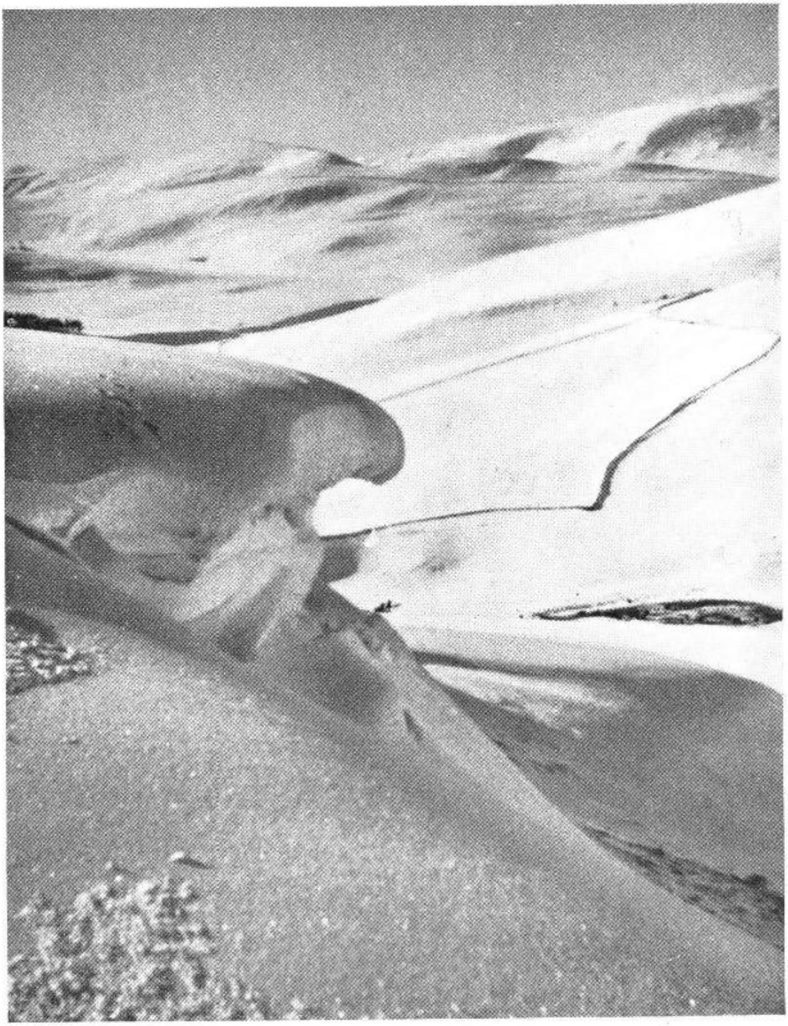
HILL FARMING research organisation

THIRD REPORT



Sourhope, February 1963

HILL FARMING RESEARCH ORGANISATION

THIRD REPORT

1961-64

29 LAUDER ROAD, EDINBURGH, 9

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(as at 31st March, 1964)

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DEFINITION OF TERMS

In this and all other publications of the Hill Farming Research Organisation the following terms, which are used locally, have the meanings indicated below:—

Eild Ewe	Ewe which has not produced a lamb that season.
Gimmer	Female sheep from $1\frac{1}{2}$ to $2\frac{1}{2}$ years. Most hill ewes are mated and lamb for the first time as gimmers.
Heft	A group of sheep which habitually graze within the confines of a particular area of hill ground, and also the area of ground itself. Each heft of ewes is self-replenishing.
Hirsel	An area of hill with natural boundaries, which is normally shepherded by one man. A hirsel may contain several hefts.
Hogg	Sheep from 6 months to $1\frac{1}{2}$ years.
Mossing	An area on which *Eriophorum vaginatum* (drawmoss or cotton grass) occurs, providing valuable late winter and early spring food.
Muirburn	The practice of burning in winter or early spring, heather or the accumulated dead growth of *Molinia caerulea*, *Nardus stricta* and *Deschampsia caespitosa*.
Raking	The movement of a heft of ewes so that they graze the lower ground during the day and move to higher ground in the late afternoon and evening. Raking is partly instinctive, but is also induced by skilled shepherding.

INTRODUCTION

THIS, the third report of the Hill Farming Research Organisation, marks the end of the first ten years of the Organisation's existence. It has been a period of planning and development, as well as of some achievement. Much basic information has been acquired on the problems involved, and on this the next phase of more intensive and more critical research can be solidly based. With the advantage of greater knowledge of the possibilities and limitations of conducting research under hill conditions, future efforts should be more productive.

The purpose of the Organisation is to investigate the problems of the agricultural use of hill land. This implies in the long run the investigation of methods of securing increased production consonant with the maintenance of the natural resource, if possible with its improvement but never with its deterioration. Such increased output may be possible by a variation in the environment in which sheep and cattle live and by the adaptation of these animals to enable them to function more efficiently in their environment, but before genuine progress can be made along either avenue it is necessary to understand thoroughly all aspects of both the environment and the animal, what they are, their behaviour, their influence on each other and in what directions modification is possible. From the beginning it has been our policy to concentrate the available staff and resources to a large extent on this ecological approach.

In the Second Report reference was made to the need for facilities for more critical research and to the limited provision that had been made at that stage. Further experience has confirmed the view that if research is to be of real benefit to hill farming it must be pursued with greater vigour under carefully controlled conditions before it is taken 'to the hill' for extended trials. Because this was not then possible much of the earlier work with sheep, though valuable in high-lighting some aspects of the problems, did not help in pointing real paths to their solution. Similarly our lack of laboratories for chemical analysis has been a severe restriction and though our sister institutions have been most generous in their assistance they cannot take the place of adequate facilities of our own. It is hoped that this will be partially remedied at an early date

Every endeavour has been made to avoid rigid divisions between departments or groups of workers but some subdivision of staff is essential. At the inception it was thought desirable to have two departments—Animal Studies and Botanical Studies, and to these an Agronomy department was added in 1962. This was done by an administrative re-arrangement of the existing research staff, and those allocated to Agronomy were already engaged on established research projects. Some of these, but not all, would rightly have been termed Agronomy, and the reports which follow under this heading are all on projects upon which the individual workers were engaged when the new arrangement took effect. Only when some of these have been concluded will this department be able to develop new studies in this field.

The work of the two older departments has gone ahead and the following pages outline their progress. In Animal Studies research has concentrated on the responses of sheep of varied breeding and at all stages of their life to the nutritional and climatic conditions prevailing under hill management systems. Only a few aspects of this large problem can be investigated with the resources available and the period has seen a definite co-ordination of effort under the four main headings of the report on animal investigations.

At first glance the social behaviour of sheep may seem of little importance but under extensive grazing the behaviour of one sheep towards its neighbour may be much more important than it appears to be where sheep are more closely controlled on a heavily stocked improved pasture. Dr. Hunter and his colleagues have devoted a part of their time to studying in detail this fascinating topic on which hill shepherds have a vast store of unrecorded information. One result has been to emphasise the difficulty of conducting comparisons on the hill where there is not one but several environments and where it is extremely difficult to ensure that animals subjected to different treatments will be living in the same environment. This imposes a restriction on the number of reliable research projects that can be staged under hill conditions and to some extent explains why so many past investigations by this and other organisations have given conflicting results.

Staff

In addition to the staff listed as at March, 1964, the following served for varying periods on the Scientific, Experimental and Administrative staff during this triennial period:—

Animal Studies

J. F. Robinson, B.SC. (AGR.)
Miss Joan Munro, B.SC. (AGR.), PH.D.

Botanical Studies

M. M. Boyd, B.SC. (AGR.)

Records Section

Miss P. F. Riches, B.SC.

Glensaugh

R. R. Shepherd, B.SC. (AGR.), DIP. AGRIC.
R. E. A. McVicar, B.SC. (AGR.)
B. Owen, S.D.A.

Administration

R. S. Boyd, F.C.C.S.

It was with particular regret that the resignations were received of Mr J. F. Robinson, Head of the Animal Studies Department, who is now farming and of Mr R. S. Boyd, Secretary, now Secretary of the Edinburgh and East of Scotland College of Agriculture. Both played a vital part in building up the Organisation, Mr Boyd from its inception, and both contributed greatly to its progress.

Visits

Members of staff have visited research centres in Austria, West Germany, the Netherlands and Switzerland and have contributed papers to International Congresses. Following the award of a Kellogg Fellowship to Dr John King in 1960, Mr Ian Nicholson received a similar award in 1963. Both spent three months in the United States visiting research centres specialising in their respective fields.

The number of visitors to the Organisation and its research stations continues to grow and we have welcomed in particular many scientists from research stations in the United Kingdom and from overseas, with whom we have had highly beneficial exchanges of research information. At the research farms parties of advisory officers and of farmers are regular visitors each year.

