannula when out at pasture; No. 2 failed to regain flesh after rearing a very good lamb and so was relegated to other work; No. 3 died of pneumonia following on probable grease contamination of the lungs; No. 9 died of blow fly strike in the trachea while out at pasture; Nos. 6 and 4 died of pneumonia probably connected with a pasteurella infection for which No. 2 was suspected of being the carrier; No. 21--a very good and fit animal--died for no readily discernible reason.

It is noteworthy that the first two sheep to be cannulated

Table 3. Showing for the energy metabolism experiment ewes:

a. Mean liveweights in kilograms (experiment Blocks I - VI).

b. Square metres computed surface areas* (experiment Blocks I - IV).

c. Final liveweights in kilograms.

d. Square metres measured surface areas.

	19/9 - 4/10/56		7 - 17/10/56		23/1 - 3/2/57		8 - 12/2/57		29/3 - 7/4/57		8 - 27/4/57			
	Block I		Block II		Block III		Block IIIa		Block IV		Blocks			
											V	VI		
	a	b**	a	b**	a	b**	a	b**	a	b***	a	a	c	d
R 1	53.5	1.61	54.0	1.17										
R 2	42.6	1.02	40.4	0.99										
R 3	44.0	1.04	36.7	0.93										
R 4	49.0	1.10	46.3	1.07	49.0	1.10	50.6	1.12						
R 5	40.8	0.99	39.5	0.97	54.1	1.17	51.5	1.13	50.8	1.12	43.5	44.4	51.7+	1.13
C 6	43.5	1.03	39.0	0.97										
C 7	46.3	1.07	42.6	1.02	41.1	1.00	42.9	1.02	36.7	0.98	34.0	34.0	31.7+	0.91
C 8	48.1	1.09	46.7	1.07	44.1	1.04	45.6	1.06	45.3	1.04	39.5	40.8	40.4+	1.06
C 9	50.3	1.12	47.2	1.08										
C 10	43.5	1.03	39.4	0.97	45.0	1.05	47.2	1.08	49.4	1.09	44.0	45.3	44.4+	1.02
R 15					54.6	1.17	53.5	1.16	57.6	1.18	49.9	50.8	51.7+	1.22
R 16					47.7	1.09	46.0	1.06	51.0	1.10	45.3	47.2	44.0+	1.16
R 17					45.5	1.06	46.0	1.06	47.6	1.07	41.3	42.2	40.8+	1.02
C 20					42.3	1.01	44.0	1.04	44.4	1.04	41.3	42.2	41.7+	1.02
C 21					48.1	1.09	50.1	1.12						
R X									58.0	1.21	54.6	54.4	++	1.17
C X									60.8	1.24	54.4	56.2	56.6+*	1.20

* Brody (1945 f)
** Computed from the weights of the animals in the particular period
*** Computed from the weights of the animals over the period 15/1/57 - 7/4/57 excepting for no.'s X and Y whose surface areas were computed from their weights over the period 4/2/57 - 7/4/57.
\+ Slaughtered 8/5/57
++ Died 4/6/57
+* Slaughtered 8/8/57

Table 4. Showing (1) The breed means and St. D's per experiment for oxygen consumption* in litres per five minutes.

(2) The F. values derived from between breed analyses of variance (Appendix A, tables 8, 9, 10, 11) carried out on the oxygen consumption data related to the following bases.

(a) Animal (b) Kg. body weight (c) Sq. metres surface area (computed) (d) Kg. body weight to the power 0.73

(3) Significance of difference between breeds.

(4) Mean body weights for periods in kilograms..

Dates	Mean Oxygen Consumption in litres per five minutes	Cheviot Mean	Cheviot St. D	Romney Mean	Romney St. D	(a) Animal F.	(b) Kg. body weight F.	(c) Sq. metres surface area (computed) F.	(d) Kg. body weight 0.73 F.	Mean body weights for periods in Kgs. (Groups) Romney	Cheviot
19/9-4/10/56	Block I	1.57	0.16	1.79	0.29	2.70	2.50	3.71++	3.18++	46.0	46.3
	Breed Difference		0.22								
7 - 17/10/56	Block II	1.45	0.20	1.44	0.25	0.02	0.00	0.04	0.02	43.4	43.0
	Breed Difference		----								
23/1-3/2/57	Block III	1.40	0.29	1.53	0.21	1.18	0.32	0.02	0.00	50.2	44.1
	Breed Difference		0.13								
8 - 12/2/57	Block IIIa	1.37	0.31	1.56	0.22	2.34	0.53	1.06	0.90	49.5	46.0
	Breed Difference		0.19								
29/3-7/4/57	Block IV	1.18	0.12	1.39	0.11	10.50**	0.05	4.68++	1.81	53.0	47.3
	Breed Difference		0.21								
8 - 17/4/57	Block V	0.86	0.14	1.05	0.13	19.12+	2.42	18.61+	8.53**	46.9	42.6
	Breed Difference		0.19								
18 - 27/4/57	Block VI	1.06	0.20	1.18	0.19	3.57++	0.00	1.45	0.37	47.8	43.7
	Breed Difference		0.12								

* Appendix A, tables 1-7 give the data from which these figures were calculated
++ Approaches significance
** Significant at 5% level
\+ Significant at 1% level

(Nos. 5 and 10) survived in good condition until the end of the project--a period of about ten months. Of the original animals in Block I (Appendix A, table 1), Nos. 5, 7, 8, and 10 made the whole journey.

B-VIII (c) Body Weights and Surface Areas

Table 3 shows that the body weights of all animals introduced into the experiments were maintained approximately in equilibrium. The main reason for the drop in ewe weights between Block I and Block II was probably the rearing of the lambs which themselves did very well gaining at mean rates of 0.34 lbs. and 0.46 lbs. per day for the Romneys and Cheviots, respectively (Table 5).

Surface areas for Blocks I, II, III, and IIIa were computed from the weights of the sheep in each particular period (Table 3). Surface areas for Block IV were calculated from the mean weights of the animals over the period 15/1-7/4/57 excepting for Nos. X and Y whose areas were calculated on their weights from 4/2-7/4/57. There is a good level of agreement between the surface areas computed at various times for individual sheep. The computed and the measured surface areas for each sheep also agreed closely. Owing to the difficulties involved in obtaining a true measurement of actual surface area (Benedict 1938 i) the actual measurements were used only as a check on the computed figures. A standard surface area was adopted for each ewe in Blocks IV, V and VI, normal, starvation and rehabilitation periods respectively. The validity of this

Table 5. Showing (1) The lamb production data of ewes 1-10 in the energy metabolism experiments.
(2) The analysis of variance between breeds for lamb rate of gain.

	Ewe No.	Parturition Date	No. of Lambs	Birth Weight lbs.	Weaning Weight lbs.	Lamb Liveweight gain in lbs./day	
ROMNEYS	1	6/9/56	1	7	20	0.29	mean 0.34
	2	24/8/56	1	8	29	0.35	
	3	7/9/56	1	8½	23	0.33	
	4	6/9/56	1	10	39	0.39	
	5	30/8/56	1	7	27	0.35	
CHEVIOTS	6	12/9/56	twins	17½	34	0.53/2 0.26	mean 0.46
	7	27/8/56	1	8	33	0.41	
	8	13/9/56	1	8½	28	0.44	
	9	28/8/56	1	8	26	0.33	
	10	13/9/56	twins	15	36	0.57/2 0.28	

<u>Analysis of variance between breeds for lamb rate of gain</u>

	D.F.	Variance	F.	Nec.F 5%	Nec.F 1%
Breed	1	.0325	6.25	5.32	11.30
Error	8	.0052			

procedure may be questioned; however, it is felt that no useful purpose would be served by introducing more mathematical analyses until some investigation has been made of the effect of improving condition and starvation on surface areas.

B-VIII (d) Position in Recording Sequence

Analysis of Blocks IVand V (Appendix A, table 10) showed that position in the recording sequence was exerting no significant effect. These analyses confirmed indications given by other blocks, whose analysis was complicated by missing values.

B-VIII (e) Lability

Some concern was originally felt about the fluctuations in the metabolism of each animal (Appendix A, tables 1-7), particularly when so far as the operator could ascertain there was nothing technically wrong with the apparatus. However, Ritzman and Benedict (1938 d) remark that variations of up to 30 percent or more were commonly met with in cows and that extraordinary variations in the basal metabolism may occur in the same individual and within a relatively short period of time. The standard deviations of the recordings of oxygen consumption in this project were as follows (Table 6) when expressed as a percentage of their particular mean.

The figures in 11 cases out of 14 are within or approximate to the ± 15 percent experimental error for metabolism recordings put forward by Wiggers (1949 a) and are well below Ritzman and

Benedict's 30 percent figure. Furthermore the analyses for day effects (Appendix A, table 10) revealed no statistically significant differences between days for Blocks II and III while the significant day effect in Block I may be attributable to the effects of failing lactation in IIIa to rising temperatures, in Block IV to a season effect and in Blocks V and VI to the deliberate starvation and rehabilitation of the animals.

Table 6. The standard deviations of the breed means for O_2 consumption* within blocks expressed as percentages of the means (to nearest %).

Block	Cheviots		Romneys	
I	10.0		16.0	
II	14.0		17.0	
III	(21.0)	Hot weather	(14.0)	Hot weather
IIIa	(23.0)	period	(14.0)	period
IV	10.0		8.0	
V	16.0		12.0	
VI	19.0		16.0	

* Corrected to Standard Temperature and Pressure

B-VIII (f) Breed Comparison

Table 4 includes the mean oxygen consumption figures per five minutes for each breed in the different experimental blocks. The same table shows the significance of the differences between these means, as derived from analyses of variance (Appendix A, tables 8-11 inclusive) carried out on the oxygen consumption records on the previously discussed bases of presentation, i.e., animal; Kg. body wt.; computed surface area; Kg. body wt. $^{0.73}$.

It will be seen from table 4 that on a per animal basis except for Block II there apparently were breed differences between the mean figures for oxygen consumption, the Cheviots having an oxygen consumption rate ranging approximately from 10 to 15 percent below that of the Romneys.

The absence of an apparent breed difference in Block II may have been due to the fact that the Cheviots were in some cases quite close to their lambing dates and the Cheviot group were, as a whole, rearing their lambs statistically significantly better than the Romneys (Table 5). High milk production probably necessitates a high metabolism (Ritzman and Benedict 1938 e). Block II consisted of only nine days on the last two or which the sheep were starved. Tenth day (72 hours starvation) records were not obtained due to a breakdown in the writer's health.

However, statistical analysis (Table 4 and appendix A, table 8) showed that except for Blocks IV and V the differences between the breed means for oxygen consumption per animal were not significant although the F. values obtained are quite interesting. They indicate that the odds against the differences being significant rose for Block II and then fell steadily to Block IV where the difference was significant at almost the one percent level. Block V was a ten day starvation period and at this time the differences were very highly significant. For Block VI the gap closed and the odds against the differences being significant rose quite considerably.

Relating the oxygen consumption records to Kg. body weight, computed surface area, and Kg. body weight $^{0.73}$ (Table 4 and appendix A, tables 9, 10, 11) gives a rather different picture, for the Romneys in the experiment Blocks III, IIIa, IV, V, and VI weighed more than the Cheviots (Table 3) and thus in general the higher oxygen consumption figures of the Romneys were treated with larger divisors than the Cheviots. This tended to equalise the breeds and it is recognised that the breed difference in oxygen consumption may be due to the greater weight of the Romneys. However, it is noteworthy that the Cheviots had the lower oxygen consumption, firstly, in Block I when the Romneys paired with Cheviots of almost equal weights, and secondly, in five cases out of eight in the other experiment blocks when individual Cheviots paired with Romneys of equal weights. In two cases out of the remaining three the Romney (No. 5) was not eating concentrates and this was possibly reflected in her metabolism records (Appendix A, tables 1, 2).

On a per kilogram basis (Table 4 and appendix A, table 9) none of the differences in oxygen consumption between the breeds were statistically significant. Calculations based on computed surface areas (Table 4 and appendix A, table 10) raised the F. value for Block I while Block IV approached significance at the five percent level and Block V was highly significant. The difference between the breed means for Block V were again significant when the oxygen consumption was related to the body weight in kilograms $^{0.73}$ (Table 4 and appendix A, table 11).

It is not a main object of this project to discuss or criticise the various methods of reporting energy metabolism studies, but in view of the above results it is impossible not to recall the words of Ritzman and Benedict (1938 f):-

> "The general picture of such a complex combination of biological forces indicates that the basic need for heat production is not dictated primarily by the size of the body, its surface area and consequent heat loss, but by other factors that are essential to actuate the inherited function to which the organism is adapted."

In this respect tables 3 and 4 are most enlightening. From experiment Blocks II to IV inclusive the trend is for the mean weights of the groups of animals to be rising (Table 4) and so the oxygen consumption should also have shown a tendency to rise in the raw data as greater total body weight is supposedly associated with higher total oxygen requirements. What is quite obvious, however, is that the oxygen consumption was, in fact, falling (Table 4).

This fall in metabolism to reach a low point towards the end of March is in complete agreement with Brody (1945 g) who found in goats that the minimum metabolism occurred in the autumn or breeding season. Ovulation in the human is notable for its effect in increasing metabolic activity (Wiggers 1949 b) so that the effect of season would appear to counteract this possibility in the sheep. However, Brody, in showing that the metabolic peak in goats occurs in early spring, states that the weight gains in growing goats are also maximum in early spring. Although data could not be obtained, the writer would venture that under normal spring conditions, at least in the Cheviot hills, lactating ewes do not put on weight but rather produce milk "off their backs".

Ritzman and Benedict (1938 g) concluded that some factors connected with season exert a dominant role in stimulating the metabolism of the tissues. In experiments on steers fed to maintain body weight they found a low metabolic level occurred in all cases between the end of January and the middle of March. In the period from May to November a high level of metabolism occurred in all cases during late May, June, or July. This was followed in all cases by a general decline in September with a relatively precipitate drop in October (March in New Zealand corresponds to October in the Northern Hemisphere.). Comparison of their cow data with their steer data suggested a striking parallelism in the reaction of the metabolism to change in season. Periods of high and periods of low stimulus not attributable to the ingestion of food were definitely indicated. These authors considered these seasonal variations to be so pronounced that special experiments were designed to investigate them using six cows. At that time no other experiments on the effects of season on the energy metabolism of ruminants existed in the literature. Ritzman and Benedict (1938 h) summarise their work with the statement, "This influence of season presents a perplexing paradox to the theory that heat production is governed by heat loss, for the heat production of their cows was in all cases greater in summer when they least needed it."

Brody (1945 h) in commenting on seasonal metabolic rhythms writes to the effect that thyroid activity increases in spring, reaches a maximum in mid-summer, and thereafter declines to a minimum in late winter. He believes that this variation is possibly related to seasonal food supply. Coop (1953) refers to thyroid activity as a possibly influence on wool production. The energy metabolism of the sheep in this project would appear to have followed a similar rhythm.

So far as the present writer is aware after Ritzman and Benedict's work (1935 g) no further energy metabolism experiments deliberately designed to explore the effects of the seasons have been reported for large farm animals. It does seem to the writer, however, that the autumn fall in energy metabolism may pre-relate the animal to food shortages in the coming hunger season. This trait is doubly interesting when it is considered from the standpoint that the sheep in this project and Ritzman and Benedict's cattle were being adequately fed without a hint of a time of shortage to come. It should also be considered from the standpoint that in the autumn the sheep is laying up reserves for the winter and a high metabolic rate would perhaps defeat the function of the animal which is, at that time, food storage. Remembering also the words of Keyes *et al.* (1950), that to the starving individual the reduced metabolic rate means that his rate of loss of strength and endurance is diminished and that, to carry it to the limit, he will survive longer, it is worthy of note that the differential in oxygen consumption (per animal) between the Romney Marsh and Cheviot breeds (Table 4) had widened quite considerably between 3/2/ and 7/4/57. The latter date corresponds to autumn in the Northern Hemisphere. Under natural conditions the Cheviot is the breed most likely to be exposed to food shortages, and this may be what is reflected in the comparatively low metabolism of the breed at this time.

Emphasis is given to this viewpoint by the reactions of the breeds to complete starvation over a considerable period (Table 4, Block V and appendix A, table 6). Under these conditions the difference in energy metabolism between the breeds was reduced below the point of statistical significance only when expressed as oxygen consumption per 5 minutes per Kg. body weight.

It is not intended to digress far from the main subject, but as this period of complete starvation is (so far as the writer is aware) the longest reported in which metabolism records have been taken, the opportunity cannot be missed for drawing attention to two points (Appendix A, table 6).

(1) That a point of equilibrium appeared to have been reached in the Cheviots at the 96th hour of complete starvation which corresponds very well with the figures given by other workers for the post absorptive stage (Forbes *et al.* 1926,

Ritzman and Benedict 1938 b; Marston 1948 b).

(2) The Romneys on the other hand show no obvious metabolism plateau, the trend being downward but in a rather erratic fashion. In the rehabilitation period (Appendix A, table 7) the Romneys' metabolism rose faster than that of the Cheviots.

For comparison purposes table 7 lists a number of references to the metabolism in Cals./24 hours for sheep together with those derived from this investigation.

It will be seen that the caloric values calculated from the oxygen consumption records obtained in this investigation are in general higher than those of the other authors. As has been mentioned, the error in calculating a 24 hour figure from a five minute recording may be considerable. Also, the animals were standing; and except for one experiment, Block V, they were on full feed. Nevertheless, the fact of large seasonal and breed variations in energy metabolism may indicate a need for a revision of many of the figures put forward for the nutritional requirements of sheep.

B-VIII (g) Carcass Data

Despite the ten day period of starvation to which they had recently been subjected, of the eight sheep slaughtered on 8/5/57 all but No. 7 showed ovulation activity (Table 8), and their packed red cell volumes did not suggest anaemia (Table 9).

Carcass analysis (Table 8) carried out on the slaughtered

Table 7. Showing -- figures in the literature and those calculated from the data in this project for the Calories/24 hours heat production of sheep.

Author	Cals/24 hours	Metabolism classification
Benedict (1938 a)	1200	Basal (24 hour fast, 45 Kgs. sheep)
Blaxter (1954)	1557	Adult sheep on 862 gms. feed per day
Brody (1945 i)	1580	Resting at 30 months
" "	1760	Resting at 24 months
Lines & Pierce (1931)	1270	Standard (48 hour fast)
Wood (1927)	1340	Maintenance requirement

This Project
Cals./24 hours*

Block	Cheviots		Romneys		Metabolism classification
	Mean	St. D.	Mean	St. D.	
I	2182	222	2487	403	Group Average (on full rations)
II	2015	278	2001	347	" "
III	1945	403	2126	292	" "
IIIa	1904	431	2168	306	" "
IV	1640	167	1931	153	" "
V	1195	194	1459	181	Ten day starvation period
VI	1473	278	1640	264	Full rations

* Using 4.825 Cals. per litre as calorific value of oxygen

Table 8. Carcass and organ data, energy metabolism experiment ewes.

	8/5/57	8/5/57	8/5/57	8/5/57	4/6/57	8/5/57	8/5/57	8/5/57	8/5/57	8/8/57	Significance of difference between the breeds
	Romneys					Cheviots					
	17	15	5	16	X	7	10	8	20	Y	
Ovaries gms.	2.7	2.8	3.0	2.5	2.7	1.2	3.2	2.9	2.8	3.2	
Adrenals "	4.9	6.0	5.3	*	6.2	5.0	6.4	6.9	6.4	7.5	
Thyroids "	5.4	3.7	5.2	6.7	7.8	3.8	6.9	4.1	6.1	9.5	
Heart "	231	221	194	234	273	248	266	208	235	265	
Live wt. lbs.	90	114	105	97	+	70	98	89	92	125	App. 5% level
Dressed wt. lbs.**	45	56	48	49	+	36	49	45	50	63	
Dressing %++	46.0	45.4	42.0	46.4	+	46.0	46.1	46.0	46.0	45.5	App. 5% level
Carcass Classification	lean	good	fat	fat	+	thin	good	lean	v.good	good	
Heart/body wt.	2.57	1.94	1.85	2.41	+	3.54	2.71	2.34	2.55	2.12	App. 5% level
Ovaries (Corpus lutea)	1:1	2:0	0:1	1:0		0:0	0:1	0:2	2:0		

* Accidentally unweighed
\+ Dead

** Hot carcass weight plus head and cannons

++ $\frac{\text{Hot carcass weight minus head and cannons}}{\text{liveweight}}$

Table 9. Haematological data of energy metabolism experiment ewes 7/5/57.