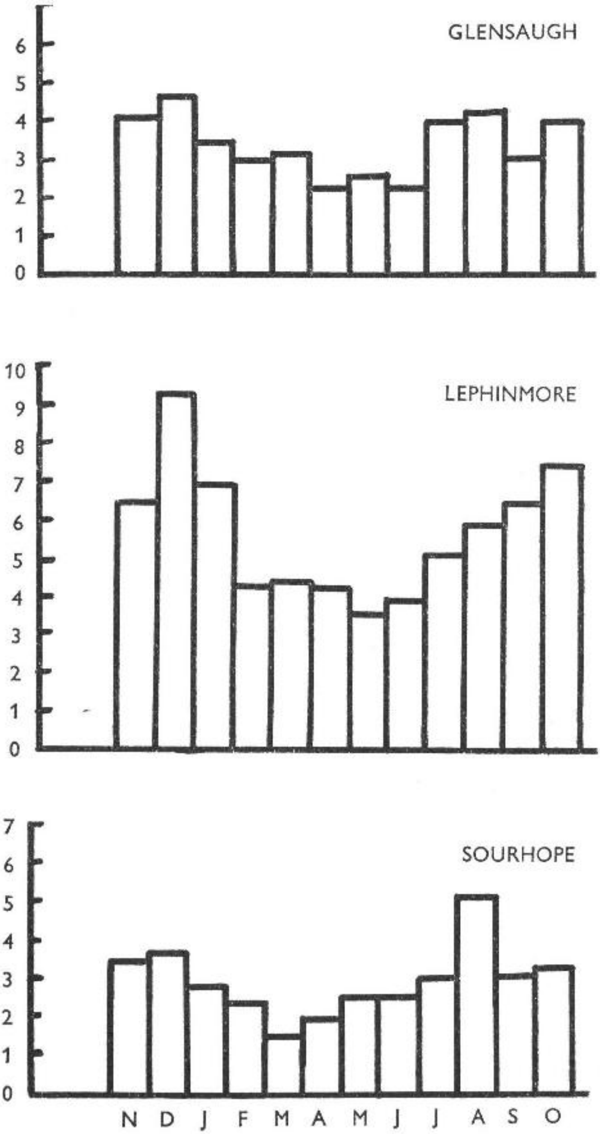
Acknowledgements

Throughout its brief existence the Organisation has been deeply indebted to its sister research and educational institutions and their staffs and it wishes once again to express its indebtedness to them. In particular we would desire to thank the Animal Breeding Research Organisation, the Animal Diseases Research Association, the Forestry Commission, the Macaulay Institute for Soil Research, the Nature Conservancy, the Rowett Research Institute, the Scottish and Welsh Plant Breeding Stations, the Veterinary Schools of the Universities of Edinburgh and Glasgow and the three Scottish Colleges of Agriculture. Many farmers have also given us facilities for experimental work on their farms and to them also we express our gratitude.

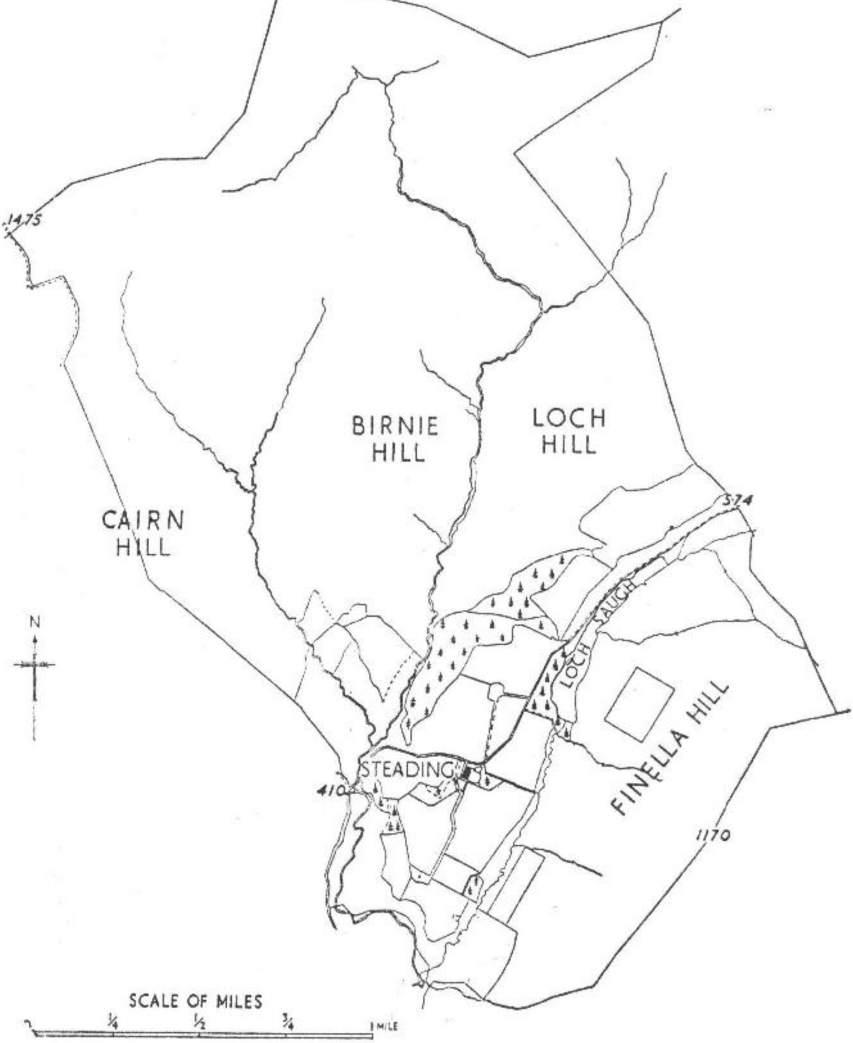
METEOROLOGICAL DATA RESEARCH FARMS

	Rainfall (inches)			Sunshine (hours)		
	Glensaugh	Lephin-more	Sourhope	Glensaugh	Lephin-more	Sourhope
Nov. 1960-Oct. 1961	39·4	81·6	29·0	1149	1056	1189
Nov. 1961-Oct. 1962	33·3	68·3	33·3	1377	1138	1160
Nov. 1962-Oct. 1963	40·2	60·4	38·7	1272	1140	1255
Average (1951/2-1962/3)	40·5	67·7	34·8	1309	1233	1364

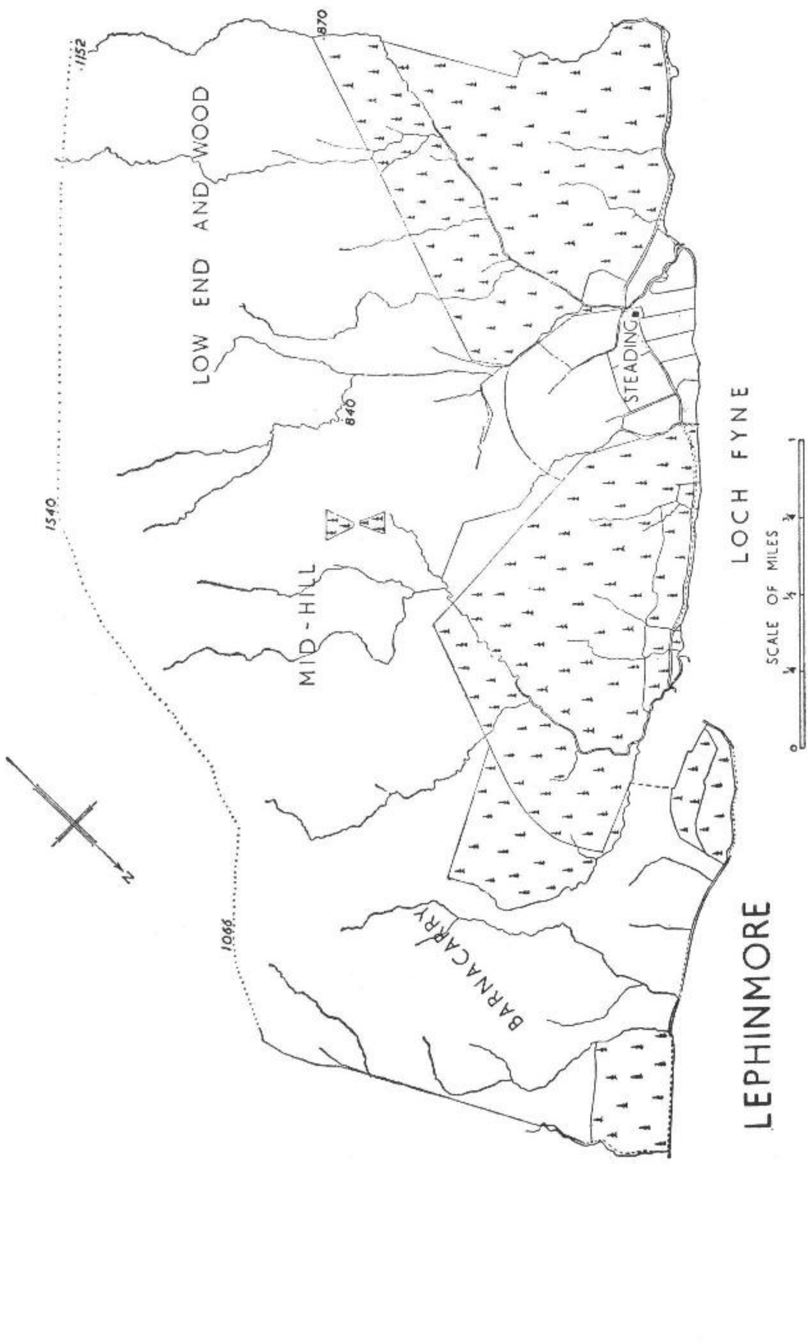
Mean Monthly Rainfall (inches)
November, 1951 - October, 1962