	Romneys					Cheviots				
	17	15	5	16	X	7	8	10	20	Y
Blood vol. (litres per animal)		2.03	2.82	2.10	2.39	2.13	1.87			
Plasma vol. (litres per animal)		1.52	1.96	1.60	1.79	1.56	1.33			
Red cell vol. (litres per animal)		0.51	0.86	0.50	0.60	0.57	0.54			
Packed red cell volumes (ml/100 ml blood)	39	26	32	25	26	28	30	27	-	41

animals and Nos. X and Y, which died and were killed respectively on subsequent dates, indicated a heavier heart in the Cheviot. Analysis of the carcass data for the eight animals slaughtered on 8/5/57 did not confirm this difference to be statistically significant, but when the heart weight was related to body weight the difference approached the five percent level of significance. Of the other weights recorded, only total body weight and dressing percentage indicated a breed difference. the Cheviot dressing out two percent (up to five percent if the head and cannons are included) better than the heavier Romney.

B-IX ADDENDUM

The development of Division "B" of the overall project led to several incidental studies which have no part in the main body of the results but being derived directly from the work are therefore presented as an Addendum to it.

CONTENTS

(a) The effect of shearing and drenching with simulated rain on the oxygen consumption and respiratory pattern of sheep.

Introduction

At the beginning of November 1956 some of the tracheotomised sheep began to cast their wool. It was therefore decided to discontinue, for the time being, regular metabolism studies, as it was unknown at that juncture whether or not variations in fleece cover affected oxygen consumption.

Ritzman and Benedict (1938) report the effect of temperature changes on the energy metabolism of sheared sheep but not the effect of shearing itself which is surprising as they put forward an argument that sheep offer a striking illustration of the effect of covering on their adaptability to changes in environmental temperature. The opportunity was therefore taken to study the effect of shearing on the energy metabolism of as many animals as was possible.

Procedure and Results

Starting 23/11/56 normal oxygen spirometer recordings were taken using eleven sheep for five days following several days of preliminary recordings. On the fifth day seven of the sheep were sheared following early morning oxygen spirometer recordings. Of the remaining sheep three Cheviots had cast their wool prior to the commencement of this work and the fourth, a Romney, was left unsheared to act as a control.

The metabolism charts (Plate 24) revealed an abrupt change in the respiratory pattern of the sheep which were sheared. In all animals the respiration rate fell by approximately two thirds and the depth of inspiration was almost doubled. The seven sheared sheep showed slight increases in oxygen consumption after shearing (Table 10).

On 13/12/56 the sheep were utilised for a further aspect of climatological work. A routine oxygen consumption record was taken from each animal. Each animal in turn was then subjected to soaking with simulated rain for three minutes. This period resulted in the collection of approximately one inch of water on the floor of each small pen. The sheep were subsequently reconnected to the oxygen spirometer and recordings taken (Table 10). It was found that soaking with water had a profound effect on the respiratory pattern and in every case (except for one Romney which still carried a full fleece) the oxygen consumption rose; plate 25 illustrates the respiratory pattern of a shorn sheep before and after wetting and plate 26 the respiratory pattern of the control also before and after wetting.

One week later, 19/12/56, the sheep were recorded twice, with an eight minute gap per sheep between recordings. This eight minute gap was estimated as being equivalent to the period between recordings before and after soaking. No change occurred in any of the records (Table 10, plate 27) which confirmed early exploratory work (Plate 21)

Plate 24. The respiratory pattern of a sheep before and after shearing.

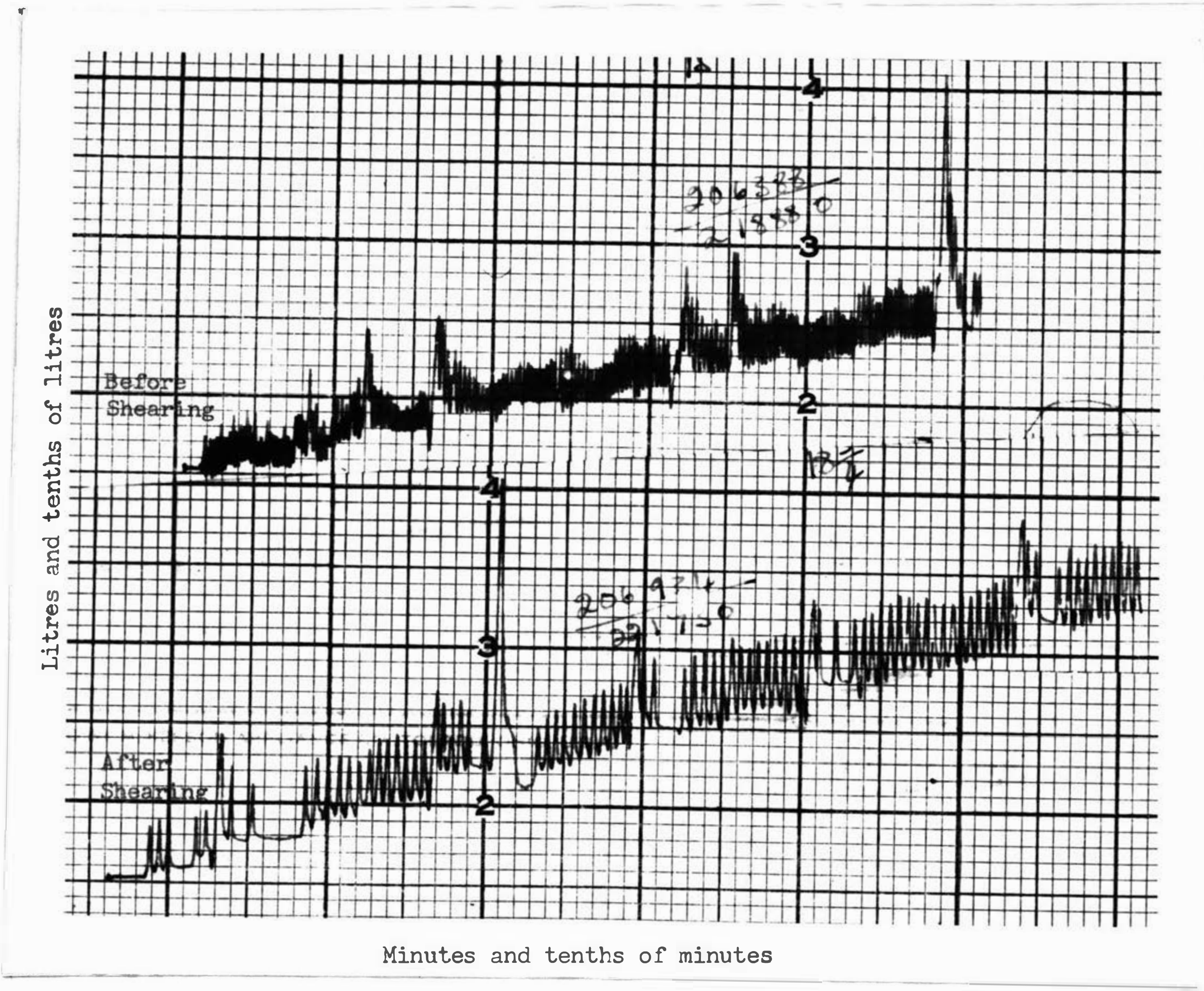


Table 10. Showing the oxygen consumption records (litres O_2/5 minutes)* of eleven sheep;
(1) Pre and post shearing,
(2) Pre and post wetting after shearing,
(3) Routine recordings with an eight minute time interval,
(4) One final routine recording.

		Cheviots					Romneys					
Date		8	10	20	6	7	21	16	5	4	2	15
23/11/56	Normal	1.13		1.41	1.32	1.33	1.41	1.60	1.33	1.55	1.14	1.32
26/11/56	"	1.52	1.69	1.23	1.71	1.43	1.43	1.43		1.71	1.14	1.43
27/11/56	"	1.32	1.52	1.43	1.81	1.32	1.13	1.60	1.14	1.41	1.13	1.41
28/11/56	"	1.23	1.52	1.22	1.41	1.51	1.23	1.13	1.22	1.41	1.13	1.42
29/11/56	Pre shearing	1.04	1.43		1.23	1.32	1.32	1.41	1.42	1.33	1.13	1.51
		sheared	no wool	no wool	no wool	sheared	sheared	sheared	sheared	control	sheared	sheared
29/11/56	Post shearing	1.31			1.40		1.73	1.49	1.59		1.12	1.49
30/11/56		1.38	1.34		1.29	1.43	1.38	1.58	1.52	1.33	1.53	1.34
1/12/56		1.43			1.43	1.42	1.42	1.57	1.37	1.32	1.57	1.43
2/12/56		1.43	1.52		1.66	1.42	1.72	1.62	1.57	1.38	1.42	1.57
13/12/56	Pre wetting	1.48	1.50	1.41	1.54		1.59	1.59	1.31	1.45	1.13	1.50
13/12/56	Post wetting	1.57	1.69	1.50	1.87		1.87	1.97	1.97	1.45	2.44	1.68
19/12/56	Normal	1.28	1.38	1.49		1.28	1.65	1.58	1.28	1.47	1.37	1.63
						Eight minutes interval						
		1.28	1.38	1.49		1.28	1.65	1.58	1.28	1.47	1.37	1.63
28/12/56	Normal	1.39	1.39	1.30		1.21	1.30	1.39	1.30	0.93	1.11	1.53

* Corrected to Standard Temperature and Pressure

Before wetting

After wetting

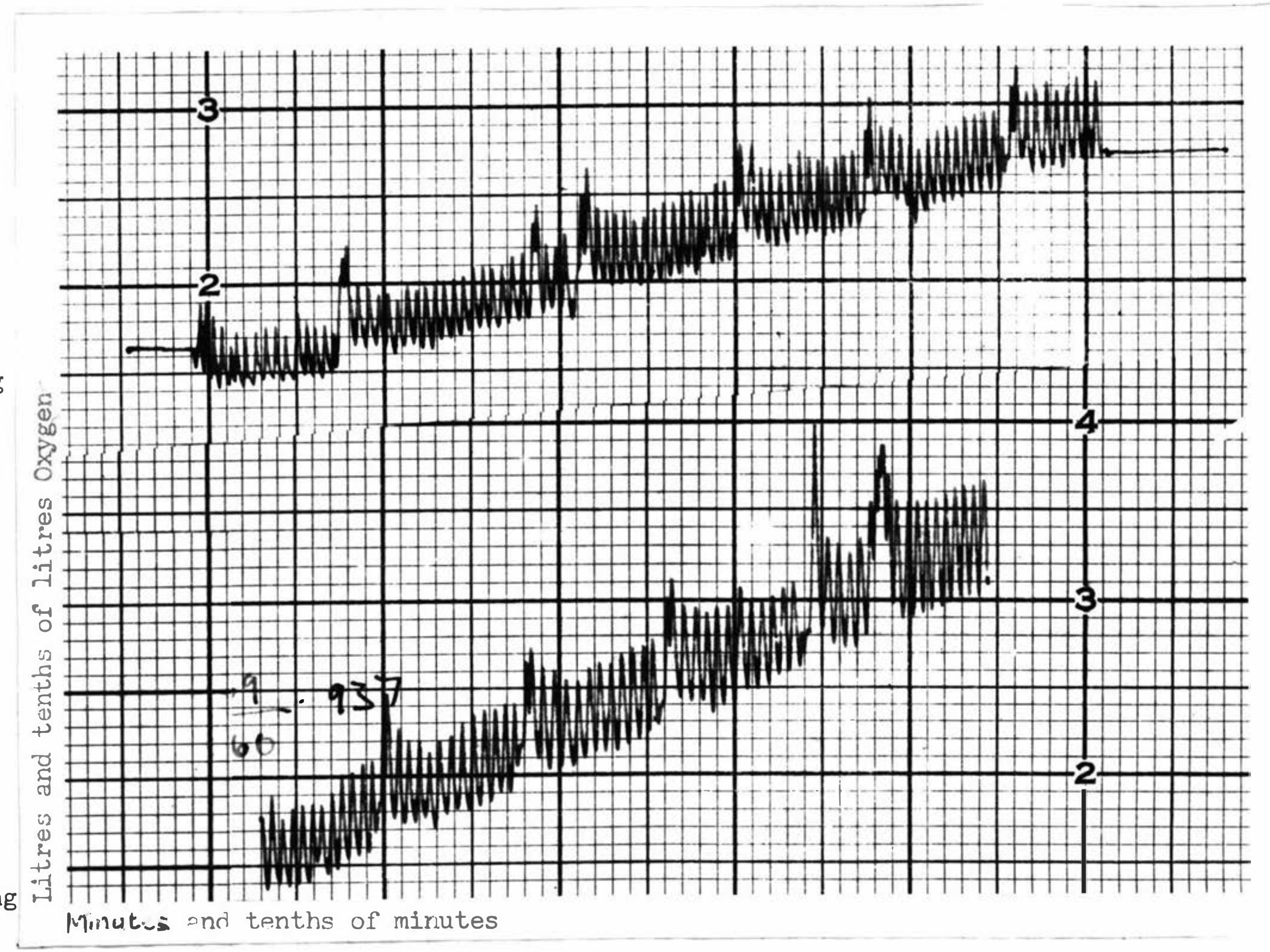


Plate 25. The respiratory pattern of a shorn sheep before and after wetting.

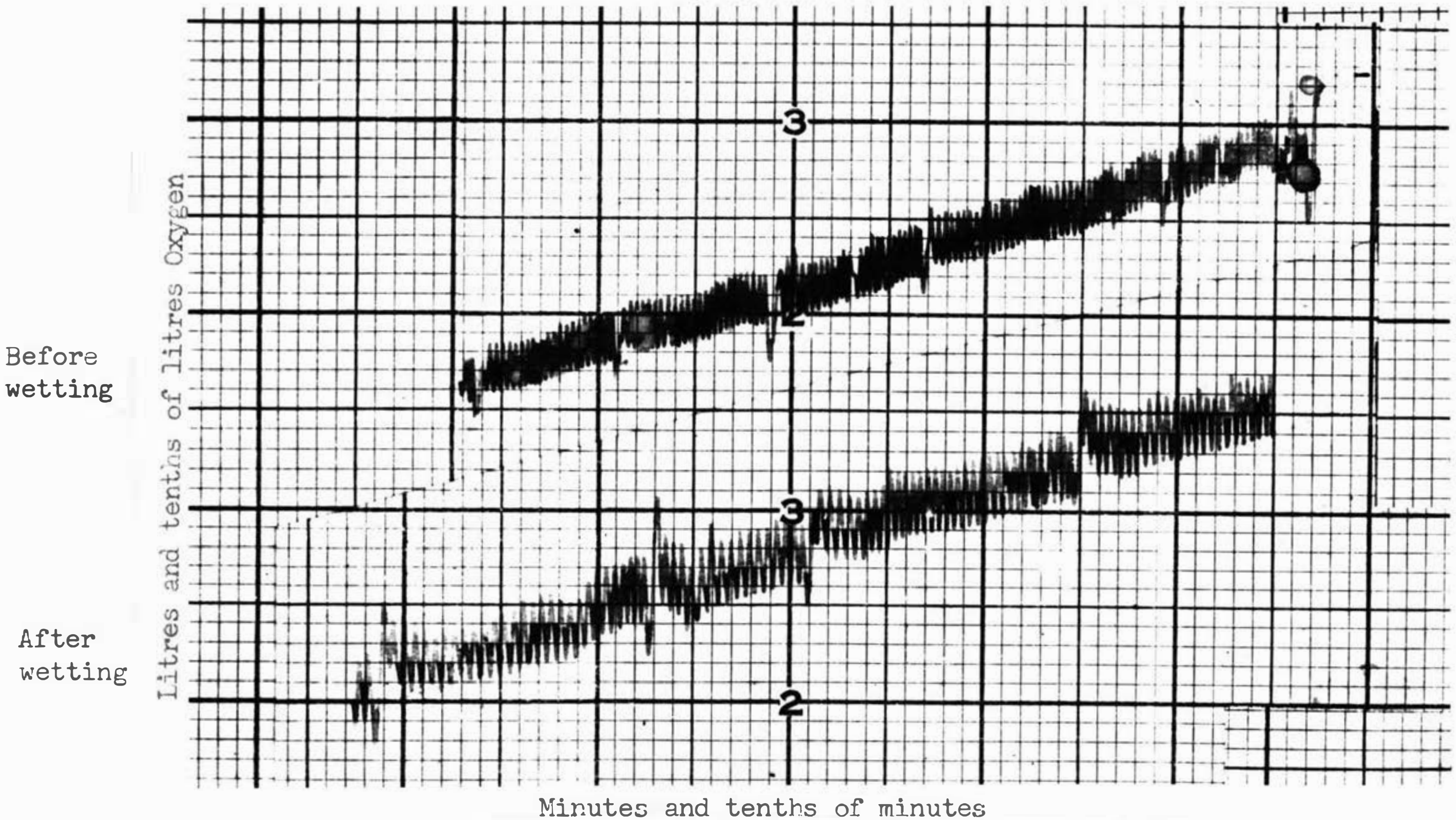


Plate 26. The respiratory pattern of an unshorn sheep before and after wetting.

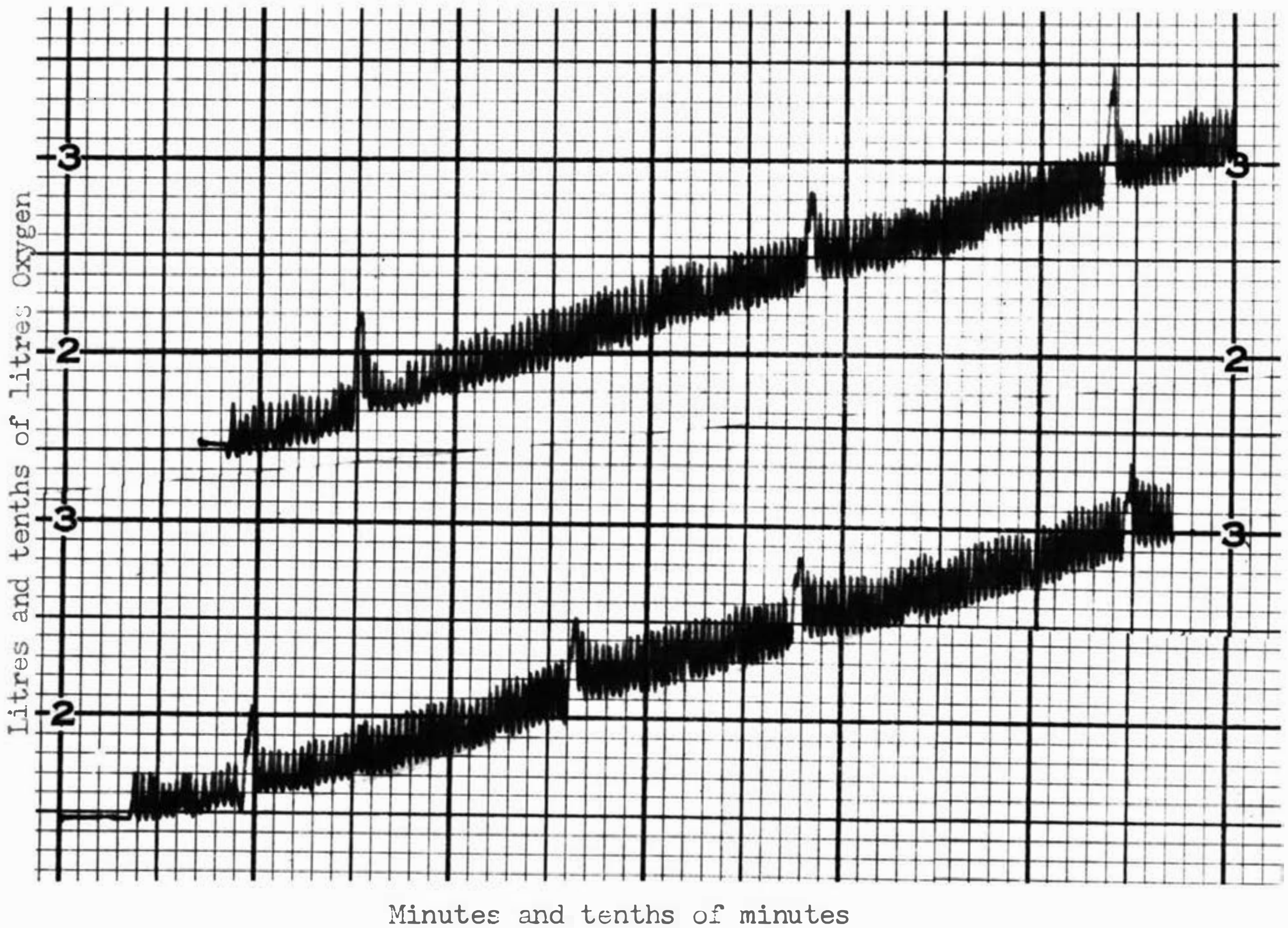


Plate 27. Oxygen spirometer graphs made with an eight minute gap between recordings using the same sheep.

into the repeatability of records made within a few minutes of each other.