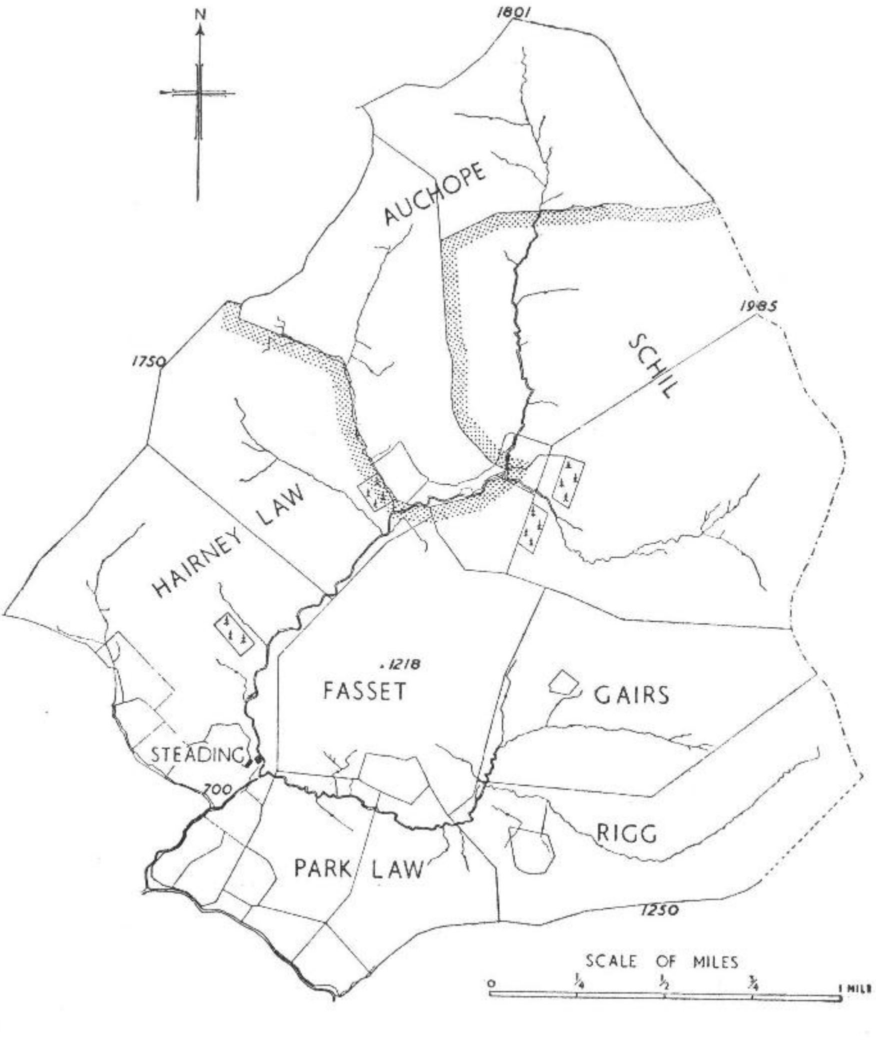



SITUATION
OF
RESEARCH STATIONS
SCOTLAND
ABERDEEN
GLENSAUGH
LEPHINMORE
EDINBURGH
GLASGOW
SOURHOPE
CARLISLE
NORTHERN
IRELAND
EIRE
ENGLAND
WALES
LONDON
Scale 1:5.000.000
50 0 50 100 Miles


1475
BIRNIE
HILL
LOCH
HILL
CAIRN
HILL
574
LOCH SAUGH
N
STEADING
410
FINELLA HILL
1170
SCALE OF MILES
¼
½
¾
1 MILE

GLENSAUGH


LOW END AND WOOD
MID-HILL
BARNACARRY
STEADING
LOCH FYNE
LEPHINMORE
SCALE OF MILES
0
¼
½
¾
1
1152
870
840
1540
1066
N


N
1801
AUCHOPE
1985
SCHIL
1750
HAIRNEY LAW
.1218
FASSET
GAIRS
STEADING
700
RIGG
PARK LAW
1250
SCALE OF MILES
0
¼
½
¾
1 MILE

SOURHOPE

ANIMAL STUDIES

J. M. DONEY

GROWTH AND DEVELOPMENT

Early Growth and Life-Time Performance (R.G.G.)

WORK on the wintering of ewe hoggs at Sourhope and Glensaugh has opened up a much more complex field of research than was visualised when the husbandry trials, described in the first two H.F.R.O. Reports, were originally set up. The purely comparative approach on the advantages or disadvantages of different methods of wintering ewe lambs for flock replenishment has given way to a more critical study of different levels of winter nutrition on growth, development and subsequent performance. This in turn has indicated the need for further study of growth during early life and of the effect of differences in such early growth on long term production under the stresses of the hill environment.

At Sourhope, in 1956-57 and 1957-58, different levels of winter feeding were imposed on groups of South and North Country Cheviot ewe hoggs, in an attempt to examine the effect on adult performance. High plane (H.P.) and mid-plane (M.P.) diets were fed for comparison with low plane (L.P.) diets, the latter being achieved by shed feeding in 1956-57 and hill wintering in 1957-58.

Mean group differences in live-weight at 12 months between H.P. and L.P. ranged from 34% to 57% according to year and strain. Between M.P. and L.P. the differences ranged from 11% to 24%. These were reduced greatly in later life but differences in size between the more extreme groups did persist until 6½ years. First year lamb production was 15% higher in H.P. and M.P. than in the L.P. groups. Over 5 years the M.P. groups gave the greatest lifetime production, while that from the H.P. groups was little better than from the L.P. Earlier maturity, greater size and greater initial production in the H.P. groups was associated with lower production in later life and a lower survival rate under the stresses of a hill environment.

In this type of field experiment the uncontrollable variables can often swamp the experimental treatments. In the present experiment where, with the exception of the hill group in 1957-58, the average level of nutrition in the critical period was controlled, it was found that seasonal factors, both before and after the treatment period, affected the long-term responses to the winter treatment. The results, therefore, were not sufficiently conclusive to do more than indicate trends and suggest further questions. In an attempt to clarify the situation, an experiment was set up in 1961 involving a closer control of growth rate by nutrition, not only during the winter but also during the preceding period between weaning and the beginning of wintering. Preferential treatment was given to a group of Blackface ewe lambs during the period from 3 to 12 months of age. They were well fed in fields from 3 to 6 months (period 1) and in a shed from 6 to 12 months (period 2). A control group remained unsupplemented on the hill throughout. Two more groups were included in the experiment; one, in the field-fed group during period 1, returned to the hill for period 2, while the other remained on the hill during period 1 and joined the treated group indoors in period 2. At 12 months, all shed wintered sheep returned to the hill.

From this experiment it had been hoped to describe conclusively the relationship between rapid growth in early life and long term productivity on the hill but the uncontrollable seasonal factors again tended to minimise the intended treatment differences. A further complication has arisen from work by the Botanical Studies department which has shown that the hill does not necessarily provide the random environment for all groups that it is usually assumed to provide. Social and grazing pressures may result in significant differences in weight and production between groups of animals on different areas of ground. The development of social groups by the shed wintered animals resulted, on their return to the hill, in a non-random distribution of treatment groups within the hill environment. This confounding of social behaviour and treatment tends to upset the experimental design and may help to explain why it is difficult to get easily interpretable results from such extensive studies.

Experiments are now being planned which aim at either eliminating non-random home-range distributions or equalising the treatments within each developed social group. We do not know how long these artificially produced groups persist after return to the hill but if permanent there may be some detrimental effects of wintering ewe hoggs off the hill in sheds or fields.

In the 1956-57 and 1957-58 experiments with Cheviots at Sourhope, the effects of different levels of winter feeding on the growth and development of animals both above and below average weight at 6 months were also studied. The results suggest that preferential wintering for those below average may be of more advantage than expensive wintering for all. Sheep of above average weight appeared to be little affected in the long term by sub-optimum wintering.

However, the advantages to those below average in weight appear to be only temporary and disappear rapidly over the following year. These results suggest that the wintering period is too late to create any permanent difference and that greater attention to growth and development during the first 6 months may be more advantageous. Past records are now being analysed and specific experiments are being carried out to test this hypothesis.

(Publications 90, 91 and 92.)

Lamb Fattening (A.J.F.R.)

The development of management systems which would enable the hill farmer to fatten at least a proportion of those lambs not required for flock replacement would be of considerable advantage to the industry. The principle problems involved are nutritional and the results of research on lamb fattening in general are directly applicable to the hill bred lamb. The only problems peculiar to hill lambs are concerned with transient economic and land utilisation problems which cannot be solved by biological research. In Autumn 1962 preliminary investigations into the two basic systems of fattening—continuous housing and supplementation of grazing—were initiated. Concurrently with these trials, efforts have been made to develop better criteria of feeds and conditions of feeding and of the animals' response in terms of efficiency of fattening. Only the results from the early field trials are available.

Housed Lambs

Preliminary studies at Glensaugh suggest that although maize based concentrates gave a slightly better daily gain than diets based on barley, the price differential between the two cereals leaves little if any difference in cost per pound of live-weight gain. The results also indicated that the pelleting of the concentrate gave an advantage of about 5% in live-weight increase over the dry feed mix.

Hay was fed in chopped and in ground and pelleted forms, and although observations showed that lambs fed pelleted hay did not ruminate, there was no difference in performance attributable to the physical form of the hay.

Grazing Lambs

(i) *Supplementation of Rape.* The supplementation of rape with high energy concentrates has been effective in increasing the daily live-weight gains of Blackface lambs at Glensaugh and of South Country Cheviot lambs at Sourhope. The control and supplemented groups of Blackfaces at Glensaugh gained more rapidly and were ready for slaughter sooner than the comparable groups of South Country Cheviots at Sourhope. A trial is planned at Sourhope to give a valid comparison of these two breeds.

There is some evidence from the preliminary studies of a relationship between blood urea level and nitrogen balance which is itself a measure of the efficiency of protein utilisation. The effect of different levels of supplementary feeding on the nitrogen balance of lambs grazing rape is now being studied at Sourhope. High energy supplements increased daily live-weight gain and appear to have resulted in a more efficient use of the crude protein in rape.

The preliminary studies have also shown that the thyroid glands from rape fed lambs were heavier (4·5 g.) than those from lambs grazing aftermath (2·2 g.). Histological examination suggested that this hypertrophy was an attempt to compensate a hypothyroid condition, probably caused by goitrogenic factors which are known to exist in many of the Brassica species, and an experiment is in progress to test this hypothesis and to assess any effect of this condition on performance.

(ii) *Supplementation of Aftermath.* The supplementary feeding of a high energy concentrate was also effective in increasing the daily gain of Blackface lambs grazing aftermath at Glensaugh and at Lephinmore, and of South Country Cheviot lambs on aftermath at Sourhope. As with rape feeding, the live-weight increments of the Blackface were superior to those of the Cheviot lambs, but it is not yet possible to state whether a real breed difference is involved.

At Glensaugh the Blackface lambs on aftermath were initially comparable to those on rape, and at Sourhope the South Country Cheviots on aftermath were of the same genetic and environmental background as those on rape. In both breeds the lambs fattened on aftermath gained more rapidly than those on rape. This was true of both the supplemented and unsupplemented treatment groups. The relative conditions of the two crops could markedly affect the outcome of this type of comparison.