On 28/12/56 a final recording (Table 10) was taken from all animals. This revealed that one month after shearing and in summer temperatures the respiration rhythm was still slower and deeper than it was before shearing.

(b) <u>The effect on their metabolic rate of feeding 1 lb. of oats to each of three sheep after twelve hours starvation</u>.

Introduction

It has been found that shortly after the taking of food there is always a marked rise in the rate of heat evolution as measured directly or indirectly.

Armsby (1906) dealt very fully with the subject of the increase in metabolism due to feeding and remarks that this increased expenditure is often, although rather loosely, spoken of as the "work of digestion". Modern authors refer to it as the Specific Dynamic Action of the foodstuffs.

This isolated experiment was carried out to ascertain whether or not the technique was suitable for this type of nutrition study. The advantage of the technique is that such studies could be carried out on large numbers of animals and this would enable between animal and between breed reactions to various rations to be ascertained.

Procedure and Results

On the afternoon of 4/1/57 three of the tracheotomised sheep, two Cheviots and one Romney, were confined in the small recording pens. They were left without food but with water available until early the following morning. Oxygen spirometer records were then made after a fasting period of about twelve hours. The sheep were subsequently fed one pound of crushed oats each. The oats were consumed voraciously, the animals having been selected partly on their liking for concentrates.

Shortly after feeding was completed oxygen spirometer records were again made, the animals being taken in the sequence in which they finished their oats (Table 11). In every case the rate of oxygen consumption had risen quite markedly when compared with the fasting level. No further food was offered and metabolism records were taken approximately every hour until about 4:15 p.m. when each animal was again fed one pound of oats. Two further oxygen spirometer records were then taken.

It will be seen from table 11 that the increase in oxygen consumption due to feeding one pound of oats was not at all regular but that the fall which followed the peak readings was uninterrupted except in the case of Cheviot B where the 5:40 p.m. reading was higher than that of 4:55 p.m.

Table 11. The oxygen consumption records in litres consumed/five minutes* of three sheep each fed 1 lb. oats after twelve hours starvation and again eight hours later.

Cheviot A		Cheviot B		Romney		
Time	O_2*consumption litres/5 mins.	Time	O_2*consumption litres/5 mins.	Time	O_2*consumption litres/5 mins.	
7.45a.m.	1.03	7.25a.m.	1.17	7.35a.m.	1.03	1 lb. crushed oats fed
8.40	1.41	8.55	1.32	8.30	1.27	
10.05	1.32	10.20	1.32	9.55	1.27	
11.25	1.21	11.35	1.16	11.15	1.25	
1.25p.m.	1.11	1.40p.m.	1.11	1.10p.m.	1.22	
3.35	0.93	3.45	1.02	3.25	1.02	
4.15						1 lb. crushed oats fed
4.45	1.25	4.55	1.11	4.30	1.40	
5.30	1.25	5.40	1.21	5.20	1.35	

* Corrected to Standard Temperature and Pressure

(c) The effect of l thyroxine on the oxygen consumption, respiratory rate, and body weight of one Romney Marsh ewe.

Introduction

In connection with studies which were being carried out at Massey Agricultural College (Kirton 1957) on the effects of thyroxine on body weight and its components, the writer was asked to co-operate in ascertaining the result of a certain dosage rate of l thyroxine on the energy metabolism of ewes. A review of literature has been compiled by Kirton and the following references are cited from it.

Cited Literature

Although in low doses, thyroxine as such or as iodinated casein, has been used as a growth stimulant, it is well known that hyperthyroid animals receiving thyroxine at levels above physiological normality, lose weight (Blaxter et al. 1949). In sheep, weight losses under thyroxine treatment are common, (Hart 1955; Jordan 1954; Warwick et al. 1948). Turner and Reineke (1946) used weight loss in this species as an assay technique for the thyroxine potency of thyroprotein. Blaxter (1948) working with wethers recorded losses of up to 28 percent of the original body weight in 24 days. In ruminants it appears that one of the ways that thyroxine reduces liveweight may be by lowering the volume of gastro-intestinal contents. This could be caused by an increased rate of peristalsis or in more severe cases of hyperthyroidism by lowered food intake or by starvation. In cattle Blaxter et al. (1949) reported that

7.7 percent showed signs of scouring or digestive upset as compared with 1.7 percent of the controls.

As it was no part of this project to develop a detailed study of the effect of thyroxine on the metabolic rates of sheep, no original review of literature was attempted although Brody (1945) is cited for the following reference.

Magnus-Levy (circa 1895) discovered that loss of the thyroid may reduce the basal energy metabolism by nearly half, and that suitable thyroid feeding may almost double the metabolic rate. Metabolic rate was therefore adopted as a measure of thyroid function.

For the present work starting 28/1/57 measurements were taken on the influence of thyroxine injected daily on the metabolic rate (oxygen consumption) of a five year old Romney ewe, fed hay ad libitum. This animal had previously been involved in metabolism studies (R. No. 2). Her lamb was weaned at 29 lbs. having gained 0.35 lb. per day which compared very favourably with those of other ewes (Table 5). The results of the thyroxine treatment on oxygen consumption, respiration rate and body weight are presented in table 12.

This sheep was quite thin and it was thought unlikely for any change to occur in the surface area of the animal. The oxygen consumption figures are therefore presented corrected to Standard Temperature and Pressure only. The results show that for this animal the thyroxine treatment raised its oxygen consumption by as

Table 12. The effect of thyroxine treatment on the oxygen consumption, respiration rate and liveweight of one Romney Marsh ewe.

	Oxygen consumption+ litres O_2/5 mins.	Respiration Rate	Liveweight lbs.	Treatment
28th Jan. 1957	1.0	55	-	
29th "	1.0	50	-	
30th "	0.9	50	-	5 mg thyroxine
31st "	0.9	50	62	10
1st February	1.0	60	59	5
2nd "	1.4	70	-	5
3rd "	1.4	100	59	5
4th "	1.8	110	59	-
5th "	1.6	110	58	-
6th "	1.1	80	60	-
8th "	1.1	40	61	-
20th February	1.2	50	75	
24th "	1.0	40	-	
26th "	*	60	70.5	5 mg thyroxine
27th "	1.1	45	68	5
28th "	1.3	50	65.5	5
1st March	1.5	90	-	5
2nd "	1.6	80	60	5
3rd "	1.5	100	57	-
4th "	1.3	100	60	-
5th "	1.2	90	60.5	-
6th "	1.2	80	64	-
7th "	1.0	60	67	-
8th "	1.0	60	66	-

\+ Corrected to Standard Temperature and Pressure

* An air leak developed and so this reading was discarded. This did not effect respiration rate.

much as 80 percent (it was increasing when the treatment was stopped in both cases). The respiration rate was doubled at the peak point and live weight was reduced. A lag of about two days occurred between the first injection and the change in the pattern of oxygen consumption, respiration rate and live weight. There was a distinct carry over effect of several days duration for both experimental periods.

It was noted that the output of faeces was quite considerable on about the second day after the commencement of thyroxine administration and that there was a tendency to scouring on the fifth day in both experimental periods. On both occasions the animal suffered a very considerable decline in appetite which did not return to normal until some days after the cessation of treatment.

Since these results agree substantially with the known effects of thyroxine administration to humans and farm animals it is concluded that the technique here used is suitable for such investigations.

(d) Methane exhalation in sheep.

Introduction

In view of the statements made Brody (1945), Ritzman and Benedict (1938), and Blaxter (1954) to the effect that the ruminant exhales methane in considerable quantities it was deemed necessary to investigate the amount of methane which accumulated in the oxygen spirometer during metabolism recordings. Accordingly, appropriate arrangements were made for gas analyses to be carried out by the Dominion Physical Laboratory* at Wellington.

Procedure and Results

On 14/3/57 seven animals were chosen at random and each in turn was attached to the oxygen spirometer in the normal manner until it had exhausted one half the reservoir capacity--a period of about ten minutes.

The gas remaining in the spirometer was then expelled and collected over water (Dominion Physical Laboratory instruction). The samples, taken in one litre Winchester bottles, were promptly despatched to Wellington. The results of the analysis of these samples are presented in table 13.

* Particular thanks are due to the Director of the Dominion Physical Laboratory, Wellington, for offering the necessary laboratory staff and facilities for this work.

Table 13. The results of analyses of gas samples drawn after the sheep had exhausted half the resevoir capacity of a closed circuit oxygen spirometer.

Sheep No.	7	8	10	20	2	5	X
Methane	0.30%	0.05%	0.15%	0.20%	0.15%	0.15%	0.05%
Hydrogen	(0.02% or less)		(------------not found--------------)				

There was no possible way in which the methane could have entered the spirometer other than from the lungs of the sheep. However, in view of the fact that in eructation some eructated gas does flow back down the trachea--this is believed to be an original observation--the presence of traces of methane in the pulmonary system may be due to residues from previous eructations. When applied to the total gas volume of approximately two litres remaining in the spirometer, the methane percentages give maximum, minimum and mean values of 6, 1, and 3 ml. respectively of methane exhaled in approximately ten minutes.

As the spirometer graphs cannot be ruled to a greater accuracy than 0.05 of a litre, a possible volume error of at the most 3 ml. of methane per five minutes is considered to be low enough to be ignored.

(e) Regurgitation in sheep.

Based on the work of Bergman and Dukes (1926), who acknowledged the investigations of Toussaint (1875), Colin (1871) and Fluorens (1844), the generally accepted current theory of regurgitation is that a quick inspiratory effort with a closed glottis leads to a sharp fall in intrapulmonary pressure with the lungs tending to contract towards the rigid walls of the "costal box". This in turn is believed to create a negative pressure within the thoracic oesophagus causing it to dilate and so allow the highly fluid rumen contents to siphon rapidly through the relaxed cardia when it is transported to the fauces by its own momentum aided by an anti-peristaltic wave in the oesophageal wall.

Bergman and Dukes (1926) found that breathing and mastication are interrupted for several seconds at the time of regurgitation and that there was no increase in chest movement or rectal pressure and only a small and apparently insignificant momentary increase in intra-ruminal pressure. On the other hand a small cannula inserted into the trachea and attached to a recording manometer showed a sharp fall in intra-tracheal pressure at the moment of regurgitation. By using an animal with an established rumen fistula they were able to demonstrate, by direct examination, that a negative pressure occurred at the cardia at the instant of regurgitation. Dukes (1955) states, "...in regurgitation the entrance of food into the oesophagus is brought about by intra-oesophageal negative pressure due to an inspiratory effort with a closed glottis." He also quotes Kryzwanek (1934) as an authority for the statement that ruminants with pneumothorax or an opening into the trachea are unable to regurgitate or do so only with difficulty.

Another modern worker, Stigler (1931), also investigated the mechanism of rumination and reviewed earlier theories paying particular attention to those of Toussaint, Colin, Wester and Mangold.

According to the above worker, Chauveau and Toussaint took the view that the entrance of the ingesta into the oesophagus is accomplished by an inspiratory effort with a closed glottis. Colin is credited with the belief that the oesophagus relaxes with regurgitation and forms a funnel shaped widening into which the half fluid forestomach contents stream. The same author writes, Wester's theory was that the oesophagus sucks up the regurgitate by its active widening without the inspiratory fall in pressure being necessary. He believed that the cardial opening occurs when the diaphragm first contracts while simultaneously the circular muscle ring in the caudal part of the oesophagus is relaxed and that the oesophagus contracts in its entire length. Thus the posterior end of the oesophagus must be widened. The opening of the cardia is, according to Wester, assisted by a stretching of the stomach wall round the cardia.

Stigler lists Mangold as the originator of the theory that primarily no significant activity of any organ may be necessary to cause the ruminating mass to go from the forestomach to the oesophagus as soon as the cardia opens. According to Mangold the greatest quantity of water giving sufficient difference in hydrostatic pressure to bring food into the oesophagus on opening of the cardia is 10 to 15 cm. in the goat, and as one can see clearly in X-rays, the opening of the oesophagus into the stomach (in the standing animal) lies deeply under the level of the rumen contents and under the air bubble in the food. Stigler comments that transport of the regurgitate by hydrostatic pressure alone is comparatively slow whereas in X-rays one sees that the ruminating mass is conveyed at great speed from the cardia through the cervical oesophagus to the neck. Stigler considered that this speed is brought about by a force derived from:-

(1) Greater pressure in the forestomach following its active contraction, or by abdominal pressure.

(2) Decrease of the pressure in the oesophagus either by inspiratory lowering of the intra-thoracic pressure, or through active widening of the oesophagus.

After a lengthy investigation, Stigler gives the following sequence of events as his explanation of how regurgitation takes place and comments that the mechanism of insuction described corresponds to the theory of Chaveau and Toussaint.

(1) Rumination begins as a rule with the swallowing of saliva.

(2) Immediately after this appears a quick contraction of the

oral parts of the thoracic oesophagus, apparently in order to press out swallowed air.

(3) The glottis closes and the insuction phase begins.

(4) The diaphragm makes a backward inspiratory movement.

(5) At the same time the head and neck are flexed more or less dorsally. This has the object of improving the closure of the cervical oesophagus and hindering the insuction of air from the mouth into the thoracic oesophagus.

(6) Following the fall in the intra-thoracic pressure brought about by the inspiratory movement with a closed glottis, the thoracic oesophagus is sucked open and a decrease of pressure occurs inside it.

(7) Simultaneously the cardia opens.

(8) Some of the rumen and reticulum contents, mostly as a fluid broth, are sucked up into the oesophagus by the negative pressure in the thorax and thoracic oesophagus and are carried by an anti-peristaltic wave to the mouth.

As objections against the acceptance of this theory, Stigler notes that it is said, rumination can still take place after:-

(1) The cutting of both phrenic nerves

(2) Tracheotomy

(3) Pneumothorax

He states however, that these objections are not acceptable for the following reasons:-

(1) According to experiments on the cat, one quarter to one half of the usual inspiratory force remains after the paralysis of the diaphragm through the cutting of the phrenic nerves. Such a remaining force would be sufficient to suck up the regurgitate.

(2) Tracheotomised animals ruminate only with a very strong respiratory movement and the respiratory variations of the chest circumference are much larger than with normal rumination because the checking of the diaphragm movement by closure of the glottis does not take place. The breath rush is very much louder than under normal circumstances.

(3) Experiment showed that a goat with pneumothorax could not ruminate in spite of strong endeavours on its part, but sixteen days after the operation, when the wound had healed, the animal ruminated again. Stigler argues from this that it is obvious that the oesophagus, diaphragm and abdominal muscles together are not sufficient to produce rumination, since an intrathoracic fall in pressure was not produced by inspiration, and that this is a very strong objection to Wester's theory that the oesophagus may suck up regurgitate without the respiratory fall in pressure being necessary.

However, observations on sheep tracheotomised as described in Division "B", this project, made it abundantly clear that the statements that regurgitation occurs only with difficulty in tracheotomised ruminants could not be borne out.

Close daily study of seventeen sheep tracheotomised for periods of up to ten months and of a similarly intubated Jersey bullock calf for four months (Plate 28) revealed no interruption of the rumination pattern, irrespective of whether the tracheal opening was open or closed.

Spirometer recordings (Plate 29) frequently showed a transient increase in rate and decrease in depth of respiration followed by a much greater than normal inspiratory intake coincident with each regurgitation. However, direct observation of the animal gave no outward indication of a deeper than ordinary intake of breath at this moment although the extra intake was generally of the order of 150 to 250 ml. The greater than normal inspiratory effort was not always made, for some animals appeared to be able to regurgitate with very little or no effort at all and with no dorsal flexing of the head and neck as described by Stigler. These observations were made in many cases when the animals were connected to the spirometer and the writer was sitting virtually at their feet. It was therefore thought that the diaphragm must contract much more forcibly at the moment of regurgitation whereas the remainder of the muscular apparatus involved in the respiratory act maintains its normal rhythm. Quite an appreciable force must be required to draw an extra 200 ml. or thereabouts of air into the lungs, and such a force applied with a closed glottis in the intact animal would cause

Plate 28. A tracheotomised calf.

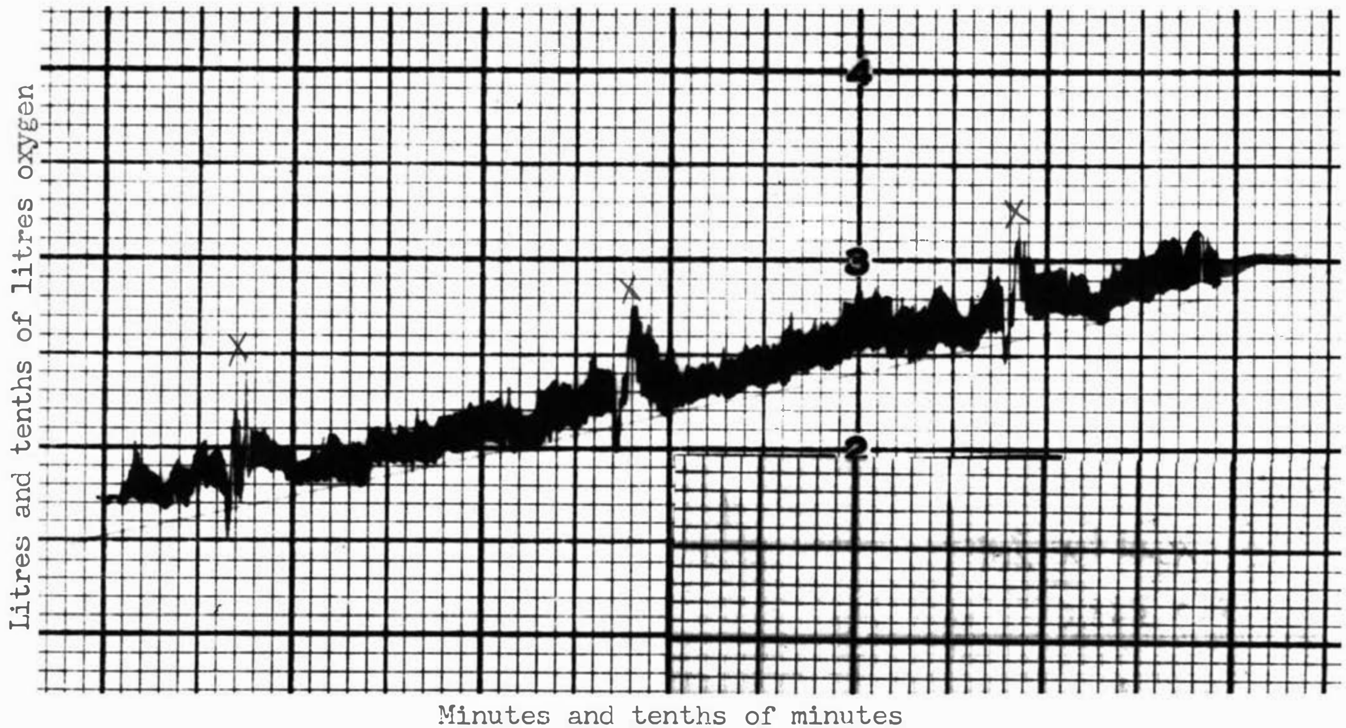


Plate 29. The respiratory pattern of a ruminating sheep. The points of regurgitation are marked by the large upward blips "X".

a marked intratracheal and intrapulmonary negative pressure at the critical moment. However, the belief that closure of the glottis and the resultant negative pressure are essential to the regurgitation reflex is clearly invalidated by the behaviour of the tracheotomised sheep in which the presence or absence of additional negative intratracheal and intrapulmonary pressures appeared to be entirely irrelevant to the operation of the reflex. It is thus perhaps justifiable to allow that Wester's hypothesis may have some merit despite the attack that has been made on it.