Comparisons of different classes of lambs showed that the live-weight gain of wether lambs was significantly greater than that of ewe lambs (3·1 v. 2·5 lb./hd./wk.) and that lambs which were heavier at weaning made significantly more rapid gains than those which were lighter at weaning (2·9 v. 2·6 lb./hd./wk.). This makes difficult the choice of which class of lamb to fatten and which to sell as store.

The Effect of Castration

The performance of castrated and entire male lambs grazing aftermath was studied at Lephinmore in 1962. Lambs were allocated at random to the two groups at marking time, and from then until slaughter in early October the entire lambs gained appreciably faster than the castrated group. It was necessary to slaughter the lambs before they had attained a desirable degree of finish in order that the entire males would qualify for the guarantee payment. Approximately half (9 out of 20) of the entire lambs were refused certification for the guarantee payment, not because they showed any strongly masculine characteristics in the carcass, but because they lacked sufficient fat cover. Only two of the 18 castrated lambs were refused certification. Had slaughter been delayed until all lambs were considered fit to be certified it is likely that an even higher proportion of the entire lambs would have been refused the guarantee payment on the grounds that they exhibited strong male characteristics in the carcass. Although the live-weight superiority of the entire lambs at the time of slaughter was more than five pounds, their greater lack of finish resulted in a very poor dressing-out percentage which reduced their advantage over the castrated lambs to one pound of carcass weight.

Under the present legislation governing the payment of subsidy on fatstock, the greater potential meat production of the entire male cannot be exploited to the full. Bearing in mind the current interest in bull beef, this may be a propitious time to re-examine the effects of rearing, management and treatment on the carcass characteristics and consumer appeal of the meat of entire male animals, and to ascertain the extent to which prejudice in the public mind influences the market for this commodity.

Carcass Studies

The carcasses of lambs used in the 1962 studies were separated into commercial cuts or joints in a study designed to develop an index of carcass merit related to commercial value and which would reflect good development of high priced parts and favour those carcasses of superior conformation. The results to date suggest that because of the very small variation in the proportions of the various joints, the resultant index may give little information beyond that already supplied by carcass weight. The results further indicate that this type of index may be more suitable for comparisons between breeds than within breeds.

Lactation and Lamb Growth (J.M.D., J.M. and A.J.F.R.)

Studies of the effects of management treatments and of the number of lambs suckled on the milk production of the Blackface ewe, as estimated by early lamb growth, were carried out at Glensaugh between 1956 and 1963. At this farm the ewes are brought down to improved pastures before lambing and are returned to the hill a few days after the lamb is born. It was found in most seasons, that the provision of inbye grass during the first four weeks of lactation did not result in any increase in the early live-weight gain of single lambs above that achieved by the standard management practice of the farm. The inbye ewes showed a greater rate of gain. Lambs reared as twins under standard conditions had growth rates of about 60% of single lambs. When twin lambs were retained on improved pastures they were found to gain at the same rate as single lambs on the hill. These results suggest that an increase in available feed supply above that provided by the standard practice would reduce the gap in performance between single and twin reared lambs but would not usually give a comparable increase in the early growth of single lambs.

Early results suggested that output under hill conditions might be more easily increased by allowing all ewes to rear single lambs, the other member of twin pairs being reared artificially. It is well known that the actual level of milk production reached by a ewe is influenced by the demand made by her lamb or lambs in early life as well as by nutritional and genetic factors. Experiments were therefore set up to find out whether any residual effect from lactation stimulation by twin lambs could be passed on in the form of greatly increased utilisation by the remaining single when one lamb was removed. Twin pairs were separated at 1 and 8 days in 1961 and at 3 day intervals to a maximum of 21 days of age in 1962 and 1963. In all cases it was found that the growth rates of singled twin lambs were equivalent to, but not better than, those of natural singles. Artificially reared lambs showed some slight benefit from being allowed an early suckling period. No ill effects on the ewes were found even when the twins were separated as late as three weeks.

(Publications 59 and 63.)

Fleece Structure (J.M.D. and W.F.S.)

In order to plan and interpret experiments on wool growth in the hill environment, some knowledge of fleece structure and its development from lamb to adult is needed. Not enough information on the Blackface and Cheviot breeds, with which much of our work is concerned, was readily available so a series of experiments have been carried out to provide this necessary background.

Post-natal development

The development of the adult fleece from the lamb birth coat has been studied in the Blackface breed. The effect of modification of pre- and post-natal body growth rate was studied by drawing experimental animals from those involved in the experiment on lactation modification. The nutritional limitation imposed on the lamb before birth by being one of a twin pair affected the development of the coat. At birth fewer of the secondary follicles were actively producing fibres, giving a lower secondary/primary fibre ratio than in single born lambs. Given adequate nutrition after birth this delay was made up in less than six weeks. Nutritional limitation in the early post-natal period had a much greater effect. The development of the secondary fibre population was delayed in lambs reared as twins compared with those reared as singles. Lambs reared artificially at a very slow rate of growth ($1\frac{1}{2}$ lb./week) during the first six weeks were considerably delayed in that the secondary/primary fibre ratios and rates of wool production were below those of single reared lambs as late as six months of age. By twelve months, however, the mean s/p ratio and rate of production did not differ amongst the groups. Post-natal nutritional limitation also delayed the timing of the first shedding cycle of primary fibres which occurred between 8 and 14 weeks of age in single reared lambs. The second shedding cycle, occurring in September, was unaffected even by the severe post-natal treatment. It was concluded that, for all practical purposes, the development of the adult fleece structure in Blackface sheep could not be permanently affected by late pre-natal or early post-natal limitation of feed intake.

Pre-natal development

In connection with their work on tooth development, a series of foetal lambs were provided for the Manchester Dental school at monthly age intervals during the winter of 1961-62. The opportunity to obtain information of foetal skin development in the Blackface breed was taken by collecting the skins of these lambs and of others obtained at mid-monthly intervals. Thus a series of samples at fortnightly intervals from 90 days onwards were obtained from Glensaugh and Sourhope. Slaughter of the ewes at the right time was made very convenient by carrying out oestrus synchronisation before mating. Thirty ewes at each farm were injected every second day in a fourteen day period with 10 mgm. of progesterone ('Protormone', donated by Burroughs Wellcome and Co.). Rams were introduced after the last injection. Seventy-five per cent. of ewes held to first service within four days, 90% within twelve days. The project was developed in co-operation with Mr. H. B. Carter, then at the Animal Breeding Research Organisation, who will carry out histological examination of the skin samples.

Adult Fleece

Studies have been made on adult fleece structure; Blackface sheep at Lephinmore, Lanark, Lewis and Galloway strains at Glensaugh and Cheviot at Sourhope. The importance of variation in the components of fleece weight—namely surface area, density of follicle population, fibre type distribution and the mean length, diameter, degree of medullation and weight of each fibre type—to the variance in fleece weight itself was investigated and it was found that within a single flock of the same strain 36% of variation in fleece weight was accounted for by surface area, 25% by fibre number and 39% by mean fibre weight. Differences in fleece structure between the Lanark and Galloway types were not great, being mainly confined to the ratio, in length and weight, of the hair and wool fibres. The Lewis fleece type differed considerably from the other two in that it had a much smaller difference between hair and wool in all characteristics. There were no obvious differences in the relative numbers of each fibre type or in total fibre number. An unusual type of medullation was found in both hair and wool fibres from several sheep at each farm. The distribution and origin of this character is the subject of further study.

(Publications 60, 80 and 88.)

NUTRITION AND CLIMATE

Supplementary Feeding of Hill Ewes (J.F.R.)

THE PRE-LAMBING feeding trials of ewes on the hill initiated on all three farms in 1955-56 have now concluded. The results for Lephinmore and Sourhope, covering six years, have been summarised and published. There was considerable variation in the response to feeding due to factors beyond experimental control and so firm conclusions, from which to extrapolate to any situation, could not be drawn. For practical purposes the results suggest that:—

(a) A feeding policy must be flexible and be adjusted according to seasonal need.

(b) Post-lambing supplementation deserves further consideration, particularly in respect to seasons when spring growth is retarded as in 1956 or 1958.

(c) On hazardous ground like Lephinmore (where lambs are subject to drowning) lambing under closer control is a desirable complement to pre-lambing supplementation.

(d) Advantages may be derived from reverting to the old custom of wintering, managing and lambing gimmers in isolation from the older ages of ewes. Gimmers appear to be handicapped in grazing in competition with older ewes. They also suffer greater loss of body weight in winter.

Since 1961, no trials of this nature have been carried out at Sourhope. At Lephinmore, pre-lambing feeding with cubed concentrates has been continued on the Mid-hill and Low-end hirsels with the object of clarifying and demonstrating some of the improvements in technique suggested above. As yet it is too early to draw any conclusions from these developments.

At Glensaugh, work on pre-lambing supplementation had, as was described in the last Report, changed from a comparison of physically different diets to that of chemically and nutritively different diets. The effects of feeding rations containing constant energy but different levels of protein of both animal and vegetable origin for 6 weeks before lambing were studied in 1960, 1961 and 1962. All these diets were fed on the hill and the experiments were used to make preliminary tests on the use of blood urea determinations in examining the relationship between blood urea level and protein intake. No distinct advantages in lamb or wool production appear to accrue to any one level or type of protein intake provided this lies within the range of, say, 7% and 17% D.C.P. Extreme levels may result in differences in certain situations, but here this is almost certainly due to interactions with uncontrollable variables such as season.

(Publication 66.)

Dentition and Mineral Status (R.G.G.)

As described in previous Reports, Glensaugh in common with many other farms in the North-east of Scotland has a history of premature 'broken-mouth' in the Blackface ewe stock. This has been studied from several different angles by the Rowett Research Institute and their clinical results have been recently published. In most respects these results were inconclusive and the problem is still receiving considerable attention.

In the second H.F.R.O. report, it was stated that the incidence of defective teeth was much reduced, although not eliminated, by the substitution of hay or concentrate feed for turnips. It was then inferred that the basic predisposition to 'broken-mouth' might be of a 'ground' nature or related to management practice outwith the feeding of turnips. The mineral drain during lactation under hill conditions could be one factor in the causation of 'broken-mouth', possibly by the withdrawal of minerals from the skeleton with a consequent weakening of the attachment of the incisor teeth.

Preliminary determinations of blood minerals in 1960 showed a marked depression of phosphorus and magnesium when the ewes were brought inbye for lambing. In 1961 this was again the case with phosphorus. After transfer back to the hill in 1960 the twice weekly feeding during lactation of cubes containing 20% steamed bone flour helped to maintain or improve the blood phosphorus level. The daily feeding of monosodium phosphate in a special cube on the lambing pastures in 1961 had a similar effect. Withdrawal of this latter supplement after four weeks was followed by a fall in the blood phosphorus level in two groups of ewes, one of which was transferred to the hill shortly after lambing and the other of which was retained inbye for three weeks after the mineral supplementation ceased.

These results suggested that the ewes required phosphorus supplementation immediately on transfer to the inbye lambing pastures and throughout lactation. The addition or withdrawal of a magnesium supplement (calcined magnesite) had no effect on the blood magnesium level in either year, a not unexpected result in that this can fluctuate according to the amount of disturbance to the ewe and the time the sample is taken.

In the light of these results with phosphorus supplementation, an experiment was set up in the autumn of 1961 to examine this situation more closely. Since mineral supplementation by feeding on the hill during lactation is not very practicable on an experimental basis, a fluid dosing technique was used to ensure that each treated animal would receive its exact ration.

This experiment, which is still in progress, involves four groups, each of 20 ewes, all of which receive the same concentrate mixture, before and after lambing. There are no mineral additives in the concentrate mixture. To assess the influence on blood mineral levels of the change from hill to inbye pastures at lambing, one group remains on the hill over the whole period whilst the other three are brought off the hill before lambing in the traditional manner of the district. These three inbye groups are run on inbye pasture, one group having no mineral supplement and the others being dosed on alternate days, one with phosphorus (13 gm. monosodium phosphate) and the other with calcium (12 gm. calcium carbonate). Dosing starts in the middle of February and continues as long as the sheep remain on inbye pastures, until the end of May. The period of supplementation covers the first eight weeks of lactation when the mineral drain is likely to be at a maximum. Blood samples are taken periodically before each change in management and are analysed for phosphorus, calcium and magnesium by the A.D.R.A., Moredun.

There are two main objectives in this study. One is to determine the effectiveness, if any, of mineral supplementation in the reduction of the incidence and degree of 'broken-mouth' condition in these Blackface ewes. Incorporated in this is the examination of the effects of different levels of management on the above incidence and degree. The second objective is to establish a picture of the variation in level of minerals in the blood of hill sheep throughout their lives as affected by management and mineral supplementation.

In 1964, the ewes in this experiment are four years of age and have received their treatments over three lambing seasons. As far as the dentition is concerned there are already trends which suggest that the mouths of the ewes which came inbye before lambing, but received no mineral supplement, are in poorer condition than those of the ewes in any of the other groups. Differences amongst the inbye groups in terms of lamb production have been negligible.

During the severe winter of 1962-63, hand feeding was necessary for a longer period than normal. During this time the blood phosphorus levels dropped to the lowest values yet recorded in this experiment, the mean values for all groups being well below the recognised low level of the normal range. These levels were raised considerably during the last few weeks of pregnancy and were depressed only slightly during May. This situation, similar to that occurring in 1962, differed considerably from that of the first two years. No data are yet available on the levels of blood calcium and magnesium.

(Publications 65 and 67.)

Shelter (J.G.G., J.M., J.M.D. and A.J.F.R.)

Use of Natural Shelter

In a free grazing system information is needed on the extent to which grazing behaviour is modified by weather conditions and the effects of these modifications on the productive capacity of the animal. This will allow evaluation of the need for modification of the environment, either through the provision of some form of partial shelter or by complete housing. In studying natural shelter we are concerned with its definition, evaluation, and location.

Critical observations of behaviour when related to detailed weather observation can indicate when animals are suffering from climatic stress. While this method may be somewhat crude, it has the advantage that a large number of animals can be used, and the principal patterns are not lost through individual deviations.

The position on the hill of 16 Blackface ewes was observed at least once daily on 314 days during 1960. Weather conditions were measured at a control point and at the grazing position of the flock. The grazing areas were then assessed in terms of the exposure to wind and the type of pasture. Observations over the year showed that a sheltering response was largely dependent on the wind speed exceeding 24 m.p.h. Sheltering increased markedly at temperatures below freezing. Temperatures above freezing, except for rapid falls in temperature exceeding 4° F., had little effect on sheltering. No relationship could be found between sheltering behaviour of the sheep and other factors which included rain, relative humidity, wind direction or season of the year. From these observations it appears that sheep are more sensitive to wind than to any other climatic factor.

In 1962 an experiment was set up at Lephinmore to examine the value of providing voluntary artificial shelter when fattening hoggs on inbye land. There was no evidence from the live-weights of the groups of hoggs that the provision of artificial shelter was of any value. In the autumn of 1963 a similar type of experiment was carried out. The lay-out of this experiment involved four groups of 18 Blackface hoggs, receiving the following treatments:—

1. Concentrate feeding, no shelter.
2. Concentrate feeding, shelter.
3. No Concentrate feeding, shelter.
4. No Concentrate feeding, no shelter.

The artificial shelter was provided by small huts with an open end.

Since no definite results had been obtained in the first year, it was intended, through direct observations, to note how the hoggs used the shelters, the extent to which grazing behaviour and sheltering were motivated by the weather conditions, and the effect of concentrate feeding on grazing activity.

Observations were made on the animals for three days beginning at dawn and continuing until dusk. Note was made of the activity and position of the animals at 15 minute intervals, and a half hourly record of wind speed and temperature was maintained. The three days of observation provided contrasting types of weather condition. The first day was characterised by strong winds (17-24 m.p.h.) with sunny periods and temperature around 11° C., the second day by moderate winds (10-12 m.p.h.), sunny periods and showers and the third day by heavy rain, average temperatures and moderate winds (9-14 m.p.h.). Despite this range of weather conditions no use was made of the artificial shelter, but when shelter appeared necessary, resource was made to the natural shelter provided by the topography—hedges, rushes, and morphological undulations. Grazing behaviour appeared to be occasionally affected by the weather conditions, a cessation of grazing occurred with sudden squalls of rain, but in conditions of continuous discomfort, the animals moved to less exposed areas and continued to graze. As noted earlier, strong winds affected grazing patterns, but did not diminish the grazing intensity unless there was an inadequacy of natural shelter.

The feeding of concentrates was of limited success, a lack of interest in the food for most of the period, probably due to the high quality of the pasture, resulted in no definite conclusions being formed.

The daily routine of grazing appeared to begin at dawn and continued intermittently until mid morning when resting took place, and then continued at an increasingly intensive pace throughout the afternoon, to reach a peak just before dusk, when grazing ceased, and the animals lay in their night camps. These night camps were situated in positions which offered a moderate exposure to wind and the same camps were used by each group of animals as they were moved around the paddocks. The influence of weather conditions on voluntary food intake in the non-grazing animal is being studied simultaneously in a series of pen feeding experiments at Sourhope.

(Publications 64 and 89.)

Assessment of the Climatic Environment

The nature and the effects of the climatic environment on sheep production is a topic requiring quantitative assessment. The very complexity of the climatic environment, and its relationship with that of the micro-climate of the animal poses problems of adequate measurement. Out of doors the mobility of the animal allows it to move through a range of micro-climates, but the value of this mobility is limited by the location of the grazing and the range of micro-climates into which it can move. Methods of measuring these variable patterns of environment are being developed.

Response to Climatic Exposure (J.M.D. and J.G.G.)

An important corollary to the work concerned with the use of natural and artificial shelter by sheep is the study of the actual effects of exposure to climatic hazards that the provision of shelter is intended to combat. Differences in response may have a considerable influence on the choice of type of shelter or even on the basic question of the necessity of artificial shelter. The climatic conditions of wind, rain and low temperature produce an effect characterised by increasing energy requirements for the maintenance of body temperature. Response by the animal may be by compensatory increased energy production, involving changes in feed intake and in partition of nutrients, and by changes in thermal insulation. Aspects of nutritional adaptation are considered in other projects described in this section and in the Agronomy section.

Investigations on variation in thermal insulation have been confined to those differences conferred by variation in fleece structure. Two approaches have been used. In one experiment, repeated over the last four winters, a group of adult Blackface ewes have been wintered at Glensaugh in pens allowing individual feeding. Half the ewes were allocated to pens erected outdoors on an exposed site, whilst the remainder were housed in a well-ventilated and insulated shed capable of protecting the sheep from exposure to wind and rain and able to maintain an air temperature considerably above that outdoors. All sheep were fed the same amount of a pelleted complete ration, the amount being designed to maintain weight in a 100 lb. non-pregnant ewe in the indoor pens. In two of the years the outdoor group, as expected, lost live-weight relative to the housed group; the mean losses being 5 lb. and 12 lb. in the first and second year respectively with considerable variation within each group. Live-weight loss did not occur at a steady rate throughout the winter but fell most rapidly at first. Change in fleece length during this period would be very small and would have a negligible influence on fleece insulation. Evidence of a relationship between several components of fleece structure and variation in live-weight change were sought without any conclusive results. There was a suggestion that differences amongst sheep in fibre length, number of fibres per unit skin area and weight per unit area were correlated with live-weight change. In the third winter (1962-63), characterised by cold weather and long periods of snow cover, sheep in the outside group did not lose weight relative to those which were sheltered. Associated with the cold conditions were much lower than usual amounts of wind and rain, suggesting that low temperature alone imposes very little hardship on the fully fleeced ewe. It is apparent that whilst these experiments have provided information on nutritional requirements in contrasting climatic environments they do not allow adequate study of the role of the fleece as a weather protection.