Stigler's observations that there is a closing contraction of the oesophagus to remove swallowed air and that the strength with which the oesophagus of a cow can contract is considerable, lend some support to the opinion which was formed as a result of the present work. This opinion was that at the moment of regurgitation the cardia and posterior portion of the oesophagus dilate and simultaneously the oesophagus is jerked into a state of relative tension by a sudden forcible contraction of itself and the diaphragm. This would create a negative pressure within the oesophagus sufficient to cause the stomach contents to siphon rapidly forwards, although the inspiratory effort must also produce intrathoracic negative pressure which may have a primary or secondary effect. The supposed jerking of the oesophagus into a state of tension would possibly be aided by the skeletal muscle which runs throughout its entire length. In this latter respect the ruminant oesophagus differs from that of most other species. After the entrance of the regurgitate into the oesophagus the cardia closes and the fluid bolus is carried to the mouth by an anti-peristaltic wave in the wall of the oesophagus.

It is nevertheless recognised that all inspiratory efforts, glottis closed or not, are made as the result of the creation of intrathoracic negative pressure and so any "Oesophagus-Diaphragm" hypothesis cannot but be extended to include "Inspiration."

Indirect evidence in support of an "oesophagus diaphragm" hypothesis is supplied by some recent work of Dougherty and Meredith (1955) and Dougherty and Habel (1955). In the course of a study of the bloat problem these workers investigated the eructation mechanism by means of an X-ray and cinefluorographic technique and were thus able to obtain a continuous visualisation of the eructation process and to demonstrate the presence of three oesophageal sphincters. These were: a very efficient cranial sphincter normally keeping the entrance to the oesophagus closed; a second situated a short distance anterior to the diaphragm; and thirdly the cardia itself. Their films also show that the walls of the oesophagus, particularly in the rumen terminal position, can be remarkably active. Dougherty, in a personal communication (1956), stated that in similar unpublished cinefluorographic studies he observed a sudden sharp diaphragmatic contraction at the moment of regurgitation.

DIVISION "C"

RANGING BEHAVIOUR STUDIES

CONTENTS

C-I INTRODUCTION AND REVIEW OF LITERATURE

The aim of this Division of the overall project was to compare the mileages traveled by New Zealand Romney Marsh and Cheviot sheep grazing on hill and lowland pastures. It was also hoped that it would be possible to study:-

(1) The effect on activity of different sized pastures within the above two locations.

(2) The result of switching the two breeds from hill to flat and from flat to hill land.

Literature dealing specifically with the distances traveled by grazing sheep is very scanty.

Louw et al. (1948) in South Africa used a checker-board technique in which they divided pastures into 20 acre squares by means of stakes. Hourly observations made by means of binoculars traced the movements of the sheep in relation to the stakes. Table 14 presents the results of the above work.

Tribe (1949) in North Scotland studied the general features of the grazing behaviour of Cheviot sheep on one acre of lowland pasture over continuous periods of 24 hours during 12 consecutive months. The one acre pasture was divided by stakes at ten yard intervals following the method of Wallace and Kennedy (1944). He reports that the sheep walked an average of 2.60 miles per 24 hours; 2.06 miles being between 7:00 a.m. and 7:00 p.m. and 0.55 miles between 7:00 p.m. and 7:00 a.m. Most traveling was done in the spring and autumn, and least in summer. The animals walked proportionately more at night in summer than in winter. (Tribe does not

Table 14. The daily distances walked by different sheep breeds (Louw _et al_ 1948) singly and in various combinations.

	Black Headed Persians	Dorset X Persian	Karakul	Merino
	Daily Distance Traveled			
	Yards	Yards	Yards	Yards
1st day together	5229	6738	4868	4836
2nd " "	4580	4053	3764	2795
3rd " "	6405	4845	5075	5945
1st day separately	4555	5505	3325	4515
2nd " "	6240	5645	4260	3350

	Merino & Karakul (Together)		Dorset X Persian & Black Headed Persian (Together)		Black Headed Persian & Karakul (Together)	
	Daily Distance Traveled					
	Yards	Yards	Yards	Yards	Yards	Yards
2nd day	7285	6380	9685	8660	7995	6035
3rd day	6160	7410	10575	8275	8970	6860
2nd day	4560	5110	7780	7430	7125	4290
3rd day	4680	4575	4575	9385	7055	5685

mention the possible relationship between the short night of the Northern summer and these results). The method he adopted was to follow the behaviour of only one sheep at a time. Tribe reports that in confirmation of the work of Stapledon and Jones (1926) and Jones (1928), it was found that the records from a single animal, on each occasion reflected the actions of the experimental group.

England (1954), working in Wales, produced the following results from four ewes of different breeds together with their lambs on two plots each of 1.9 acres (Table 15).

Table 15. The total distance (in yards) traveled by each sheep during twenty four hour periods (England 1954).

Ewe	First Day	Second Day
Blackface	1558	2888
Clun	2268	3772
Spanish	2400	3876
Suffolk	1922	4248

Distance (in yards) traveled by the sheep from 10 p.m. to 8 a.m. D.B.S.T.*

Ewe	First Day	Second Day
Blackface	276	580
Clun	236	844
Spanish	292	436
Suffolk	398	852

* Double British Summer Time

Although he gives no distances, Hunter (1954) observes that hill sheep are more active than lowland sheep during the hours of daylight. No data were available on the night behaviour of hill sheep but Hunter (who worked in Scotland) believes it quite probable that they are more active than lowland sheep. The following data (Table 16) are presented by this author:

Table 16. Percentage time spent resting in the hours 7:00 a.m. - 7:00 p.m. by lowland and hill sheep, April - September (Hunter 1954).

	Apr.	May	June	July	Aug.	Sept.
Lowland (Tribe's Cheviots 1949)	32	32	40	45	45	47
Hill (Hunter's Scotch Black faced sheep 1954)	13	13	29	21	26	23

Hunter overlooks the fact that he is comparing not types of sheep but locations, for the Cheviot is not a lowland type. This kind of confusion of the sheep breeds can only be deplored.

In a comparative study of the grazing habits of sheep carried out by Van Rensburg in South Africa (1956) the following results were obtained (Table 17): the technique is not specified.

Table 17. The average daily distance walked by four sheep breeds (Van Rensburg 1956).

Breed	Average daily distance walked (yards)
Merino	4495
German Merino X Merino Cross	6532
Blackhead Persian	4845
Dorper	4980

Tribe (Hammond 1955) reviews the literature on grazing behaviour studies. Excerpts from the review are now presented in order that the present work can be assessed in the light of this modern summary.

Tribe writes, that valid and standardised techniques are the prerequisite of any scientific investigation and it is an important criticism of grazing behaviour studies in all parts of the world that there is no standardised technique of observation, and no comparison has yet been made of the accuracy of the many different methods used. There is, for instance, no uniformity concerning even the period during which observations should be made. Some workers have mistakenly assumed that during the hours of darkness animals will remain at rest and have therefore only recorded their observations during the hours of daylight.

Tribe continues--similarly the methods of recording vary considerably. Some workers record the behaviour of individual animals while others record the behaviour of flocks or herds. Some workers make a continuous recording while others record only observations taken at regular and frequent intervals. Some records are the work of single observers while others are made by several observers working on a shift system. Tribe further remarks that in an effort to increase the accuracy of behaviour records a number of automatic and semi-automatic recorders have been evolved, and in use with animals penned or in stalls these auto-recording machines have proved very successful. However, according to Tribe, the difficulties of using such machines to record grazing behaviour are of course much greater and have not yet been overcome. He mentions that Burton and Castle (1950) have described the construction and use of a portable infra-red ray equipment for animal observation in the field. For watching from a stationary position not more than four animals at a range of ten to fifteen yards on a clear dark night the equipment was ideal. When using it to observe a large number of animals either in the field or in the cowshed the observer was liable to miscount the animals owing to the limited field of the screen. Also, the constant wearing of the equipment which weighed 21 pounds was very tiring and, when the weather was misty, the lenses quickly clouded over.

Tribe considers that the differences between the animal behaviour patterns described by various workers are not surprising. In addition to the differences in observational technique, there is a complex of environmental factors which must be expected to influence a normal pattern of behaviour. For example, such variable factors as the climate, the density and quality of the sward, the size of paddock, the system of grazing management and of course, the individuality of the grazing animal may very significantly influence the times devoted to different activities.

Tribe discusses these and other factors as they affect many functions of the grazing animal. As this project is primarily concerned with activity, further discussion will be limited to the stated effect of various factors on this item.

1. Climate

Hot weather causes animals both to graze for a shorter time than normal and to increase the proportion of time that is spent grazing at night. When idling under these conditions the animals appear agitated and in consequence the distances traveled tend to increase.

During cold windy or rainy weather grazing times are again shortened, and the normal overall pattern may be radically altered. When a storm begins animals will usually cease grazing and walk to shelter if such is close at hand, otherwise they will stand with their heads down-wind. Under such conditions hill sheep and cattle will move to higher ground.

2. Size of Pasture

It has been shown on several occasions that the size of the pasture available to the grazing animal will influence its behaviour and in particular the daily distance it travels. In general one can say, the bigger the area of pasture the farther will an animal walk. Shepherd (1921) reported that beef cattle on a 30 acre pasture walked one and five eighth miles between 4:00 a.m. and 8:00 p.m. whereas similar cattle throughout the same period traveled three and one sixteenth miles on a 100 acre pasture and five and a half miles on a 640 acre pasture. There must obviously be limits to this tendency at both ends of the scale, but so far they have not been established.

3. Individuality

Perhaps the greatest and most imponderable problem which besets the animal watcher is the degree to which recorded behaviour may be due to environmental factors and how far merely to the personal whim of the animal.

Hancock (1950) using six sets of monozygotic cattle twins in a one acre paddock showed that inherited variability in grazing behaviour was by far the largest source of variation due to individuality. A part of these inherited differences could be explained by relating them to differences between the physiological requirements of individual animals. It seems reasonable to argue that increased nutritional requirements during growth, pregnancy, or lactation, result in an increased food intake and therefore in increased grazing and ruminating times.

C-II TECHNIQUE DEVELOPMENT

In approaching the problem of measuring sheep activity, as expressed in miles traveled per week, certain difficulties had to be considered:

(1) Work on the other divisions of the overall project would limit the amount of time available.

(2) It was necessary to measure the ranging mileage of the sheep under natural conditions on hill and lowland grazings. For this reason it was impossible to use the checker-board

technique (Wallace and Kennedy 1944). Even where the terrain would permit subdivision, no time was available for 24 hour observation shifts.

(3) Radio control, pedometers and other such devices for tracking movement were all too complicated or impossible to use satisfactorily on the grazing sheep.

The restrictions thus imposed on the work subsequently led to the development of an entirely new device. This device took the form of a machine which it has been proposed shall be known as a Rangemeter.

The Rangemeter consists of a light-weight harness, two metal shafts, and a chassis which sprung onto the ground carries a small land wheel to motivate an automatic mileage recorder--a Lucas cyclometer*--as used on bicycles. The total weight of the machine was about 8 pounds, but the sheep only carried 3 pounds or half the 'spring loaded' weight of the shafts which at one end are pivoted on the shoulder harness and at the other skidded on the ground. The draught of the machine was exceedingly light, a pull of only approximately one pound being required to move it along the flat and on the typical hill slope.

The detailed construction of the apparatus is given in plates 30, 31, 32, 33, and their key.

Development of the first machine took place at Massey Agri-

* Joseph Lucas & Co., Ltd., Birmingham, England

KEY TO "RANGEMETER" PLATES 30, 31, 32, 33

a	=	34" adjustable shafts
b	=	13"
c	=	11"
d	=	4"
e	=	2"
f	=	3"
g	=	6½"
h	=	2½"
i	=	9" adjustable belts
j	=	28" adjustable belts
k	=	12" adjustable belts
l	=	6½" diameter wheel
m	=	harness clamp
n	=	chest strap
o	=	5" bolt
p	=	leather strap (spring)
q	=	cyclometer shield
r	=	cyclometer (26" wheel)
s	=	striker
t	=	hard steel shaft
u	=	hard steel bush

Plate 30. Showing details of the design and construction of the Rangemeter.

Plate 31. Showing details of the design and construction of the Rangemeter.

Plate 32. Showing details of the design and construction of the Rangemeter.

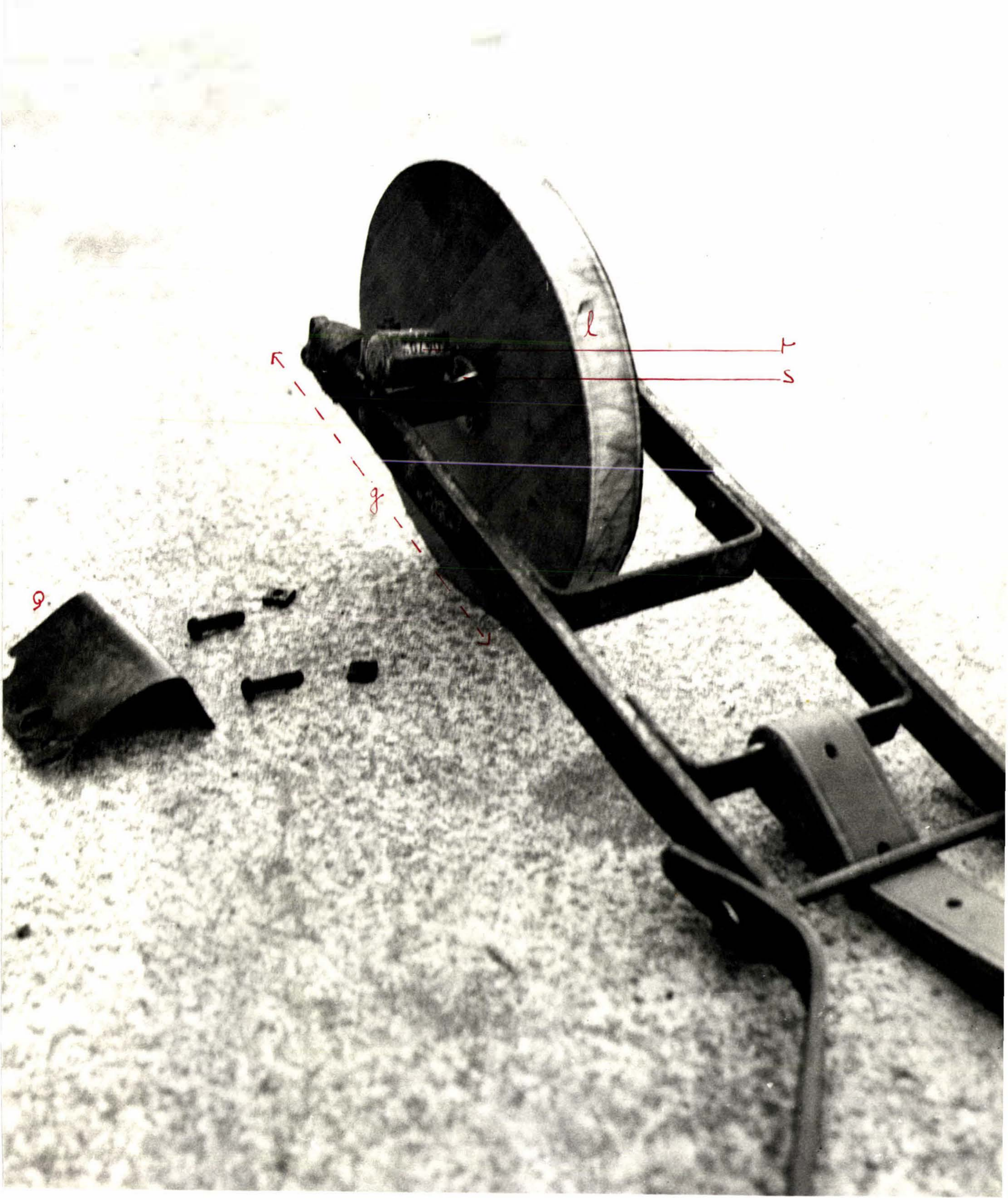


Plate 33. Showing details of the design and construction of the Rangemeter.

cultural College using one Romney ewe. Further machines were constructed as soon as it was obvious that the principle was sound and mechanical defects were remediable; e.g., the land wheels were originally fitted with one inch wide brass bushings which theoretically should not have worn to any marked degree. However, the bushings ground themselves loose on the steel shafts and the subsequent lash in the movements of the wheels was sufficient to result in bent strikers and cyclometer shafts. Eventually the brass bushings were changed for others made from hard steel tubing which revolved on the full length of the shafts (Plate 33). This type of bushing gave very efficient service. The greatest problem was the tendency for long grass stalks to wind themselves round the revolving shafts and thus cause an obstruction to the working of the strikers.

A ball bearing axle and a plate set just below the shaft to fend off grass, will probably overcome all of the technical difficulties of the mileage recorder; and these are to be fitted in the future machines.

The final and most satisfactory type of harness developed was that shown in plate 30. The machines complete with harness could be removed from, or replaced on, the sheep in a matter of seconds merely by unfastening one buckle. This simplicity of arrangement was beyond value to the success of the work.

It is estimated that some of these machines must have traveled approximately 500 miles, which is a testimony to their design and construction.

There was no tendency for wheel slip to occur. As can be seen from plates 30 and 31 the pivoting of the wheel chassis means that its whole weight bears down onto the ground. In addition the pivot is fitted with a leather spring (Plate 31) which allows the wheel to rise and fall with the terrain but nevertheless keeps it firmly pressed to the ground. This spring is essential to the success of these machines.

C-III EXPERIMENTAL PROCEDURE

On 17/7/56 rangemeters were attached to five each of mature, pregnant, Romney and Cheviot ewes from hill stocks carried on Tua Paka, one of the hill farms of Massey Agricultural College.

The sheep became accustomed to being in harness in a very short time; after an hour or so they were grazing normally and were then left over night. The following morning the sheep were turned onto an 18 acre hill paddock.

This paddock is extremely steep and rough, contains a small stream and is well littered with stumps, logs, old fencing posts, etc. Plate 34 illustrates a view of this paddock from one side of the central ridge. The height of the central ridge is about 500 feet and the gradient from the sheep pens at its base direct to the top in places approaches 'one in one'. No better testing ground could have been found for both machines and sheep. Although of a precipitous nature, the hill carried an abundance of grazing throughout the year.

The rangemeters in no way hindered the movements of the sheep which walked, galloped, lay down and got up quite normally. Experimental animals were accepted by the other sheep, which evinced only curiosity about their changed brethren. After parturition the ewes were quite able to suckle their lambs while in harness. Only twice during the whole course of the investigation did a sheep become hung up on a log or fence post.

Plate 34. A view of the holding paddock, Tua Paka, taken from the central ridge.

A number of illustrations are presented to demonstrate the machine at work. (Plates 35, 36, 37, 38, 39.)

Mileage recording commenced on 28/7/56 and from then until 24/8/57 the machines were removed only for repairs, lambing, tupping, shearing and foot dressing. It was soon discovered that once a sheep was broken to harness it never forgot and could be left for weeks between work periods without it becoming excited when harnessed up again.

Mileage records were read every Saturday morning starting at 8:00 a.m., when the sheep were mustered from their night camping spot to a nearby yard or field pen (Plate 40). Thus gathering errors were reduced to a minimum.