The second approach adopted was the development of methods for measuring the thermal insulation of a fleece in a variety of environmental conditions whilst still on the sheep's back. The method adopted involved the measurement simultaneously of skin temperature (by thermistors) and heat flow from the skin (by means of Hatfield discs) which together with air temperature allows the calculation of the insulation provided by the fleece. There have been many delays caused by the fragility of the discs and by difficulties associated with their calibration and the standardisation of methods of mounting. Early trials were encouraging but demonstrated that much improvement in the accuracy and repeatability of the methods were required. On analysis these early results suggested that differences in insulation might be found even amongst sheep from a single Blackface flock but that the effects of these differences were small compared with those depending on the environment. The rate of heat loss from the fleece-covered surface could be increased by a factor of 3 or 4 times by removing an animal from a sheltered environment and subjecting it to quite moderate wind speeds (12 m.p.h.). The analyses suggested again that some characteristics of the fleece might be more important than others but no clear answer was found. Since these early trials, improvements in disc mounting and adhesion have increased the reliability of the observations and the construction of a wind tunnel has allowed greater control over the weather factors involved. The current trials involve small numbers of sheep with radically different fleece types, including Merino, Lewis and Lanark type Blackface, and lowland breeds.

To provide further information on fleece insulation an electronically controlled guarded hot plate device has been constructed for use in a model sheep. This instrument is at present undergoing intensive calibration trials.

As a development of the work on the insulation an initial study into aspects of the aerodynamics of airflow over the fleece has been started. The effect of wind on heat loss is generally recognised, but there appears to be no appreciation of the way in which the wind is able to penetrate the fleece, and of the mechanics of this penetration. Initial observations have been made with wind tunnel facilities to note changes in the morphology of a fleece caused by varying wind pressures. The interesting feature about a fleece when exposed to pressures is its malleable form, the amount of distortion being partly a function of increasing pressures, partly a function of the lie of the fibre and presumably a function of the resistance of the staple to a break up. Each of these features can affect the type of flow over the fleece, and thus modify the rate of heat removal from the fleece surface.

A lack of suitable measuring equipment has resulted in merely a preliminary examination of these features, but the interest is to continue as facilities become available, and techniques become more refined. The effects of shape, profile, and fleece type can then be examined more critically.

(Publication 74.)

Control of Wool Growth (J.M.D. and A.J.F.R.)

Wool samples have been taken at frequent intervals from one whole age group of flock ewes at Lephinmore throughout their life. Experiments have been designed round these sheep to study the effect of pregnancy and lactation and of changes in nutrition on the growth of wool under free ranging conditions in the normal climatic environment of the hill system. It was found that pregnancy slightly depressed the rate of wool growth relative to that of non-pregnant sheep in the same environment but that lactation had a much greater effect. The cycle in rate of production, shown over several seasons, is characterised by a high level in summer, reaching a peak in July-August, followed by a sharp drop in December to a much lower level (as low as 10% of peak value) in January and February. A similar pattern has been demonstrated in a group of Cheviot wethers which have been sampled monthly for the past three years at Sourhope. It now seems that the wool growth cycle does not exactly follow the feed intake cycle. Experiments involving the provision of supplementary food to grazing ewes in winter and spring have shown that extra feed given to pregnant ewes can convert the usual 10-15% live-weight loss in winter into a slight gain in live-weight without any increase in wool production. Extra feed given to lactating ewes in spring however, had little effect on rate of live-weight gain but produced a marked increase in the rate of wool production. These findings have led to the hypothesis that there is a non-additive interaction between seasonal (probably climatic but possibly related to day length) and nutritional factors in the control of wool growth and the partition of intake. The evidence has suggested that rate of production varies with the level of feed intake from late spring to early autumn. During winter, however, the very low rate of production does not appear to respond to variation in feed intake, at least up to maintenance levels. Differences between these results and those described for some other breeds have suggested that genetic differences in the physiological control of wool production exist and that these differences may have been produced by selection.

It is possible that the reduced sensitivity to variation in feed intake in winter might be due to a greater sensitivity to climatic stress conditions. Such a mechanism would be of a probable advantage to a wild type sheep in the Northern hemisphere in allowing the partition of the limited winter feed to provide for foetal development and the maintenance of body temperature. Some limited observations on Soay sheep kept near Edinburgh and supplemented with good quality lucerne hay and flaked maize to appetite, have shown that wool production in January declined to less than 5% of that in September. The growth in February and March from some of these sheep was so short that it could not be removed with Oster close clippers. A series of preliminary experiments to test different parts of this hypothesis are in progress at all three farms.

At Glensaugh, mated ewes of two Blackface strains were maintained over the winter in individual feeding pens. Half of these were in an insulated sheep house and the remainder occupied an exposed outdoor site. A complete pelleted ration was fed at three levels designed to promote live-weight gains and losses of approximately 10% and to maintain the mean live-weight of about 100 lb.

At Sourhope a group comprising North Country Cheviot, ¾ bred Merino and Soay sheep are involved in a long term experiment in which all sheep are fed at the same rate per annum. One third are fed at a mean daily rate for the whole year, another third are fed on a basis of the expected seasonal levels of intake for sheep grazing the hill and the remainder have this seasonal pattern completely reversed. Changes in feed level are made at the end of each calendar month at which time wool and blood samples are taken. Plasma non-esterified fatty acids are measured from the latter. Other experiments to establish this character as an index of nutritional and climatic stress are in progress.

At Lephinmore the field scale trials have been extended to provide normally grazing hill sheep with supplementary feed. The unsupplemented group lost 10-15% of live-weight during winter. Two levels of supplementation to provide no loss and 10-15% gain were given. All three groups were kept on young grass and given a concentrate supplement during the first eight weeks of lactation.

In all studies involving the periodic sampling of wool growth from mated ewes the technique of oestrus synchronization, described on page 27, has been used in an attempt to provide uniformity in the experimental groups. We have had varied, but on the whole good, results from this technique and further attention will be given to the development of a suitable method of experimental control. It is apparent that ram management is of prime importance.

(Publication 86.)

Miscellaneous

1. *Selenium*

Tremendous responses to selenium supplementation have been obtained in other parts of the world. At Glensaugh members of the Rowett Research Institute staff are studying the effects of selenium injections on the 'broken-mouth' conditions. Concurrent with this is a study of the effect of selenium on wool growth. It is not yet possible to present any results.

2. *Vitamin D_3* (R.G.G.)

In the autumn of 1959, trials were set up to examine the effects of a vitamin D_3 preparation on the growth and subsequent performance of Blackface and Cheviot ewe hoggs at Lephinmore and Sourhope respectively and also on the performance of adult Cheviot ewes at Sourhope.

At Lephinmore, where the hoggs are away wintered on grass, approximately half those from the Barnacarry and Low End hirsels received two injections of 2 ccs. each of Vitamin D_3 in January and March. Live-weight changes (in lb.) from 6-18 months were as follows:—

		Number	October 1959	April 1960	June 1960	August 1960	October 1960
Barnacarry	Treatment	22	64	72	90	94	95
	Control	24	64	71	90	97	97
Low End	Treatment	21	61	65	85	95	94
	Control	26	61	65	87	95	94

At Sourhope, where the hoggs are wintered on the hill with their dams, approximately half the South Country and half the North Country Cheviots on the Hairney Law hirsel received the same Vitamin D_3 treatment. Live-weight changes (in lb.) from 6-18 months were as follows:—

		Number	October 1959	April 1960	May 1960	August 1960	October 1960
S. C. C.	Treatment	13	67	54	66	83	99
	Control	12	67	51	65	83	98
N. C. C.	Treatment	13	75	59	76	98	113
	Control	14	75	60	77	99	114

Mean fleece weights (lb.) clipped from these hoggs were:—

Barnacarry	Treatment	4·6	S. C. C.	Treatment	3·9
	Control	4·7		Control	3·3
Low End	Treatment	4·4	N. C. C.	Treatment	3·7
	Control	4·7		Control	3·7

Apart from the South Country Cheviot group which showed a slight response in fleece weight and live-weight in April the treatment had no apparent effect. Without further treatment the South Country Cheviot group which received the Vitamin D_3 injections in their first winter went on to produce a much higher lamb weaning percentage in the following year. There were no major differences in any of the other groups. The differences between treated and untreated in the South Country Cheviot group were too small to be statistically significant so no further trials were carried out. It must be pointed out that the group of South Country hoggs on Hairney Law were in poor condition at the beginning of the trial and the winter was hard. It may be that under such conditions signs of Vitamin D_3 deficiency might be expected to show more readily but the indiscriminate use of Vitamin D_3 is unlikely to result in general and significant advantages.

The Soay and Blackface Sheep of St. Kilda (R.G.G., J.M.D. and W.N.M.F.).

Studies in conjunction with the Nature Conservancy and others, of the feral populations of Soay sheep on Hirta and Blackface on Boreray have been continued throughout the period. Visits to the islands have been made in spring of each year to carry out a census and obtain information on flock health and adaptation. The results to date are presented in the form of an occasional paper in this report. A small flock of Soay sheep were brought back from St. Kilda and are now located at the Edinburgh Zoological Gardens. It is intended that these will form a nucleus of this breed type for use in studies of methods of climatic adaptation and wool growth.

(Publication 83.)

BREEDING

Comparison of Pure Strains and Crosses in the Blackface and Cheviot Breeds (J.F.R., J.N.P., and D.C.C.)

THE strains of Blackface sheep described in the last report (Lanark, Lewis and Newton Stewart) have ceased to exist as separate breeding units, only the pure Lewis strain being still maintained at Glensaugh.

The remainder are being graded into the normal strain of the district of each farm by the use of flock rams. Interpretation of results of experiments involving competition amongst separate breeding strains must depend on the ecological background of the experiment. Different effects might be expected depending on whether the strains to be compared were introduced simultaneously to new ground as established flocks or as collections of individuals without a flock social structure or whether one flock was introduced to ground already grazed by another or whether the strains were developed by breeding up from a common stock. Examples of each of these methods of introduction have been covered in the experiments carried out on the Blackface strains at all three farms and on the North and South Country Cheviot breeds at Sourhope. Analysis of the results of these experiments to provide an answer to the simple question of difference between strains in merit and of the existence of gene/environment interaction is made very difficult by the intrusion of social factors. The importance of these has only recently been demonstrated and their effects are still imperfectly known. It is therefore impossible to give a clear answer to the question which was first set by these experiments. Some differences amongst the strains such as fleece type, skeletal proportions etc. are clearly independent of the ecological complications but others involving overall production in the hill environment are confounded with the social situation. Thus the lactation yield of twin-bearing Lewis ewes at Glensaugh was lower than that of the other two strains on the hill but not when such ewes were kept in inbye fields. This effect was clearly caused by the nutritional disadvantage suffered by the Lewis ewes because of their 'preference' for grazing the less productive higher slopes. However it is not possible to determine whether this was a true genetic difference in preference for altitude, herbage type or isolation, or whether it was an effect of social pressure in which the Lewis strain were socially inferior or even whether the distribution was a purely accidental allocation of ground amongst the descendants of three established groups of sheep introduced to the same hill in 1950.

Evidence of strain differences or interaction with environment from the top-crossing experiments at Sourhope and Lephinmore is as yet incomplete. It seems however that, despite the fact that both these investigations were carried out by mating strain rams to random groups of flock ewes which were already established on their territory, the results were not unlike those at Glensaugh. Individual differences in performance characters such as lamb growth rate and fertility were not great. Because of the inherent size differences, which were of the same order as in the Glensaugh pure flocks, the Lanark type are inferior to the smaller framed Newton Stewart and Lewis ewes when production of lamb or wool is assessed per lb. live-weight of ewe rather than on an individual basis. This question of the basis on which sheep performance on the hills should be assessed is itself unsettled.

Interpretation of results from breed and strain crosses are also made difficult by the impossibility of providing identical conditions for both parental stocks and the crossbred generation. In an experiment involving the use of South Country Cheviot rams on Lanark type Blackface gimmers at Sourhope the mean birthweight over four seasons for first cross lambs was 7·8 lb which was significantly higher than that of the pure Lanark gimmers' lambs in the same hefts (7·4 lb.). At weaning, however, the cross bred lambs (48 lb.) were significantly lighter than either of the pure parental strains (52 and 54 lb. respectively for Lanark on the same heft and Cheviot on a nearby heft).

Inbreeding of Blackface Sheep (J.M.D.)

(a) *Effects on Performance*

The general phase of this project came to an end during the period covered by this report. The field scale investigation started in 1959 with the mating at Glensaugh of four Blackface rams to groups of their own daughters and unrelated ewes. The same matings were repeated in the following three years except that in 1961 one of the original males died and had to be replaced by a son. With the exception of this latter group all the matings in each year produced lambs with coefficients of inbreeding of 25% and 0%. The results in all seasons confirmed those of the first year (H.F.R.O. second report 1958-61), and agreed with previous work on Merino sheep. Inbred lambs were considerably smaller at birth and had slower early growth rates than their non-inbred half-sibs. Early post-natal mortality rates were very high among the inbred lambs, the smaller ones at birth having the poorest chances of survival. This heavy mortality was not found in Merino lambs and it possibly reflects an interaction between the reduced fitness of inbred lambs and the harder conditions facing all young Blackface lambs raised in a hill environment. Increased variance amongst the inbred lambs again appeared to be associated with a greater tail of small lambs in the distribution—the best inbred lambs at all stages being equal to the best non-inbred. Despite the selective mortality of small lambs in the early stages this increased variance persisted into adult life. All female lambs of both types were kept for mating but a mock-culling was carried out in the usual way each year. From this it would appear that less than 30% of the inbred females would have been retained whereas less than 30% of the non-inbred females would have been culled. Numbers were too small to test survival over winter adequately but deaths in the first two winters of life were almost entirely confined to inbred ewes. Again there was an apparent correlation between mortality and size. In 1961 the first crop of inbred and outbred were mated as gimmers within their own sire groups to produce a wider range of inbreeding levels. In view of the very low fertility shown by the inbred ewes, it was decided that subsequent matings should be with completely unrelated sires to test the relative fertility of the inbreds and their non-inbred half-sibs without the complication of producing lambs with inbred genotype. Records in 1963 for the second lambing of the first crop and the first lambing of the second crop of ewes showed the same marked reduction in fertility of inbred ewes relative to their outbred half-sibs. So far, about 40% of mated inbred gimmers and 62% of second crop ewes produced lambs compared with 85% and 95% respectively in the outbred group. Over the two seasons 25% of inbred gimmers had lambs surviving to marking time compared with 56% from the outbred gimmers. The survival percentages in the 3 year old age group were 54 and 88 respectively. Out of 13 inbred ewes barren in their first year, seven were again barren after their second mating. All inbred ewes which produced a lamb in the first year also lambed in the second. Out of six inbred gimmers which failed to rear their first lambs three failed again. In the outbred group only one ewe out of four barren in their first year was again barren in the second. One ewe was barren in the second but not in the first season. Two out of five ewes which failed to rear their first lamb also failed their second. Already, therefore, after two seasons' matings, there is some evidence of repeatability of past performance, particularly in respect to barrenness, amongst inbred ewes, which is not evident in the outbred group. No further matings to produce inbred lambs will be made in this phase of the project but the ewes already produced will be retained on the hill for their normal lifetime to allow accumulation of information on the total performance of inbred sheep in a hill environment.

(b) *Food Utilisation*

Inbred and outbred wether lambs from the above matings were chosen to initiate experiments on genetic aspects of feed utilisation. They were used to study the dependence of the observed inbreeding depression on nutritional factors and to make preliminary observations on general genetic differences in feed utilisation and partition. Twenty-four lambs, all wethers and all reared as singles were taken at weaning from amongst the progeny of three rams mated both to their own daughters and to unrelated ewes of the same age. Within each sire and breeding group experimental animals were chosen at random from amongst the available lambs of the right type. The lambs were housed and fed individually on a complete pelleted ration. It was found that, contrary to expectations based on their previous growth, the differences between the two groups in mean rate of live-weight gain and in wool production were extremely small when rations were limited to levels resulting in either a slight negative or a small positive live-weight gain. Under *ad lib* feeding conditions, however, the mean voluntary intake of the outbred lambs was about 20% greater than that of the inbreds whilst the rates of live-weight gain and wool production were about 30% greater. This suggests that the depression caused by inbreeding, which has already been shown to be partially restored by treatment with a crude extract of ovine pituitary, might operate largely through differences in appetite. Digestibility trials at low restricted feed levels showed very little variation between or within the groups. The mean killing-out percentages of the two groups did not differ when the lambs were slaughtered at the end of the experiment.

The experimental period ran from August to February and, although confounded with feed level, there was a marked change shown by both groups in the ratio of wool production to live-weight gain as the season changed from summer to winter.

The data are being examined to try to determine a suitable statistical model for assessing differences amongst genetic groups or environmental treatments in overall food utilisation and in the partition of intake amongst the various components.

(Publications 84, 85 and 87.)

HEALTH

Studies on the Aetiology of Tick Pyaemia (W.N.M.F.)

IN many tick infested areas of the north of England and Scotland a staphylococcal infection of young lambs is of some economic importance. The annual incidence of the disease on farms in such areas is commonly about 5% of the lamb crop. Probably not more than 50% of the infected lambs die but survivors recover slowly and are usually in poor condition at the autumn lamb sales. Such animals constitute a proportion of the so-called 'shott' lambs.

Prophylactic measures to control this disease are not yet available and whilst penicillin therapeutically is beneficial, its administration under hill conditions is often impracticable or delayed until tissue damage has occurred.

Earlier work by the Animal Diseases Research Association suggests that the sheep tick (Ixodes ricinus) is not the vector of the staphylococci, the role of the tick probably being confined to the transmission of a predisposing condition—tick borne fever. Moreover the incidence of pyaemia is often higher on farms with a low tick infestation. This supports the contention that tick bite is not necessarily the source of infection.

In devising means to combat this disease it would be advantageous to know precisely how the staphylococci gain entry to the lamb. One portal of entry which has not yet been investigated is per os. Expressed in another way the incidence of pyaemia, irrespective of the degree of tick infestation may be an indication of the degree of sub-clinical staphylococcal mastitis (or alternatively teat contamination) in the flock.

Preliminary investigations to examine the above hypothesis were initiated in the spring of 1963.

Fifty milk samples were obtained from ewes in an area where pyaemia was known to be common. Cultures of the milk demonstrated that haemolytic staphylococci were present in six of the fifty samples. Samples of milk were also obtained from six ewes each of which was nursing a pyaemic lamb. Cultures of these samples showed that in five of the six samples haemolytic staphylococci were present. In the sixth (negative) case the lamb had developed pyaemia some four weeks before the sampling date.

The above results are insufficient in number to draw any definite conclusions but do suggest that this subject merits further detailed study.

Although there is no recognised method of preventing pyaemia it is often claimed that tick cream smeared on the lamb at birth protects it from tick bite, and hence from tick borne disease and 'tick worry' at a susceptible phase of its life.

To study the validity of this claim alternate lambs on one hirsel at Lephinmore were smeared with tick cream at birth (68 smeared: 77 unsmeared). A tick count on eleven smeared and eleven unsmeared lambs at three weeks of age showed that tick cream had considerably reduced but not eliminated infestation with adult female ticks. However, infestation of the head region with nymphal ticks was approximately the same in both groups of lambs.

Little evidence was obtained of any prophylactic value of tick cream. Only four cases of pyaemia occurred and these were evenly distributed between the smeared and unsmeared groups.