During the whole period of the Rangemeter project the ewes were run as normal sheep. The sheep gave no indication of lack of thrift and this was amply borne out by the weights of the ewes on 24/8/57 (Table 18). It will be seen that both Cheviots and Romneys were above the mean figures established for the Haematology flock* approximately four weeks earlier. Some of this extra weight was no doubt due to the growth of the foetus, but even allowing for this the sheep were in very good condition. As a part of the investigation it was decided to measure the foreleg lengths of the Haematology and Rangemeter sheep. The Haematology sheep were measured on 13/6/57 and the Rangemeter sheep on 24/8/57.

The measurements taken were height at withers, height from

* c.f. Division "D"; table 27

Plate 35. Rangemeter flock sheep mustered for mileage recordings to be noted.

Plate 36. Front and rear views of sheep in Rangemeter harness.

Plate 37. Romney Marsh ewe nursing lamb while in harness.

Plate 38. Rangemeter flock ewes on their way out to the hill after mustering.

Plate 39. Rangemeter flock ewes on the hill.

Plate 40. Reading the Rangemeters.

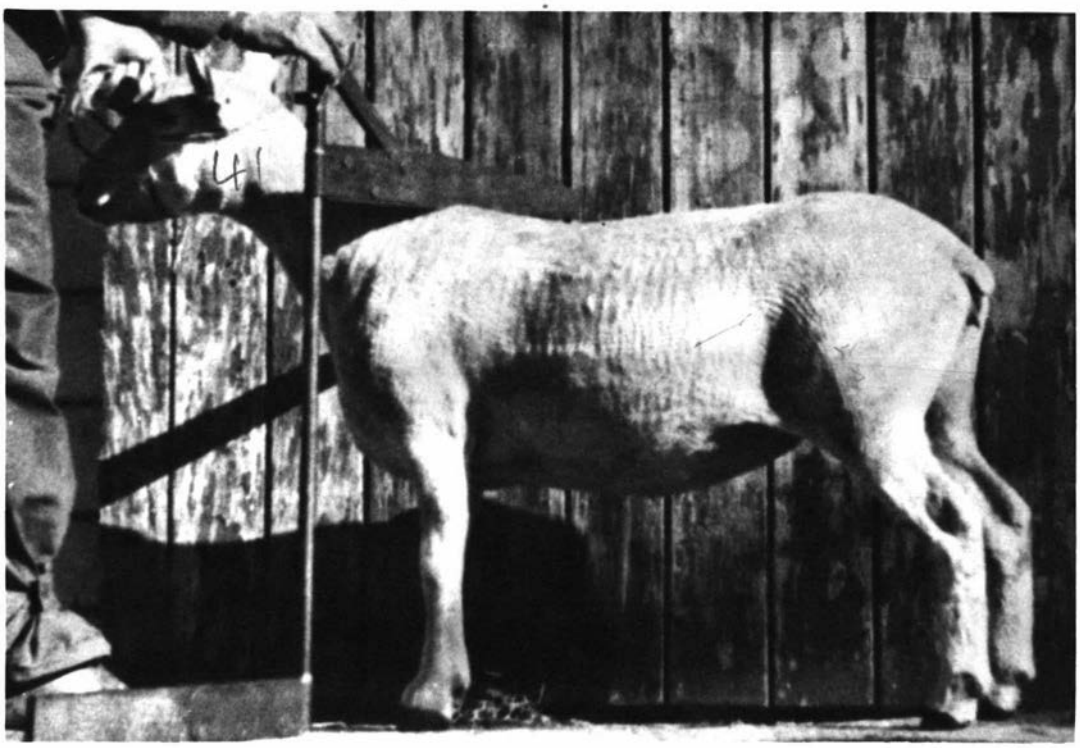


Plate 41. Measuring the height at withers.

Table 18. Rangemeter sheep weights 24/8/57.

Romneys		Cheviots	
No.	lbs. wt.	No.	lbs. wt.
37	166	53	137
32	131	42	148
36	135	35	134
59 (lamb at foot)	108	48	120
60	132	54	133

Comparison of Haematology flock* and Rangemeter sheep weights.

	Haematolgoy Flock (30/7/57)		Rangemeter Sheep (24/8/57)	
	lbs. wt.	St. D.	lbs. wt.	St. D.
Cheviots	125.4	10.9	134.4	10.0
Romneys	120.1	11.6	141.0 (4 sheep)	16.7

* c.f. Division D, Table 27.

ground to brisket and the distance from the point of the elbow to the coronet. Measurements were taken with sliding calipers (Plate 41) and a flexible linen tape. All measurements were taken four times to the nearest half inch, the sheep being moved and resettled in a normal standing position between the measurements.

C-IV RESULTS

The mileage records obtained are presented in table 19 and in figure III which is constructed from the weekly mean mileages of the breeds (Table 19).

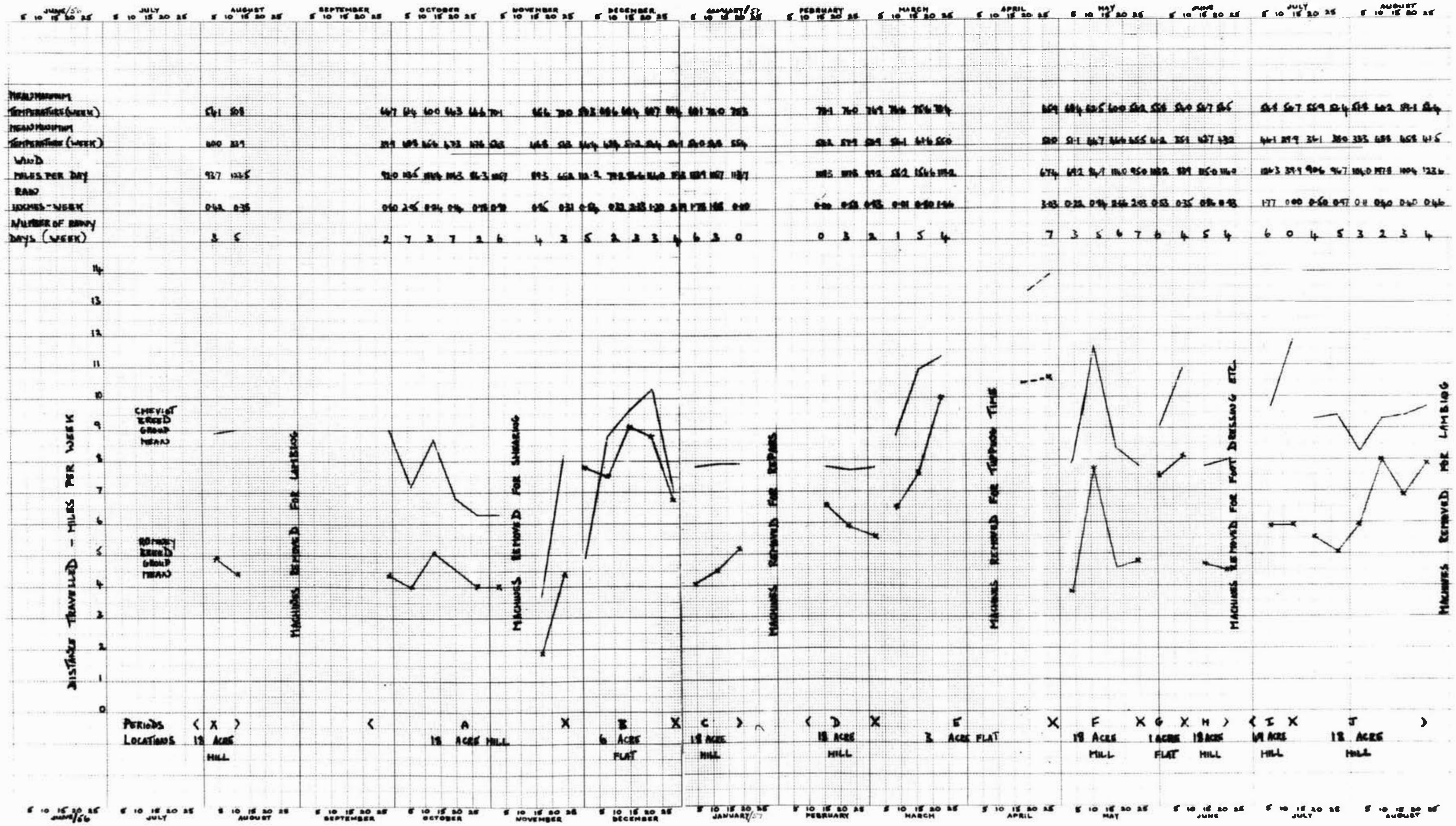
Statistical analysis of the results was complicated by missing records. It was finally decided to analyse the material between breeds using the figures that make up figure III, i.e., the weekly breed means (Table 19) and also to analyse each breed on a between period within breed basis using sheep means. The writer fully realises that analyses based on means derived from unequal numbers may contain error which should be compensated for, but having regard to the data and after consultation it was felt that little or no greater accuracy of interpretation would be obtained by complicating the statistical methods used.

Only when paddocks were being compared was there any cause to consider mustering distance adjustments to the records; but as these distances were all of more or less the same value and at the most would give an error of 100 - 200 yards, or about 0.1 miles per week

Table 19. Mileage records, Rangemeter sheep, 28/7/56 - 24/8/57.

Cheviot No.						Wk. Mns.	Romney No.							Wk. Mns.	Dates
48	55	35	42	53	54		50	59	36	60	34	37	32		1956
9.8	8.0					8.9	4.9	5.0						4.9	28 Jul. - 4 Aug.
	11.1	7.0				9.0	4.8		4.6	4.1				4.4	4 - 11 Aug.
Machines Removed for Lambing															
		9.0				9.0	5.0			3.8				4.4	22 - 29 Sept.
			7.5	8.6	5.6	7.2	4.2	3.9		4.0				4.0	29 Sept. - 6 Oct.
	10.2	7.2		8.7		8.7	3.7	6.3		4.3	6.1			5.1	6 - 13 Oct.
5.4		6.4			8.5	6.8	3.8	6.7	4.3	3.8	4.6			4.6	13 - 20 Oct.
		6.3				6.3	3.5	2.4	5.5	3.5	5.0			4.0	20 - 27 Oct.
		6.3				6.3	3.4		5.5	3.0				4.0	27 Oct. - 3 Nov.
Shearing															
3.4		4.0				3.7			1.5	2.3				1.9	10 - 17 Nov.
10.8		7.7	7.7		6.5	8.2	4.0		4.2			5.0		4.4	17 - 24 Nov.
6.1			3.7			4.9	7.4	6.7	9.4					7.8	24 Nov. - 1 Dec.
		9.0	8.6			8.8	6.0	7.1	9.5			7.4		7.5	1 - 8 Dec.
		8.1	11.2			9.6	7.9	7.8	9.5			11.4		9.1	8 - 15 Dec.
9.5			11.2			10.3	5.6	6.6	6.6			13.0	12.0	8.8	15 - 22 Dec.
				7.4	6.6	7.0		7.1		6.1			7.1	6.8	22 - 29 Dec.
5.5				8.0	9.9	7.8		3.1		4.2		4.0	5.1	4.1	29 Dec. 1956 5th Jan. 1957
8.5				7.2	8.0	7.9			5.7			4.5	3.3	4.5	5 - 12 Jan.
7.2			7.1	9.3		7.9		5.7	5.3	4.3		6.2	4.5	5.2	12 - 19 Jan.
Machines Removed for Repairs															
		7.1	7.1	6.4	10.1	7.8		7.4	8.8	3.9		6.3		6.6	9 - 16 Feb.
8.2		7.1	8.0	6.2	9.1	7.7		5.8	7.9	3.8		6.3		5.9	16 - 23 Feb.
8.3		7.1		6.7	9.2	7.8		4.6	5.6	4.3		7.3	6.2	5.6	23 Feb. - 2 March
		8.6	6.7	9.6	10.1	8.7		6.2		5.8		6.6	7.4	6.5	2 - 9 March
9.3		10.2		9.9	14.1	10.9		10.0	5.3	7.8		7.4		7.6	9 - 16 March
11.3		15.0	7.9	11.0		11.3		13.5	9.3	7.1				10.0	16 - 23 March
Machines Removed for Tupping Time															
			12.0	14.7	15.0	13.9		8.3	3.9			9.4	11.0	10.6	20 - 27 April
		7.1	9.8	6.5	8.2	7.9		3.1	3.2			6.5	2.5	3.8	27 Apl. - 4 May
			6.4	14.5	13.8	11.6		6.0	10.0	8.1		10.3	4.7	7.8	4 - 11 May
6.9			6.3	14.1	6.5	8.4		4.7	5.8	4.7		4.8	3.0	4.6	11 - 18 May
6.0			9.0		8.3	7.8		3.3	7.0	3.6		6.8	3.4	4.8	18 - 25 May
11.0		2.4		12.0	11.2	9.1		6.0	9.7	7.3			7.1	7.5	25 May - 1 June
14.0		4.4	11.9	11.6	12.7	10.9		6.3	8.4	7.9		10.0	7.7	8.1	1 - 8 June
7.5		5.1	8.2	10.5	7.8	7.8		3.1	5.1	5.2		5.8	4.5	4.7	8 - 15 June
9.3			7.3	8.1	7.2	8.0		3.2	5.4	4.4		5.2		4.5	15 - 22 June
Machines Removed for Foot Dressing Etc.															
7.4		9.1		13.0	9.5	9.7		4.4		5.0		7.0	7.4	5.9	29 June - 6 July
9.8			11.7	14.4	11.3	11.8			6.0	4.2		7.5		5.9	6 - 13 July
8.2			9.8	10.0	9.1	9.3		4.0	6.0	3.7		8.7		5.5	13 - 20 July
			9.1	9.9	9.3	9.4		3.7	6.0				5.5	5.1	20 - 27 July
		8.9	8.7	8.2	7.4	8.3		2.9	5.3			8.4	7.1	5.9	27 Jul. - 3 Aug.
		9.1	9.2		9.5	9.3			6.7			9.7	7.5	8.0	3 - 10 Aug.
		8.9	9.5	9.7	9.4	9.4			6.8			8.4	5.4	6.9	10 - 17 Aug.
		9.1	8.8	11.1		9.7			7.8			8.0		7.9	17 - 24 Aug.

Figure III. Showing (1) weather data, (2) average distance traveled in miles per week for Cheviot and Romney Marsh ewes, (3) periods and locations, (4) dates of recording periods.



it was decided to make no theoretical compensation for them.

It is desired to draw attention to the following points:-

(1) The difference in the position of the means for the breeds (Table 19 and Figure III). In general, on the hill, the Cheviot ranged about 7.5 miles per week and the Romney about 5.0 miles per week. On flat land the Cheviot covered about 9.5 miles per week, and the Romney about 8.0. In eight periods out of eleven (Table 20) the difference between the breed means was statistically significant.

(2) The way in which the breeds raised or lowered their mileages together, within the same paddock, as in periods A and F (Figure III).

(3) The way in which the Romneys raised their mileages when transferred from the hill to flat land and then dropped them sharply when returned to the hill (Figure III). For example, in the change from the 18 acre hill to the 6 acre flat paddock (Figure III, periods A - B) the Romneys raised their mileage from 4.4 - 7.8 miles per week while after the first week the Cheviots raised their mileage only from a hill mileage of 8.2 to a flat land mileage of 8.8. In the transference from flat to hill (Figure III, periods B - C) the Romneys fell from 6.8 - 4.1 miles while the Cheviots actually raised their level

Table 20. (1) Average % greater weekly mileage traveled by Cheviot over Romney sheep, within periods.*
(2) Significance of difference in weekly mileages between breeds within periods using week means.
(3) Significance of difference between weeks within periods within breeds.

Period	Location	Average % greater mileage in favour of Cheviots	Level of significance of difference between breeds	Significance of difference between weeks within periods within breeds R	C
X	18 acre hill)	69%	1%		
A	18 acre hill)		1%		
B	6 acre flat	29%	no significant difference		
C	18 acre hill)	51%	1%		
D	18 acre hill)		5%		
E	3 acre flat	30%	5%	5%	5%
F	18 acre hill	75%	approaches 5% level+		
G	1 acre flat	27%	no significant difference		
H	18 acre hill	72%	5%		
I	49 acre hill	82%	5%		
J	18 acre hill	45%	1%		

* For the identification of the periods see Fig. III
\+ High variation between weeks within breeds

of activity. The changes in activity between different periods were statistically significant in 7 cases out of 10 for the Romneys and in only 2 instances out of 10 for the Cheviots (Table 21).

(4) The general lack of variation in the mileages traveled by both breeds within periods. There were no statistically significant differences between weeks within periods except for period E in both breeds (Figure III; table 20).

(5) The small value of the rise in the Romney's mileages when transferred from an 18 to a 49 acre hill paddock, whereas the Cheviots increased their mileages significantly. (Table 19; figure III; table 21, 29/6-13/7/57.)

(6) The respective mileage levels for both breeds were approximately the same on 27/7/57 as they were on 4/8/56. (Figure III.)

(7) The extraordinary steep rise in the activity of both breeds before tupping (Figure III, period E) and the fact that after tupping, which took only three weeks, the high level of activity was repeated on the one week before the sheep were switched back to the hill. The difference between the weeks within period E was statistically significant for both breeds (Table 20.)

(8) With only one exception (Cheviots on larger hill pasture Figure III, table 21, periods H to I) no statistically

Table 21. Levels of significance of difference in weekly mileages between consecutive periods within breeds using sheep means.

Locations*	Periods*	Cheviots	Romneys
18 acre hill - 18 acre hill	X - A		
18 acre hill - 6 acre flat	A - B		1%
6 acre flat - 18 acre hill	B - C		1%
18 acre hill - 18 acre hill	C - D		5%
18 acre hill - 3 acre flat	D - E	1%	1%
3 acre flat - 18 acre hill	E - F	approaches 5%	5%
18 acre hill - 1 acre flat	F - G		1%
1 acre flat - 18 acre hill	G - H		1%
18 acre hill - 49 acre hill	H - I	5%	
49 acre hill - 18 acre hill	I - J		

* For the identification of the locations and periods referred to in this table see Fig. III

significant effect on mileages could be found for differences in pasture size within the same pasture location (hill or flat).

(9) The frequency with which identical or almost identical mileage figures occur with individual sheep for consecutive weeks (Table 19).

(10) Admittedly, weekly mileages may not be an entirely satisfactory way of examining the effect of weather on distances grazed, but except for one period, 24/11-1/12/56, no regular relationship can be traced between weekly climate and the distances traveled. However, the weather records do give a possible explanation why the Cheviot group mileage fell below that of the Romneys in the week 24/11-1/12/56 (Figure III). The week in question saw a drop of 10 to 14 degrees in mean temperatures, almost 100 percent more wind and half an inch of rain spread over five rainy days. The recently shorn Cheviots would appear to have taken badly to these weather conditions as their mileage dropped severely despite the fact of their transfer to lowland country. It is interesting to speculate whether or not the effect of weather conditions on the Romney was negated by their favourable reaction to lowland pasturage--their natural environment.

(11) Grazing distances did not increase during lactation

although they did tend to rise during the latter stages of pregnancy in 1957.

Comparison of the results with Tribe's review is of some interest, for they tend to contradict some of the ideas put forward by this author regarding the influence of pasture size, weather and lactation on the activity of grazing animals.

Analysis of the leg measurement records (Tables 22 and 23) showed that the Romneys were on the average three quarters of an inch greater in height at the withers, half an inch greater in height to the brisket and approximately one to two tenths of an inch greater in elbow-coronet measurement than the Cheviots.

This was, of course, to be expected, for the Cheviot is, generally speaking, a smaller sheep than the Romney although the measurements do not altogether agree with those of von Borstel (1951) taken on ten animals of each breed (Table 23). Von Borstel found his unshorn Cheviots to be about one quarter of an inch higher at the withers than the unshorn Romneys and one twentieth of an inch higher when both breeds were shorn.

It would nevertheless appear that the greater distances traveled by the Cheviots (Figure III; table 19) cannot be related to a greater leg length (Table 22).

Table 22. Comparison of foreleg measurements, Haematology and Rangemeter sheep.

	Haematology Flock		Rangemeter Sheep	
	Mean	St. D.	Mean	St. D.
Cheviots				
Height at withers	22.5"	0.9"	23.0"	0.6"
Height to brisket	11.4"	0.9"	11.9"	0.2"
Elbow to coronet	13.3"	0.5"	13.4"	0.2"
Romneys				
Height at withers	23.2"	0.9"	23.6"	0.8"
Height to brisket	11.9"	0.8"	12.5"	0.7"
Elbow to coronet	13.5"	0.6"	13.3"	0.3"

Table 23. Comparison of height at withers measurements (unshorn sheep) von Borstel (1951) and Haematology flock this project.

	Cheviots		Romneys	
	von Borstel	This Project	von Borstel	This Project
Mean height at withers	22.77"	22.50"	22.52"	23.20"
Number of sheep	10	37	10	37

DIVISION "D"

HAEMATALOGICAL STUDIES

CONTENTS

D-I INTRODUCTION AND REVIEW OF LITERATURE

The aim of this Division of the project was to carry out comparative haematological studies with Romney Marsh and Cheviot sheep.

A survey of the literature revealed that haematological studies have been little utilised as a means of pinpointing or explaining differences between breeds of sheep even though Kerr (1937), working with about twenty species of vertebrates, observed that the most striking feature revealed by the investigation was the wide variation in the blood composition of various sheep. Kerr found that although individuals of the same species as a rule have similar chemical composition of erythrocytes, enormous differences were found among sheep in their content of potassium. For fat tailed sheep the high values were about 64.2 m. equiv. l. and the low values about 18.4 m. equiv. l.

Kushner and Kitaieva (1938) investigated the physiological differences which distinguished hybrids from local Kirghiz and Merino sheep. They found that the blood indices, haemoglobin, erythrocyte count and alkali reserve of the hybrids in all age and sex groups were consistently higher than for local fat tailed sheep and the Merinos of the New Caucasian type. Karpov (1941) showed that crosses of the Romney Marsh and the Tsigai were higher than their parent breeds in regard to haemoglobin, number of erythrocytes, total surface area of the erythrocytes and functional capacity of the haemoglobin.

McLeroy *et al*. (1952) endeavoured to ascertain some of the physiological processes involved in the greater heat tolerance of Rambouillet sheep as contrasted with that of the Suffolk under the extreme heat of Central Arizona. The packed red cell volume (P.C.V.) of eight ewes and their lambs for each breed was investigated. The breed differences were not statistically significant.

Todd *et al*. (1953) comment on the fact that information on the cellular elements of sheep's blood largely rests on a report by Holman (1944) on Scottish sheep. In reporting a comparative haematological study of 55 healthy pure-bred Southdown and 35 pure-bred Hampshire ewes, all within two months of lambing, they attached no significance to any of the differences between the breed means. No statistical analysis is reported.

Evans (1954) found approximately 50 percent of 93 Scotch Blackfaced sheep belonged to a type with a high concentration of potassium in the whole blood and red blood cells. Only 16 percent of 43 Cheviot sheep belonged to the H.K. type.

Evans and Mounib (1957) report a survey of the potassium concentration in the red blood cells of British breeds of sheep. They present data as follows (Table 24) showing that the mountain and hill breeds on the average contain a greater percentage of high potassium animals than do the lowland breeds.

Table 24. The distribution of high potassium values in the red blood cells of British breeds of sheep (Evans and Mounib 1957).

Sheep subtype	Percentage H.K. type
Blackface Mountain	51
Other hill breeds	37
Lowland Longwools	11
Lowland Shortwools	13

These authors find it difficult to assess the significance of their findings but believe that the predominance of high potassium animals living in less favourable climates suggests that this factor may have some bearing on survival in mountain and upland regions in the temperate zone. The breeds can be classified on whole blood estimations.

Gregerson (1951) reviews the subject of blood volume and states that normal values have been reported on a number of the common laboratory animals, but beyond this little has been done in the comparative physiology of blood volume.

No literature could be located which reported blood volume studies on a comparative basis between sheep breeds.

D-II STANDARDS

To facilitate comparison, table 25 presents a number of sheep

Table 25. Summarising data in the literature on haematological values for sheep.

	Hb.	P.C.V.	R.B.C.	W.B.C.	M.C.V.	M.C.H.	M.C.H. conc.	Potassium m.equiv./l. red blood cells High	Low
Josland (1933)	10.4 ± 0.75		10.5 ± 0.97	7.0 ± 1.15					
Filmer (1933)	15.0								
Hamersma (1934)	10.0 - 21.0								
Bennetts and Chapman (1937)	11.0 - 12.0		11.0						
Kerr (1937)								64.2	18.4 conversion
Marston <u>et al</u>. (1938)	10.0 - 15.0								
Underwood <u>et al</u>. (1939)	10.8								
Allcroft (1941)	9.5 - 13.4								
Karpov (1941)*	9.7		10.0 ± 0.31	10.97 ± 0.61					
**	9.9		10.15 ± 0.23	6.97 ± 0.36					
Holman (1944)	8.0 - 10.7	26 - 38	6 - 11	5 - 14	34 - 50	12 - 20			
(1945)			11.5		27		41		
Anaemia									
Mild	9.7	23 - 17							
Moderate	7.5	17 - 12							
Holman (1947)	12.4 ± 1.4	30.5 ± 3.5	11.5 ± 1.8	9.2 ± 3.1	27.4 ± 3.6		41.2 ± 4.0		
Dukes (1947 a)	11.18		8.1	7.44					
Reda and Hathout (1951)			8.6	8.0					
Todd <u>et al</u>. (1953)+	13.41 ± 0.16	40.38 ± 0.44	12.65 ± 0.21	7.26 ± 0.26	32.23 ± 0.44				
++	12.34 ± 0.19	38.35 ± 0.66	12.47 ± 0.32	7.74 ± 0.36	31.07 ± 0.50				
Watson (1953)	15.15 (Sierra of Peru height 11000' - 15000')								
Mehrotra <u>et al</u>. (1954)									
Summer	7.0		8.4		34.5				
Winter	8.6		9.5		38.7				
Widdas (1954)								68.0	16.8
Evans (1954)								89.0	24.0

Hb. = Haemoglobin (gms. per 100 ml. blood) P.C.V. = Packed red cell volume (ml. per 100 ml. blood) R.B.C. = Erythrocytes (millions per cu.mm. blood) W.B.C. = Leucocytes (thousands per cu.mm. blood) M.C.V. = Mean corpuscular volume (cubic microns) M.C.H. = Mean cell haemoglobin (micro micrograms) M.C.H. conc. = Mean cell haemoglobin concentration (percentage)

* Romney Marsh ** Tsigai + Southdown ++ Hampshire

blood values reported by various workers.

Cited from Hansard et al. (1953) table 26 gives a summary of their findings for sheep blood volumes together with those in the literature at that time. To these must be added, the results of Barcroft (1939) and Schambye (1952). The former reported the average blood volume of three hysterectomised sheep as being 60 ml./kg. The latter author obtained mean values of 2.94 litres per animal and 60 ml./kg. body weight for six sheep.

D-III TECHNIQUES

Estimations of haemoglobins, packed red cell volumes, cell counts and potassium values are very frequently carried out in medical, veterinary and agricultural investigations; and the techniques are well standardised. In this project, cell counts were carried out according to the methods of Dacie (1951), potassium values were estimated using an EEL flame photometer and haemoglobins were done on a Hilger Biochem-Absorptiometer. However, blood volume estimations are not so commonly attempted, at least in Agricultural research; nor are the techniques standardised.

In measuring blood volumes early investigators used the Welcker exsanguination method (Wiggers 1949a). This technique depends on bleeding the animals to death and measuring the volume of blood so obtained. The blood remaining in the animal is washed out by post-mortem perfusion and its volume calculated from the comparative

Table 26. Summarising data in the literature on blood volumes of sheep (Hansard *et al* - 1953).

No. of Animals	Age	Average Weight lbs.	ml. Blood 100 gms. Body Weight	St. E.	Ref.
4	1 day	7	16.9	-	Gotsev 1939
4	3-4 days	16	10.9	-	" "
-	-	-	8.0	-	Dukes 1947 b
5	4 months	27	8.0	0.2	Hansard *et al* 1953
4	6 "	92	6.3	0.1	" "
4	1 year	135	5.5	0.3	" "
4	3 years	156	5.8	0.3	" "
3	7 years	115	8.0	0.4	" "

haemoglobin content of the normal blood and of the washings.

Today, most determinations are made by measuring the dilution of a known quantity of material which is added and which remains confined to the blood stream. One of the commonest substances used is the dye Evans Blue (T-1824). This dye combines with plasma albumen in vertebrates and leaves the blood very slowly. Carbon monoxide and red cells containing radio-active iron or phosphorus, or protein with radio-iodine have also been used in determining blood volume.

There is little information in the literature on the minute details of estimation procedures for the blood volumes of farm animals.

Turner and Herman (1931) state that the dye injection method, as with all blood volume methods, has been the subject of some criticism. The proper time after injection for the drawing of the samples and the rate of disappearance of the dye from the blood stream immediately following the injection are most perplexing problems. These workers eventually arrive at the conclusion that four to eight minutes would seem to be the optimal time for withdrawing the samples after injection of the dye in the bovine. Miller (1932) using vital red dye estimated the blood volumes of 19 mature cattle several times each during an 18 month period. The quantity of dye he used was 1 ml. of a 1.5% aqueous solution for each ten pounds of body weight. The sample of blood was taken from the opposite jugular vein ten minutes after the administration of the dye. On the basis of 81 determinations the average quantity of blood per pound of weight was 27.07 ml. or 6.7 percent of body weight. The results showed a considerable variation, i.e. 22-33 ml./lb. but 75 percent of the values were in the narrower range 25-30 ml. lb. During pregnancy there was a marked increase in blood volume proportional to the weight increase until parturition occurred. Shortly afterwards there was a decrease in both blood volume and body weight.

Barcroft et al. (1939) give the blood volumes for three hysterectomised sheep. The technique appears not to have included a starvation period and the sheep were transported singly about two miles to the laboratory anything from half an hour to one day before the estimation. Evans blue (T-1824) was used.

Gotsev (1939) estimated the blood volumes of 5 lambs at birth by the injection of a 2 percent solution of Congo red dye. This was injected into the jugular which was exposed by a skin incision under a local anaesthetic.

Courtice (1943) using Evans Blue (T-1824) on rabbits, dogs (including greyhounds), goats and horses, at about 0.8 mg. dye per Kg. body weight first drew a sample of blood to act as a standard. The dye was then injected into a jugular vein, a further sample being withdrawn from the opposite vein after six minutes. The concentration of the dye in the plasma was then determined by means of the haematocrit spun for 45 minutes at 3000 r.p.m. A correction factor of 4 percent for the dye trapped between the corpuscles was used after the figure put forward by Gregerson and Schiro (1938).

Reeve (1948) deals with the difficulties of the indirect method of blood volume determination as follows:- A sample may be cloudy when drawn, or cloudiness may develop or increase subsequently. The dye content of all plasma samples should be estimated as soon as possible after withdrawal, preferably within two or three hours, and the temperature of the sample is best kept above 20°C. On standing, fat may separate from the plasma and float to the top; and this process becomes more rapid as the temperature falls. When fat rises to the top either the plasma beneath may be removed uncontaminated by very slow pipetting or the superficial fat layer may be held in an added surface layer of mineral oil. Plasma cloudiness is reduced to a minimum by the starving of man or animal for at least twelve hours before the experiment.

Prosser et al. (1950a) say that the various methods for estimating blood volumes give somewhat different values, but there is a striking general agreement.

Schambye (1952) used both Evans Blue (T-1824) and P^{34} tagged erythrocytes, and Hansard et al. (1953) used a phosphorus labelled red cell method for blood volume estimations.

The procedures for blood volume estimations in this project were adopted after a consideration of the aforementioned techniques. Evans Blue dye (T-1824) was the agent used. Possible complications due to pregnancy, lactation and oestrus were avoided by carrying out the operation when the sheep were approximately half-way between weaning and tupping, i.e. weaning 12/12/56, tupping 27/4/57, blood volume estimations 19-20/2/57.

D-IV EXPERIMENTAL ARRANGEMENTS AND PROCEDURE

A flock of 35 of each of Cheviot and Romney Marsh ewes was established at Tua Paka, one of Massey Agricultural College's hill farms. Both groups of sheep originated in similar hill country and consisted of mature ewes of equal ages in-lamb to the Southdown. During the entire period of the investigation this flock was maintained as a single unit on the same hill paddock. Age, growth and environmental variations were therefore minimised as far as was possible. Hewitt (1947) describes this area as second and third class hill country of an easy nature and running up to approximately 700 feet. The pasture is mostly browntop-dominant, capable of carrying one ewe to the acre at the most.

The ewes were weighed at appropriate intervals; and account was taken of lambing records, lamb growth and wool production. Total worm egg counts carried out in July/56 indicated that the ewes were not heavily infested with worms. It is recognised that low worm egg counts do not necessarily mean a low worm burden, but at no time during the project were any obvious symptoms of parasitic infestation shown.

The first 'bleedings' took place on 7-8/7/56, the Romneys being dealt with on the first day. More than 35 of each breed were included in the first bleedings. This was because several of each breed were provided as spares for the over-all project, and it was decided to utilise them in the establishing of the breed means for the haematological values investigated.

Second and third bleedings took place in early October/56 and mid-February/57.

On all occasions bleeding took place in the late afternoon. The samples drawn from the jugular were examined in the Haematology Department of the laboratory, Palmerston North Public Hospital.*

The mid-February operation was different to the previous two as at this time procedures for blood volume estimations were carried out in addition to routine blood sampling.

At this time location of the jugular was facilitated by shaving the necks of the sheep (Plate 42). Also at this time the animals were housed in the evening before each of the bleeding days. This gave a starvation period of approximately 24 hours, as the first dye was not injected until 6:00 p.m. on the bleeding day.

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* No haematological laboratory being situated at Massey Agricultural College, the Medical Superintendent, the Senior Pathologist and the Principal Bacteriologist of this hospital generously offered the use of their facilities for a limited amount of work. All equipment was calibrated and controlled by the Principal Bacteriologist of the Palmerston North Public Hospital.

Plate 42. Blood dye injection. Note the shaven neck.

Being too great a number to deal with on one night, the flock was divided into two groups, each group consisting of an equal number of each breed. These groups were then dealt with in sub-groups of seven, alternating between the breeds.

The operation proceeded very smoothly on both nights. No difficulty was encountered in locating and entering the jugular because of the close shaving of the animals' necks. An initial sample of blood was drawn from the first Cheviot and Romney on each night, these samples being thereafter utilised as a standard. There was no breed difference in the opacity of the plasma samples. 20 ml. of 0.9 percent NaCl containing 15 mg. of Evans Blue (T-1824) was then injected into the right jugular (Plate 42). This is the concentration of dye recommended by Mollinson (1951) and is that used in routine blood volume estimations for humans from 100-200 lbs. weight at the Palmerston North Public Hospital. Eight minutes later a sample of blood was withdrawn from the left jugular into a heparinised bottle. Timing was arranged so that the samples were centrifuged within two hours of the first injection of dye. The plasma dilution of the dye was then calculated using a VIC photo-electric colorimeter. Packed red cell volumes were obtained and the total blood volumes etc. arrived at by using a correction factor of 4 percent (Gregerson and Schiro 1938) for the dye trapped between the corpuscles.

Owing to a miscalculation of the amount of dye available, the final score was Cheviots 27, Romneys 24.

D-V RESULTS

It was impossible to set up the three bleeding dates as a two-way table, there being numbers of differing animals missing from the second and third stages of the work. Statistical analysis was therefore restricted to analyses of variance between breeds and between dates within breeds (Appendix B, tables 1 to 5 inclusive).

Table 27 clearly demonstrates that the Cheviot ewes started heavier and maintained their weight lead over the Romneys throughout the project. The Cheviots lambing percentage (Table 27) was greater than the Romneys (140:115%). Only three Cheviots and two Romneys lost their lambs. The rate of gain of the Cheviots' lambs (Table 27) was significantly superior to the Romneys when expressed in pounds of lamb per ewe between docking (27/9/56) and weaning (12/12/56), although the difference in the weaning weights of the lambs of the two breeds was not statistically significant (Table 27).

Romney wool production was 50 percent greater than that of the Cheviot (Table 27).

Comparison of the haematological data obtained in this investigation (Table 28) with those in table 25 indicates that there were no abnormalities in the general haematological picture of the flock. It will be seen from table 28 that in early July/56 there was a highly significant difference between the haemoglobins, packed red cell volumes (P.C.V.'s) and leucocyte counts for the two breeds, the

Table 27. The general production data of the Haematology flock.

Factor	Date	Cheviot mean	Cheviot St. D.	Romney mean	Romney St. D.	Level of significance of difference between breeds
Ewe weight lbs. (Pregnant)	6/7/56	128.0	8.8	105.3	8.4	1%
Ewe weight lbs.	27/9/56	117.5	9.8	111.2	10.7	5%
Ewe weight lbs.	21/2/57	111.2	9.4	103.6	11.1	1%
Ewe weight lbs.	30/7/57	125.4	10.9	120.1	11.6	approaches significance
Lamb production lbs.	27/9/56 to 12/12/56	49.1	14.7	41.6	8.5	5%
Weaning weights of lambs lbs.	12/12/56	74.6	20.8	66.2	11.3	-
Wool production lbs.	22/11/56	5.25	1.03	8.10	1.27	1%
Lambing%		140%		115%		

Table 28. Haematological data of the Haematology flock and the results of analyses of variance carried out on the same data.

Date		Cheviots			Romneys			Levels of sig. of diff. between breeds	between following dates		between July/56 Feb./57	
		n.	mean	St. D	n.	mean	St. D		C.	R.	C.	R.
	Haemoglobin											
9/ 7/56	(Hb.)*	42	13.45	0.80	43	12.58	0.96	1%				
3/10/56		33	11.84	1.10	30	11.81	1.13		1%	1%		
19/ 2/57		30	13.37	1.43	29	12.27	1.80		1%	5%		5%
	Leucocytes											
9/ 7/56	(W.B.C.)*	41	8.40	2.20	42	11.09	2.50	1%				
3/10/56		32	8.75	2.30	30	11.24	2.44	1%				
19/ 2/57		30	9.42	2.05	29	10.98	2.56	app.1%			app.5%	
	Packed red cell volume											
9/ 7/56	(P.C.V.)*	42	45.3	3.6	40	42.2	4.4	1%				
3/10/56		30	37.6	4.1	30	37.4	4.0		1%	1%		
19/ 2/57		30	42.0	6.8	29	38.8	5.2	5%	app.5%		1%	5%
	Erythrocytes											
9/ 7/56	(R.B.C.)*	8	13.16	1.58	8	11.46	1.04	5%				
3/10/56		13	10.46	1.50	15	10.72	1.39		1%			
19/ 2/57		14	11.18	1.15	13	10.50	1.68				1%	
	M.C.V.*											
9/ 7/56		8	34.6	4.3	8	36.5	4.4					
3/10/56		12	36.5	7.0	15	35.3	3.4					
19/ 2/57		14	37.6	4.9	12	36.7	6.2					
	M.C.H.*											
9/ 7/56		8	10.4	1.2	8	11.2	1.1					
3/10/56		12	11.6	2.3	15	11.0	0.8					
19/ 2/57		14	12.0	1.6	12	11.8	1.9				5%	
	M.C.H. conc.*											
9/ 7/56		42	29.8	2.3	40	30.0	2.4					
3/10/56		30	31.4	1.8	28	31.5	1.2		1%	1%		
19/ 2/57		29	31.7	3.1	29	32.1	5.2				1%	5%

* See table 25 for definitions

Cheviot being higher in the first two and lower for the last factor. Erythrocytes were significantly higher in the Cheviots (at the five percent level) but no significant breed differences existed for those indices of normality, the mean cell volumes (M.C.V.), mean cell haemoglobin (M.C.H.), and mean cell haemoglobin concentrations (M.C.H. conc.). Just how much these figures were influenced by pregnancy and the recently differing locations of the breeds (brought together in early June/56) it was impossible to assess. However, in October/56 the flock had existed as a single unit for upwards of four months.

At that time leucocyte counts were the only significant (very) difference between the breeds, these counts being very close to their July values. Haemoglobin and P.C.V.'s in both breeds, and erythrocyte count in the Cheviots, had fallen very significantly. There was virtually no difference between the breed means for these items. M.C.V. and M.C.H. were again not significantly different and corres-ponded closely with the July values. There was no significant difference between the breed means for M.C.H. conc. but both values had risen very significantly from their July level.

In February/57 leucocytes and P.C.V.'s were the only two factors showing a significant breed difference. Haemoglobin levels had risen very significantly and significantly in the Cheviots and Romneys respectively since October/56. In the Cheviots the packed red cell volumes had risen almost significantly.

On a comparison being made between the July/56 and February/57 values it was found that in February the Cheviots had recovered to their July mean for Haemoglobin, but the Romneys were still significantly lower than their July level. A slightly larger difference between the breed means for haemoblogin in February (as compared with the July figures) was not significant, possibly due to a higher variability within the groups.

The July/56 and February/57 Romney leucocyte counts were similar, but those of the Cheviots had risen almost significantly. Despite this rise, the Cheviot means for the three bleedings lay below 10,000, and all of the Romney means lay above 10,000. P.C.V.'s suffered very significant and significant falls in the Cheviots and Romneys respectively between July/56 and February/57 and erythrocytes were very significantly lower in the Cheviots in February/57. The M.C.V. showed no change between the two dates, but the M.C.H. for the Cheviots was significantly higher in February/57 than July/56. This latter was due to the fall in the Cheviot erythrocyte counts. The M.C.H. conc. showed very significant and significant rises between the July and February records in the Cheviots and Romneys respectively.

Although both sets of figures lay within the normal limits for mammals, of seven to ten percent of the body weight (Dukes 1947 b; Wiggers 1949 b; Prosser *et al*. 1950 b) the results for the blood volume estimations (Table 29) revealed a very marked difference between the breeds. The Cheviots had an average of 1.06 litres more blood per sheep than the Romneys. This difference remained statis-

Table 29. Blood volume and relevant data--Haematology flock, February/57.

Factor	Cheviots Mean	Cheviots St. D	Romneys Mean	Romneys St. D	Level of significance of breed differences
Total blood volume in litres	4.64	0.46	3.58	0.72	1%
Total plasma volume in litres	2.76	0.28	2.26	0.39	1%
Total erythrocytes vol. in litres	1.88	0.12	1.32	0.14	1%
Body weight Kg.	49.8	4.3	46.1	4.9	1%
Blood ml./Kg.	93.2	9.2	77.7	14.1	1%
Plasma ml./K .	55.6	6.9	49.3	8.5	1%
Erythrocytes ml./Kg.	37.5	6.9	28.4	9.2	1%
Average sheep body surface area (sq. metres computed)*	1.11	0.05	1.06	0.06	1%
Blood litres/sq. metres surface area	4.17	0.38	3.36	0.62	1%
Plasma litres/sq. metres surface area	2.48	0.26	2.13	0.35	1%
Erythrocytes litres/sq. metres surface area	1.68	0.32	1.27	0.43	1%

* Brody (1945)

tically very significant when plotted against Kg. body weight* and sq. metres computed surface area.* The mean difference in blood volume is composed of approximately equal parts of plasma and erythrocytes.

Estimations of whole blood and red blood corpuscle potassium (Table 30) showed that approximately three fifths of the Cheviots and one fifth of the Romneys belonged to a high potassium type.+

The mean values for whole blood and red blood cell potassium in the H.K. and L.K. types agreed very well with those obtained by Evans (1954). However, the distribution of the values for the Cheviot is different to Evans' findings. He found only 16 percent of Cheviots belonged to the H.K. type.

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* The sheep were weighed the day after the blood volume estimations were completed, i.e. on 21/2/57.
\+ As defined by Evans, 1954.

Table 30. The mean concentrations of Potassium in the whole blood and red blood cells, Haematology flock 3/10/56, also data ex Evans* (1954).

Breed	n.	High K. values (m.equiv./litres) mean	St. D	n.	Low K. values (m.equiv./litre) mean	St. D
Whole Blood						
Cheviot	17	31.02	3.39	13	10.48	4.43
Romney	5	30.34	6.35	21	10.27	1.70
Scotch Blackfaced*	47	36.00		46	15.00	
Red Blood Cells						
Cheviot	17	77.03	12.05	9	21.14	12.98
Romney	5	78.82	4.63	21	21.63	4.63
Scotch Blackfaced*	47	89.00		24	24.00	

* These figures are the high and low mean values put forward by Evans (1954) for Scotch Blackfaced sheep.

DIVISION "E"

DISCUSSION AND CONCLUSIONS

OF THE OVERALL PROJECT

(Divisions "A", "B", "C", "D")

DISCUSSION

This investigation found its roots in the fact that in New Zealand the Romney Marsh sheep is being asked to live and perform on certain poor hill country on which it is giving disappointing results (Peren *et al.* 1951) whereas the Cheviot (and the cross between the two breeds) thrives well under the same conditions.

An examination of the United Kingdom backgrounds of the breeds confirmed that the Romney is historically a sheep of fat lowland pastures and comparatively clement climatic conditions, while the Cheviot was developed as a sheep for a hill region noted for its thin pasturage and severe climate.

These backgrounds suggested three lines of investigation which would possibly pinpoint differing breed characteristics acquired in Great Britain and now related to the comparative success and failure of the Cheviot and Romney respectively in the particular New Zealand conditions. The studies taken up were Energy Metabolism, Ranging Behaviour and Haematology.

For energy metabolism studies (Division "B") a new technique in closed circuit indirect calorimetry was evolved. This enabled comparatively long term energy metabolism experiments to be carried out; and was also used to demonstrate its usefulness for other types of study; climatological, physiological and nutritional.

So far as the writer is aware, this is the first inter-breed metabolism study with sheep set up as such both in its conception and experimental plan.

Interpretation of the results of this division of the project is complicated by the introduction of new animals and the fact that the Romneys (except for the first block of energy metabolism experiments) tended to be heavier than the Cheviots. It can thus be argued that for future work every effort should be made to maintain equal weights between the experimental groups and so avoid the necessity for mathematical equating. However, the policy adopted would depend upon the hypothesis being investigated, i.e. is there a differential between the breeds at typical breed weights or between members of different breeds which happen to be, as individuals, at identical weights.

Analysis of the records obtained over an eight to ten month period indicates that the Cheviot--a true hill breed--has a lower metabolic rate than the Romney--a true lowland sheep. The Cheviots (per animal) normally metabolised at a level 10-15 percent below the Romneys. However, when the oxygen consumption records were related to kilograms body weight, sq. metres surface area (computed) and kg. body weight to the power 0.73, the differences between the breeds were not statistically significant, except under severe starvation conditions for the latter two bases of presentation.

When starved the Cheviots rapidly adjusted their metabolic rates in an orderly manner to a low level, while the Romneys appeared to be more erratic in their response to food shortage.

This reaction of the Cheviot to starvation is considered to be support for the hypothesis on which the energy metabolism division of the overall project was based, namely that the Cheviot in New Zealand should possess physiological mechanisms related to the ability of its forebears to survive on the barren and often snow bound pastures of the Cheviot hills; physiological mechanisms which the fat-land Romney need not have developed.

Some basis was found for doubting the validity of the presently used mathematical techniques designed specifically for making homeotherms of varying sizes fit into a general metabolism law. This finding was that the metabolism of both Cheviots and Romneys fell slowly but quite consistently from lambing time to the autumn despite the tendency for both groups to be maintaining or even increasing weight. Greater body weight is supposedly associated with greater oxygen consumption per animal. The fall in energy metabolism as autumn approached would appear to follow the seasonal rhythm in thyroid activity (Brody 1945a). This trend was unbroken despite the introduction of new animals (four Romneys, three Cheviots) into each group during the experimental period.

Carcass analysis carried out on experimental animals indicated that the Cheviot dressed out better then the heavier Romney and that the heart-body weight ratio may be higher in the Cheviot.

Although these differences were not statistically significant, they are interesting when considered from the view-point of relating body weight or some portion of the body weight to oxygen consumption.

If further work were to confirm that the Cheviot is a more muscular animal, has a higher dressing percentage, a greater heart weight and/or greater blood volume then it would be quite feasible to rate this breed with a higher physiologically effective body weight than the Romney. Work is being undertaken at Massey Agricultural College on the chemical and dissection analysis of the dressed carcasses. The indications are that the Cheviots were, in fact, the more muscular group. This work is to be published independently.

In view of the above, the writer contends that no justification can be seen for the present methods of equating races within a species by mathematical techniques that are based on an assumption of constant ratios of weight and function* between the various parts of their bodies. Such methods may be very well for general studies on a comparative basis which show that homeotherms all obey basically the same laws, but it is certainly not a good enough approach for critical intraspecific studies.

Support for this contention is found in Hellbergs argument (1949) that, so far as is possible, variations in body weight ought to be analysed with reference to its causes and that the different items ought to be treated differently in the way of correction.

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* Behavior and haematological studies with Cheviot and Romney Marsh sheep in this project indicated that there were large breed differences in activity, blood factors and blood volume.

When the oxygen consumption data were expressed as Calories/24 hours, the mean breed figures were in general higher than those in the literature. That the sheep in this project were standing and on full feed may be implicated, as well as the error of conversion; however, the fact of large seasonal and breed variations may indicate a need for a revision of many of the figures put forward for the nutrition requirements of sheep.

As an Addendum to the energy metabolism studies, five incidental reports are presented:-

(a) The effect of shearing and drenching with simulated rain on the oxygen consumption and respiratory pattern of sheep.

(b) The effect on their metabolic rate of feeding 1 lb. of oats to each of three sheep after twelve hours starvation.

(c) The effect of 1 thyroxine on the oxygen consumption, respiration rate, and body weight of one Romney Marsh ewe.

(d) Methane exhalation in sheep.

(e) The regurgitation process in sheep.

These reports are self contained, but taken as a whole do indicate that there is a wide field of work to which the devised techniques can be adapted.

It being also hypothesised that the Cheviot should be a more active animal than the Romney, an entirely new device--the Rangemeter--was developed to enable weekly grazing mileages to be recorded under completely normal conditions on all types of pasture in any location (Division "C").

The records show conclusively that of the animals under investigation the Cheviot, the shorter legged breed, was 50 to 100 percent more active than the Romney under hill conditions. The Cheviots also responded to wider spaces on the hill. Under lowland conditions, however, the Romney increased its distance traveled and, in fact, very nearly equalled the Cheviot, only to fall back again quite decisively when returned to the hill. The fact that the Romney greatly increases its activity on flat lowland pastures contradicts the commonly held idea that the Romney Marsh sheep in New Zealand has adapted itself to hill grazing.

The rangemeter was enlightening in other ways, for it allowed the first long term records derived from a number of sheep to be critically compared with the ideas put forward in recent publications on animal behaviour (Hammond 1955). Contrary to these ideas were the findings that:-

(1) Within the breeds under lowland conditions, size of field had little or no effect on the distances traveled and that this applied to the Romney on the hill; however, the Cheviots' increase in grazing distance in a change from an 18 to a 49 acre hill pasture may have been due to a pre-ordained grazing routine rather than nutritional necessity.

(2) Weekly weather as such had no regular effect on the weekly distances traveled, although just after shearing there may have been a distinct tendency for the sheep to reduce activity when it rained.

The moving of the sheep to a lowland pasture at this time complicates interpretation of the results.

(3) Lactation did not appear to result in increased grazing distances. However, in 1957 when the records were much more complete, there was a rise in the activity of the pregnant animals as they approached parturition. This rather contradicts the shepherds' traditional idea that ewes tend to spend more time lying down as lambing approaches.

Four other interesting findings were:

(1) The frequency with which almost identical records turned up for individual sheep in consecutive weeks. This may possibly be due to the particular animal establishing a grazing beat for itself.

In this respect further observational work in combination with the use of the rangemeter may vindicate the belief of many shepherds that sheep establish a home within a paddock (Firbank 1940). Such work could also help to explain the working of hefted sheep on unfenced hills in Great Britain.

(2) The way in which the activity of one animal reflected the activity of its breed group.

(3) The greatly increased activity of both breed groups in the breeding season. At that time (autumn), according to the findings of the previously discussed energy metabolism experiments, sheep are possibly metabolising at a low rate--a contradiction which may

repay further investigation.

(4) Foreleg measurements showed that the more active Cheviot was the shorter legged of the two breeds--an interesting finding when considered alongside the idea that longer legs will impart to the New Zealand Romney greater ease of travel and better leverage for hill climbing (Barton 1954).

It is recognised, however, that these results were obtained in a New Zealand environment and are thus not strictly comparable with work in South Africa or in the North of Scotland. Nevertheless, it is suggested that further inquiry on the lines of the present investigation may be worth considering as the rangemeter is at least a "valid and standardised technique". There is no reason why the rangemeter should not be developed as a carrier for an arsenal of other devices which would thus automatise a deal of the work of grazing studies. For example, pressure time switches can be incorporated in the girth strap so that lying down periods can be measured and mapped within a day or week. The machine can also be modified to enable a ram to serve while wearing it.

Haematological studies (Division "D") carried out with a specially created flock on one of the Massey Agricultural College hill farms indicated breed differences for total leucocyte counts, distribution of potassium values and packed red cell and blood volumes. In other respects; haemoglobin, M.C.V., M.C.H., M.C.H. conc., the breeds were essentially equal. If the standards laid down by other workers can be accepted then neither of the flocks was in any way anaemic; in fact their haemoglobin levels were good. The distinct breed difference in the total leucocyte counts (Cheviots $<$ 10,000 c.mm, Romneys $>$ 10,000 c.mm. blood) is felt to be worthy of further investigation for the high counts for the Romneys agreed perfectly with those of Karpov (1941).

One of the difficulties in this project was at all times the tendency for physiologists, biochemists, mathematicians and even agriculturalists to regard sheep as being identical but for their appearance. Much sheep work is reported without the breed being specified, which rather restricted the field of standards for comparison (this applied equally to all experimental divisions of the project) and complicated the interpretation of some of the results. An interpretation of the breed differential in leucocyte counts is difficult, for the total counts were not split down into the composite types. However, so far as the high Romney leucocyte counts are concerned, it is felt that they may indicate that the animals were living under constitutional stress or they may be a breed characteristic possibly connected with the breed's traditional resistance to foot rot and other marshland troubles.

The whole blood and red blood cell potassium estimations revealed that the Cheviots had three fifths, while the Romneys had only one quarter high values. There was agreement between the breeds on the actual values within a classification.

The distributions of whole blood and red blood cell potassium values place the Cheviot and Romney in the categories of hill and lowland sheep respectively (Evans and Mounib 1957) even though the Romneys were obtained from New Zealand hill stocks.

Evans and Mounib (1957) are inclined to connect with 'hardiness' a large percentage of high blood potassium values within a breed. They derive their belief from a wide survey of hill and lowland breeds which revealed that the high values are found most often in hill sheep. The Romney figures presented in this project agree almost perfectly with those of Evans and Mounib for the Romney in England. However, the Cheviots do not agree nearly so well. This latter is possibly because Evans (1954) was dealing with the "Caithness" variety which in breeding, background, hardiness and thriftiness (Thomas 1945) is different to the Border Cheviots from which the Massey Agricultural College Cheviots are descended. Selection of the foundation animals for importation into New Zealand may also be implicated in that, by chance, it could have occurred that a large proportion of H.K. Cheviots and L.K. Romneys were among the original stud animals.

Blood volume estimations carried out under the conditions required for a comparative study indicated that the Cheviot had, per animal, a little over a litre more blood (25 to 30 percent) than the Romney and that this difference remained statistically significant at the one percent level when it was related to body weight and computed surface area.

The blood volume differences between the breeds are such as to bring the more active Cheviot into line with current theories on the requisites for athletic living. Dill (1938); Brody (1945b); Houssay (1955), consider that a high oxygen capacity (blood volume) is necessary for comparatively athletic living rather than any peculiarly high levels for haemoglobin or erythrocytes. The Cheviot would therefore appear to fulfill the stated requirements and backs them up by living athletically, as is evidenced by the rangemeter studies mentioned above. It is interesting to note that when expressed in ml./Kg. the blood volume for the Romney corresponds with Courtice's (1943) mongrel dogs 77:79 and the Cheviot approaches the figure for greyhounds 93:114.

It is considered likely that a high blood volume may be related to other functions--for so they may be called--such as hardiness. So far as the writer is aware, no comparative studies have been carried out on blood volume in sheep stocks in the United Kingdom, and it is felt that in view of the present findings, such studies are well warranted.

The haematological flock was also used to obtain general production data. It appears that the Cheviot was able to maintain a live-weight differential over the Romney under the particular conditions and that by and large under those same conditions the breed was the more productive as was evidenced by the rate of lamb growth and the numbers of twins born. However, the weaning weights of the Romney lambs equalled the Cheviots; but this may have been due to a difference in lambing dates.

Wool production is the point on which the Romney scored, for fifty percent more wool is an appreciable difference.

CONCLUSIONS

It is concluded that the results obtained from the overall project indicate:-

(1) That the techniques developed for these investigations have proved their usefulness for physiological, behaviour and haematological studies with sheep.

(2) That the Border Cheviot sheep in New Zealand is still possessed of physiological attributes which may explain its ability to produce better on poor hill country than the New Zealand Romney Marsh.

(3) The seasonal trends in the energy metabolism of sheep which towards autumn probably run counter to weight increases and grazing and ovulation activity, differences in breed reaction to starvation and breed differences in activity and haematological picture indicate that a critical re-appraisal of the bases for reporting intraspecific energy metabolism studies is overdue.

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APPENDIX "A"

APPENDIX A TABLE 1

Block I - 19th September - 4th October 1956

Oxygen consumption records in litres* oxygen consumed per five minute periods.

Romneys					Cheviots				
1	2	3	4	5	6	7	8	9	10
1.90	1.80	1.99	1.99	1.33	1.52	1.62	1.42	1.71	1.52
1.91	2.00	2.14	2.00	1.52	1.72	1.81	1.71	1.62	1.52
2.09	1.90	2.20	1.90	1.45	1.80	1.85	1.80	1.52	1.52
2.17	1.89	1.89	1.76	1.33	1.57	1.61	1.42	1.41	1.46
2.10	1.99	2.18	1.71	1.23	1.42	1.91	1.44	1.80	1.72
2.19	1.70	2.08	1.81	1.33	1.70	1.70	1.55	1.61	1.72
2.02	1.99	2.10	1.81	1.33	1.71	1.80	1.33	1.43	1.33
1.99	1.52	1.96	1.80	1.23	1.54	1.80	1.51	1.42	1.42
1.85	1.51	1.88	1.41	1.22	1.60	1.41	1.42	1.51	1.41
1.89	1.51	1.80	1.69	1.33	1.42	1.70	1.32	1.42	1.23

* Corrected to Standard Temperature and Pressure

APPENDIX A TABLE 2

Block II 7th - 17th October 1956

Oxygen consumption records in litres*oxygen consumed per five minute periods

Romneys					Cheviots					
1	2	3	4	5	6	7	8	9	10	
1.74	1.24	1.54	1.54	0.97	1.74	1.46	1.34	1.62	1.30	
1.82	1.64	1.74	1.44	0.96	1.73	1.53	1.35	1.72	1.07	
1.53	1.73	1.44	1.63	1.15	1.82	1.34	1.73	1.73	1.53	
1.33	1.61	1.71	1.51	1.52	1.63	1.42	1.52	1.62	1.33	
1.62	1.42	1.71	1.61	1.33	1.52	1.58	1.52	1.81	1.43	
1.43	1.53	1.72	1.24	1.62	1.43	1.34	1.53	1.72	1.24	
1.91	1.24	1.62	1.53	1.15	1.43	1.53	1.34	1.63	1.34	
1.64	1.16	1.43	1.24	1.10	1.34	1.44	1.06	1.43	1.15	24 hrs. starvation
1.35	1.15	1.28	0.96	0.96	1.25	1.34	1.25	1.26	0.96	48 hrs. starvation

* Corrected to Standard Temperature and Pressure

APPENDIX A TABLE 3

Block III 23rd January - 3rd February 1957

Oxygen consumption records in litres* oxygen consumed per five minute periods

Romneys					Cheviots				
4	5	15	16	17	7	8	10	20	21
1.73	1.35	1.73	1.47	1.71	1.40	1.54	2.11	1.30	1.19
1.19	1.57	1.61	1.18	1.76	1.33	1.33	2.10	1.14	1.43
1.42	1.61	1.37	1.28	2.04	1.52	1.42	2.09	1.18	1.66
1.67	1.33	2.00	2.19	1.80	1.28	1.24	1.38	1.19	1.19
1.38	1.32	1.51	1.71	1.42	1.14	1.33	1.86	1.28	1.37
1.70	1.41	1.79	1.41	1.41	1.27	1.41	2.07	1.51	1.32
1.51	1.57	1.76	1.61	1.47	1.14	1.23	1.47	1.38	1.14
1.43	1.26	1.52	1.38	1.52	1.19	1.62	1.66	1.14	1.09
1.42	1.13	1.42	1.37	1.42	1.13	1.37	2.09	1.00	1.18
1.40	1.49	1.54	1.55	1.59	1.16	1.50	1.40	1.40	1.26

* Corrected to Standard Temperature and Pressure

APPENDIX A TABLE 4

Block IIIa - 8th - 12th February 1957

Oxygen consumption records in litres* oxygen consumed per five minute periods

Romneys					Cheviots				
4	5	15	16	17	7	8	10	20	21
1.42	1.23	1.69	1.37	1.66	0.95	0.99	2.18	1.28	1.33
1.42	1.37	2.21	1.35	1.61	1.04	1.15	1.43	1.47	1.24
1.54	1.54	1.40	1.16	1.59	1.15	1.25	1.64	1.44	1.05
1.68	1.44	1.53	1.44	1.49	1.15	1.44	1.43	1.34	1.24
1.73	1.63	1.87	1.83	1.73	1.45	1.54	2.22	1.45	1.30

* Corrected to Standard Temperature and Pressure

APPENDIX A TABLE 5

Block IV 29th March - 7th April 1957

Oxygen consumption records in litres* oxygen consumed per five minute periods

Romneys					Cheviots				
17	X	16	15	5	8	7	20	Y	10
1.39	1.19	1.77	1.53	1.48	1.15	1.15	1.20	1.19	1.73
1.14	1.09	1.53	1.28	1.29	1.09	1.00	1.19	1.19	1.24
1.30	1.45	1.54	1.25	1.59	0.87	1.01	1.25	1.06	1.25
1.36	1.36	1.42	1.13	1.50	0.98	0.97	1.03	1.27	1.36
1.08	1.36	1.45	1.26	1.57	1.08	1.08	0.97	1.37	1.08
1.37	1.37	1.52	1.47	1.43	0.99	1.04	1.24	1.56	1.37
1.38	1.38	1.48	1.52	1.38	1.19	1.10	1.19	1.14	1.29
1.29	1.63	1.53	1.53	1.68	1.29	1.15	1.24	1.24	1.58
1.31	1.26	1.36	1.46	1.16	1.17	0.97	1.46	1.12	1.26
1.29	1.24	1.38	1.38	1.18	1.13	0.89	0.94	1.22	1.27

* Corrected to Standard Temperature and Pressure

APPENDIX A TABLE 6

Block V 8th - 17th April 1957

Oxygen consumption records in litres* oxygen consumed per five minute periods

Romneys					Cheviots				
17	X	16	15	5	8	7	20	Y	10
1.37	1.22	1.30	1.31	1.12	0.98	0.88	1.12	1.02	1.17
1.18	1.18	0.98	1.23	1.08	0.88	0.97	0.93	1.23	1.03
1.18	0.98	1.06	1.07	1.07	0.82	1.02	0.88	1.07	0.97
1.00	1.15	0.96	1.24	1.00	0.72	0.72	0.77	1.05	0.91
1.01	1.01	1.10	1.10	1.06	0.77	0.72	0.86	1.01	0.91
1.10	1.06	1.10	0.96	0.91	0.72	0.72	0.67	1.01	0.91
0.95	1.04	0.95	0.91	1.09	0.72	0.76	0.81	0.81	0.81
0.96	1.25	1.01	0.82	0.87	0.72	0.91	0.72	0.91	0.77
1.05	1.04	1.09	0.90	0.90	0.66	0.81	0.67	0.81	0.81
0.95	1.14	0.81	0.80	0.76	0.66	0.66	0.76	0.90	0.76

* Corrected to Standard Temperature and Pressure

APPENDIX A TABLE 7

Block VI 18th - 27th April 1957

Oxygen consumption records in litres* oxygen consumed per five minute periods

Romneys					Cheviots				
17	X	16	15	5	8	7	20	Y	10
0.85	1.09	0.99	0.95	0.85	0.71	0.80	0.90	0.99	0.76
1.05	1.15	0.91	0.96	0.86	0.86	0.81	0.96	1.05	0.86
1.10	1.09	0.96	1.29	0.95	0.77	0.86	0.86	1.05	0.86
1.23	1.13	1.23	1.23	0.95	0.80	0.95	1.04	1.09	1.04
1.33	1.09	1.23	1.28	1.13	0.95	1.14	1.04	1.37	0.99
1.24	1.15	1.29	1.34	1.10	0.86	1.14	1.10	1.19	1.24
1.37	1.14	1.33	1.23	1.04	0.99	0.99	1.18	1.33	1.18
1.58	1.10	1.24	1.29	1.10	0.86	0.86	1.10	1.09	1.24
1.42	1.13	1.61	1.37	1.32	1.23	1.18	1.18	1.61	1.61
1.34	1.10	1.63	1.43	1.29	1.24	1.14	1.05	1.43	1.43

* Corrected to Standard Temperature and Pressure

APPENDIX A TABLE 8

ANALYSES OF VARIANCE

Oxygen consumption in litres* consumed per 5 minutes per animal

	Sources	D.F.	Variance	F.	Nec.F 5%	Nec.F 1%
Block I						
	Breeds	1	1.1859	2.70	5.32	11.30
	Error	8	0.4399			
Block II						
	Breeds	1	0.0049	0.02	"	"
	Error	8	0.2007			
Block III						
	Breeds	1	0.3969	1.18	"	"
	Error	8	0.3368			
Block IIIa						
	Breeds	1	0.4570	2.34	"	"
	Error	8	0.1953			
Block IV						
	Breeds	1	1.1004	10.50	"	"
	Error	8	0.1048			
Block V						
	Breeds	1	0.9025	19.12	"	"
	Error	8	0.0472			
Block VI						
	Breeds	1	0.3721	3.57	"	"
	Error	8	0.1043			

* Corrected to Standard Temperature and Pressure

APPENDIX A TABLE 9

ANALYSES OF VARIANCE

Oxygen consumption in litres* consumed per 5 minutes per Kg. body weight

	Sources	D.F.	Variance	F.	Nec.F 5%	Nec.F 1%
Block I						
	Breeds	1	0.0005	2.50	5.32	11.30
	Error	8	0.0002			
Block II						
	Breeds	1	0.00000	0.00	"	"
	Error	8	0.01283			
Block III						
	Breeds	1	0.00006	0.32	"	"
	Error	8	0.00019			
Block IIIa						
	Breeds	1	0.000048	0.53	"	"
	Error	8	0.000090			
Block IV						
	Breeds	1	0.00006	0.05	"	"
	Error	8	0.00112			
Block V						
	Breeds	1	0.0001254	2.42	"	"
	Error	8	0.0000519			
Block VI						
	Breeds	1	0.0000	0.00	"	"
	Error	8	0.0000			

* Corrected to Standard Temperature and Pressure

APPENDIX A TABLE 10

ANALYSES OF VARIANCE

Oxygen consumption in litres* consumed per 5 minutes per sq. metre computed surface area

Block	Sources	D.F.	Variance	F.	Nec.F 5%	Nec.F 1%
I	Breeds	1	1.0941	3.71	5.32	11.30
	Error A	8	0.2948			
	Days	9	1.0881	7.34	2.01	2.67
	Error B	81	0.0120			
II	Breeds (to 9th day)	1	0.0083	0.04	5.32	11.30
	Error A	8	0.2071			
	Days (to 7th day)	6	0.0188	0.73	2.29	3.18
	Error B	54	0.0259			
III	Breeds	1	0.0075	0.02	5.32	11.30
	Error A	8	0.3106			
	Days	9	0.0457	1.39	2.01	2.67
	Error B	81	0.0329			
IIIa	Breeds	1	0.1812	1.06	5.32	11.30
	Error A	8	0.1703			
	Days	4	0.1271	4.24	2.61	3.83
	Error B	36	0.0300			
IV	Breeds	1	0.4186	4.68	5.32	11.30
	Error A	8	0.0894			
	Days	9	0.0459	3.50	2.01	2.67
	Position	9	0.0076	0.58	2.01	2.67
	Error B	72	0.0131			
V	Breeds	1	0.3982	18.61	5.32	11.30
	Error A	8	0.0214			
	Days	9	0.0817	12.57	2.01	2.67
	Position	9	0.0045	0.69	2.01	2.67
	Error B	72	0.0065			
VI	Breeds	1	0.1076	1.45	5.32	11.30
	Error A	8	0.0742			
	Days	9	0.1966	16.95	2.01	2.67
	Error B	81	0.0116			

* Corrected to Standard Temperature and Pressure

APPENDIX A TABLE 11

ANALYSES OF VARIANCE

Oxygen consumption in litres* consumed per 5 minutes per Kg. body weight$^{0.73}$

	Sources	D.F.	Variance	F.	Nec.F 5%	Nec.F 1%
Block I						
	Breeds	1	0.0044489	3.18	5.32	11.30
	Error	8	0.0013989			
Block II						
	Breeds	1	0.0000246	0.00	"	"
	Error	8	0.0011101			
Block III						
	Breeds	1	0.0000036	0.00	"	"
	Error	8	0.0014419			
Block IIIa						
	Breeds	1	0.0005986	0.90	"	"
	Error	8	0.0006609			
Block IV						
	Breeds	1	0.0007839	1.84	"	"
	Error	8	0.0004361			
Block V						
	Breeds	1	0.0016080	8.53	"	"
	Error	8	0.0001884			
Block VI						
	Breeds	1	0.0001664	0.37	"	"
	Error	8	0.0004439			

* Corrected to Standard Temperature and Pressure

APPENDIX "B"

APPENDIX B TABLE 1

Analyses of variance production records haematology flock

	Sources	D.F.	Variance	F.	Nec.F 5%	Nec.F 1%
Ewe weights 6/7/56	Breeds	1	9006.0	12.19	3.98	7.01
	Error	68	739.0			
Ewe weights 27/9/56	Breeds	1	631.0	5.95	4.00	7.08
	Error	62	106.0			
Ewe weights 21/2/57	Breeds	1	938.0	8.85	4.00	7.08
	Error	62	106.0			
Ewe weights 30/7/57	Breeds	1	451.3	3.55	4.00	7.08
	Error	61	127.2			
Lamb weights 12/12/56	Breeds	1	920.95	3.41	4.03	7.17
	Error	51	269.95			
Lamb production 27/9 - 12/12/56	Breeds	1	754.65	5.34	4.03	7.17
	Error	50	141.34			
Wool production 22/11/56	Breeds	1	133.60	98.96	4.00	7.08
	Error	64	1.35			

APPENDIX B TABLE 2

Analyses of variance haematological data 9/7/56

	Sources	D.F.	Variance	F.	Nec.F 5%	Nec.F 1%
Haemoglobin	Breeds	1	16.0950	20.54	3.98	7.01
	Error	83	0.7835			
P.C.V.	Breeds	1	189.00	11.80	3.98	7.01
	Error	80	16.01			
Erythrocytes	Breeds	1	11.5598	6.55	4.60	8.86
	Error	14	1.7654			
Leucocytes	Breeds	1	342.149	108.58	3.98	7.01
	Error	81	3.151			
M.C.V.	Breeds	1	14.82	3.38	4.60	8.86
	Error	14	4.38			
M.C.H.	Breeds	1	2.32	1.72	4.60	8.86
	Error	14	1.35			
M.C.H.(conc.)	Breeds	1	0.75	0.01	3.98	7.01
	Error	80	5.40			

APPENDIX B TABLE 3

Analyses of variance haematological data 3/10/56

	Sources	D.F.	Variance	F.	Nec.F 5%	1%
Haemoglobin	Breeds	1	0.00	0.00	4.00	7.08
	Error	61	1.24			
P.C.V.	Breeds	1	0.60	0.04	4.00	7.08
	Error	58	16.49			
Erythrocytes	Breeds	1	0.465	0.22	4.22	7.72
	Error	26	2.080			
Leucocytes	Breeds	1	96.02	16.99	4.00	7.08
	Error	60	5.65			
M.C.V.	Breeds	1	10.11	0.36	4.24	7.72
	Error	25	27.99			
M.C.H.	Breeds	1	2.57	0.92	4.24	7.72
	Error	25	2.79			
M.C.H.(conc.)	Breeds	1	0.22	0.10	4.00	7.08
	Error	56	2.27			

APPENDIX B TABLE 4

Analyses of variance - haematological data 19/2/57

	Sources	D.F.	Variance	F.	Nec.F 5%	1%
Haemoglobin	Breeds	1	2.2160	0.80	4.00	7.08
	Error	57	2.7572			
P.C.V.	Breeds	1	151.54	4.13	4.00	7.08
	Error	57	36.62			
Erythrocytes	Breeds	1	3.0628	1.50	4.24	7.77
	Error	25	2.0374			
Leucocytes	Breeds	1	36.331	6.80	4.00	7.08
	Error	57	5.375			
M.C.V.	Breeds	1	4.99	1.63	4.26	7.82
	Error	24	3.06			
M.C.H.	Breeds	1	0.21	0.07	4.26	7.82
	Error	24	3.14			
M.C.H.(conc.)	Breeds	1	2.32	0.12	4.00	7.08
	Error	56	18.49			
Total blood vol. litres	Breeds	1	14.25	38.5	4.03	7.17
	Error	49	0.37			
Erythrocytes litres	Breeds	1	4.0328	22.40	4.03	7.17
	Error	49	0.1800			
Plasma litres	Breeds	1	3.6651	31.60	4.03	7.17
	Error	49	0.1160			
Weight in kilograms	Breeds	1	181.20	8.69	4.03	7.17
	Error	50	20.85			
Blood ml/Kg.	Breeds	1	3035.96	21.8	4.03	7.17
	Error	49	139.03			
Erythrocytes ml/Kg.	Breeds	1	1060.38	15.89	4.03	7.17
	Error	49	66.75			

APPENDIX B TABLE 4 (Cont.)

Plasma ml./Kg.	Breeds Error	1 49	499.56 59.23	8.44	4.03	7.17
Surface area (Sq. metres computed)	Breeds Error	1 49	0.0326 0.0036	9.05	4.03	7.17
Blood volume/ Sq. metres computed area	Breeds Error	1 49	8.0936 0.2588	31.27	4.03	7.17
Erythrocytes vol./ Sq. metres computed area	Breeds Error	1 49	2.1205 0.1395	15.20	4.03	7.17
Plasma vol./ Sq. metres computed area	Breeds Error	1 49	1.6038 0.0949	16.90	4.03	7.17

APPENDIX B TABLE 5

Analyses of variance - comparison of haematological data between

July : October 1956
October 1956 : February 1957
July 1956 : February 1957

	Dates	Sources	D.F.	Variance	F.	Nec.F 5%	1%
Haemoglobin							
Breed							
Cheviots	July:Oct.	Dates	1	64.870	98.14	3.98	7.01
		Error	73	0.661			
	Oct.:Feb.	Dates	1	72.43	45.84	4.00	7.08
		Error	61	1.58			
	July:Feb.	Dates	1	0.112	0.09	3.98	7.01
		Error	70	1.210			
Romneys	July:Oct.	Dates	1	10.445	9.81	3.98	7.01
		Error	71	1.065			
	Oct.:Feb.	Dates	1	13.079	5.48	4.00	7.08
		Error	57	2.387			
	July:Feb.	Dates	1	11.681	5.94	3.98	7.01
		Error	70	1.966			
Leucocytes							
Breed							
Cheviots	July:Oct.	Dates	1	2.21	0.44	3.98	7.01
		Error	71	5.04			
	Oct.:Feb.	Dates	1	6.886	1.43	4.00	7.08
		Error	60	4.820			
	July:Feb.	Dates	1	17.94	3.93	3.98	7.01
		Error	69	4.56			

APPENDIX B TABLE 5 (Cont.)

Romneys	July:Oct.	Dates	1	0.386	0.06	3.98	7.01
		Error	70	6.110			
	Oct.:Feb.	Dates	1	0.949	0.15	4.00	7.08
		Error	57	6.247			
	July:Feb.	Dates	1	0.191	0.03	3.98	7.01
		Error	69	6.359			
P.C.V.'s							
Breed							
Cheviots	July:Oct.	Dates	1	1027.34	70.27	3.98	7.01
		Error	70	14.62			
	Oct.:Feb.	Dates	1	94.82	3.76	4.00	7.08
		Error	58	25.24			
	July:Feb.	Dates	1	182.41	9.90	3.98	7.01
		Error	70	18.42			
Romneys	July:Oct.	Dates	1	399.10	22.35	3.98	7.01
		Error	68	17.86			
	Oct.:Feb.	Dates	1	30.1	0.96	4.00	7.08
		Error	57	31.2			
	July:Feb.	Dates	1	194.1	6.32	3.98	7.01
		Error	67	30.7			
Erythrocytes							
Breed							
Cheviots	July:Oct.	Dates	1	35.9278	15.43	4.38	8.18
		Error	19	2.3280			
	Oct.:Feb.	Dates	1	3.4517	1.95	4.24	7.77
		Error	25	1.7736			
	July:Feb.	Dates	1	19.9151	11.60	4.35	8.10
		Error	20	1.7165			

APPENDIX B TABLE 5 (Cont.)

Romneys							
	July:Oct.	Dates	1	2.8186	1.71	4.32	8.02
		Error	21	1.6454			
	Oct.:Feb	Dates	1	0.3277	0.14	4.22	7.72
		Error	26	2.3333			
	July:Feb.	Dates	1	4.4877	2.06	4.38	8.18
		Error	19	2.1748			
M.C.V.							
Breed							
Cheviots	July:Oct.	Dates	1	17.176	0.46	4.41	8.28
		Error	18	37.117			
	Oct.:Feb.	Dates	1	7.637	0.21	4.26	7.82
		Error	24	35.779			
	July:Feb.	Dates	1	45.17	2.03	4.35	8.10
		Error	20	22.27			
Romneys	July:Oct.	Dates	1	8.34	0.60	4.32	8.02
		Error	21	13.96			
	Oct.:Feb.	Dates	1	13.82	0.60	4.24	7.77
		Error	25	23.06			
	July:Feb.	Dates	1	0.142	0.00	4.41	8.28
		Error	18	30.624			
M.C.H.							
Breed							
Cheviots	July:Oct.	Dates	1	7.0075	1.83	4.41	8.28
		Error	18	3.8183			
	Oct.:Feb.	Dates	1	1.1054	0.28	4.26	7.82
		Error	24	3.9612			
	July:Feb.	Dates	1	13.3878	6.08	4.35	8.10
		Error	20	2.2010			

APPENDIX B TABLE 5 (Cont.)

Romneys	July:Oct.	Dates	1	0.1574	0.17	4.32	8.02
		Error	21	0.9409			
	Oct.:Feb.	Dates	1	4.87	2.45	4.24	7.77
		Error	25	1.99			
	July:Feb.	Dates	1	2.2120	0.79	4.41	8.28
		Error	18	2.7828			
M.C.H. (conc.)							
Breed							
Cheviots	July:Oct.	Dates	1	44.50	10.32	3.98	7.01
		Error	70	4.31			
	Oct.:Feb.	Dates	1	1.13	0.18	4.00	7.08
		Error	57	6.24			
	July:Feb.	Dates	1	60.08	8.71	3.98	7.01
		Error	69	6.90			
Romneys	July:Oct.	Dates	1	38.37	9.84	3.98	7.01
		Error	66	3.90			
	Oct.:Feb.	Dates	1	4.37	0.30	4.00	7.08
		Error	55	14.67			
	July:Feb.	Dates	1	72.73	4.91	3.98	7.01
		Error	67	14.80			