Live-weight gain from birth to marking was the same in both groups of lambs. Present results thus suggest that on this farm where the tick infestation is not exceptionally heavy little benefit is obtained by applying tick cream to lambs at birth. Moreover since it is known that nymphal ticks can transmit both louping ill and tick borne fever and infestation with this stage was not reduced, it is doubtful if tick cream has any prophylactic value. The low incidence of tick pyaemia in the unsmeared group would also suggest that a factor other than tick bite *per se* is involved in the aetiology of this disease.

Helminthological Studies (W.N.M.F.)

The results of faecal egg counts at Lephinmore and Glensaugh suggest that helminth infestation is rarely a problem under the extensive system of hill management, and that the routine use of anthelmintics is unnecessary and uneconomic.

Helminthiasis is however a more important problem when hill lambs are run inbye for fattening and anthelmintic dosing is frequently advantageous. In order to express this advantage in economic terms a comparative anthelmintic trial, utilising control lambs (24), lambs dosed with phenothiazine (24) and lambs dosed with thiabendazole (24) has been carried out. Weight gain and faecal egg output in the three groups were studied at fortnightly intervals over the fattening period and the total worm count at time of slaughter is being investigated in a small representative sample of lambs from each group.

Dosing with thiabendazole significantly reduced the faecal egg count, the reduction persisting for the duration of the trial. When compared with the control group phenothiazine caused a significant reduction in faecal egg counts for one month after dosing, but did not prevent a significant increase in numbers of helminth eggs compared with the predosing egg count. These results would seem to confirm the superiority of thiabendazole as an anthelmintic.

Assessed on faecal egg counts the level of parasitism in the experimental lambs was not high, and no cases of clinical helminthiasis occurred in the control group.

Live-weight gains were disappointing and differences between the three treatments were small. There is some evidence however that the wet season predisposed to other conditions (such as foot diseases) which may have considerably influenced live-weight gain.

Further investigations will be made to evaluate the relative importance of these factors.

Lamb Mortality and Dystocia (difficult births) (R.G.G. and W.N.M.F.).

Records on lamb mortality from birth to marking at approximately six weeks have been analysed for the four seasons 1956-59 for all three farms.

This analysis showed that the mortality rates in single-born lambs from three-year-old and older ewes, following hill lambing, were 12% and 6%, respectively, in the Cheviot and Blackface flocks at Sourhope and 14% in the Blackface flock at Lephinmore. In the Blackface flock at Glensaugh, the mortality rate, following regular pre-lambing feeding and lambing on cultivated pastures, was 5%. There was considerably heavier mortality in twin-born lambs, and in single born lambs from two-year-old ewes, notably as a result of increased loss subsequent to birth. Lambs with birth weights markedly heavier or lighter than average had a higher percentage of mortality, while, among single born lambs, more males were lost than females, the difference being between 1% and 8% according to the farm, and being largely due to a greater frequency of difficult births among males.

An investigation into the actual causes of lamb mortality was carried out at Lephinmore in 1963. No evidence was obtained that deaths were due to any one specific disease. A variety of factors, in the main, physical, geographical and climatic, contributed to the toll, but it was apparent that improved management can play a considerable part in reducing losses, mainly by reducing the number drowned at or near to birth, and missing on account of 'black loss'.

Detailed recording of all difficult births on the three farms continues to be made. Analysis of these records, to indicate the incidence, predisposing causes, and possible elimination or reduction of this condition, is being carried out.

The relationship between lamb birth weight and head width is being studied by regression analysis on male and female lambs of single and twin births. Significant breed, sex, and multiplicity differences are apparent in certain seasons on both Lephinmore and Sourhope. This approach may have some bearing on the incidence of difficult births and is being studied with this in mind.

(Publication 73.)

BOTANICAL STUDIES

R. F. HUNTER

ECOLOGY

Plant Sociology (J.K. and A.D.M.)

UNDER this heading are included several studies of the disclimax hill grasslands of the Southern Uplands and Central Highlands. The object of the work is to provide a classification that will facilitate the recognition of types in the field and, by indicating their environmental inter-relationships, provide a basis for pasture improvement. For this purpose a purely floristic classification is of less value than a classification of the ecosystem as a whole and in N. America, Russia, Scandinavia and elsewhere this approach has been adopted in relation to both forest and range management. The classification is in terms of site-types, that is units of the physical environment which may support a number of vegetation and ecosystem types according to the nature of the prevailing biotic environment.

The problem as it relates to hill grazings in Britain differs from that encountered elsewhere in that virtually no climax or near climax vegetation is available for study, and also in that the conversion of one type of disclimax vegetation to another or the introduction of new species is of greater economic importance than the regeneration of the indigenous climax vegetation. There seems to be no reason however, why the site-type concept should not be applied to disclimax ecosystems so long as the nature and intensity of the biotic factor can be specified.

In the present work such a classification is being attempted using vegetation as the principal indicator of environmental variation. For this purpose the two most important characteristics of vegetation are floristic composition and production of organic matter, but unfortunately these do not lend themselves to investigation by the same methods and while a survey procedure can be used to study variations in floristic composition, an experimental approach is necessary to measure production.

The result of a preliminary classification of the survey data collected so far is summarised in Fig. 1. This is a classification of the vegetation in relation to two environmental factors, soil pH and drainage class and is not a site-type classification. Before the latter can be achieved it will be necessary to identify more precisely those vegetation differences associated with biotic differences and to

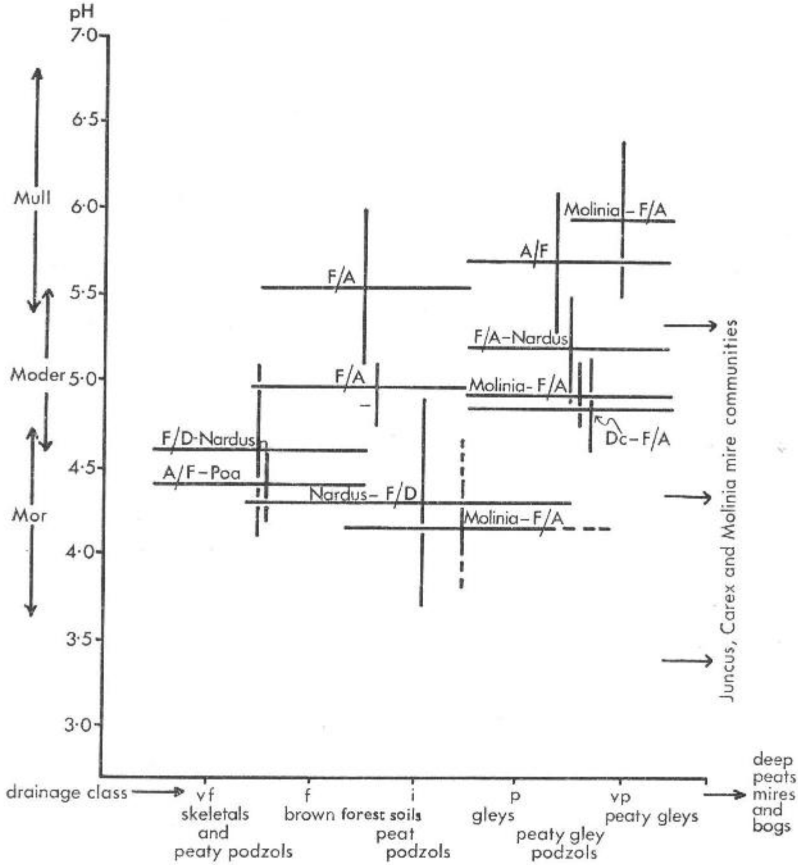


FIG. 1—The inter-relationships of certain forest zone grassland types of southern Scotland in terms of soil pH, drainage class, and profile type. The grassland types range from *Festuca ovina/Deschampsia flexuosa* dominant grass heaths (F/D) to various *Festuca-Agrostis* (F/A, A/F) types and types dominated by *Deschampsia caespitosa* (Dc) or *Molinia caerulea*. Where versions of these types rich in *Nardus stricta* can occur, this species is given last. Where it is always a dominant it is given first.

account more fully for floristic variations apparently associated with moisture regime. In addition it will be necessary to identify the significant effects of variation in micro-climate especially those associated with altitude and aspect.

Some of these problems are being examined experimentally, especially those in which the environmental factor appears to have a relatively greater effect on plant production than on floristic composition. Studies have been carried out on the relationship between the yields of a number of species of hill grassland and soil nutrient level, while an experiment is in progress to examine the effect upon plant growth of variations in altitude. This experiment is additional to the altitude studies reported elsewhere (p. 57) the species involved being *Festuca rubra* and two ecotypes of wild white clover. It is expected, if a general relationship can be established between altitude and plant growth that it will be possible to incorporate this into a site-type classification.

Ultimately it is hoped to describe variations in the ecosystem in terms of a multi-dimensional model. This could be used as the basis of several classifications each adapted to a different purpose, the class boundaries in each case being defined in terms of the principal axes of variation. Although a site-type classification based solely on indigenous disclimax ecosystems cannot be assumed to apply directly to ecosystems based on introduced species, there should be little difficulty in adapting the classification for this purpose provided the environmental requirements of the introduced species are adequately known.

Hill Grasses (S.A.G. and R.F.H.)

Investigations into the comparative behaviour of hill grass species were begun in 1960. An experiment was laid out at Glensaugh in which data were collected from single spaced plants of nine different hill species growing in a single randomized block. The plant material was collected at Sourhope during October 1960. It was transferred to Glensaugh, planted out that autumn and allowed to grow on unchecked until June 1961.

The species studied were *Holcus lanatus*, *H. mollis*, *Festuca rubra*, *F. ovina*, *Agrostis tenius*, *A. canina*, *Anthoxanthum odoratum*, *Deschampsia flexuosa* and *Nardus stricta*. These were subject to different cutting treatments and data were collected on yield, periodicity of growth, winter greenness and response to the various cutting regimes.

Gross differences in yield among the species were found which arrayed the species in the following yield order, *Holcus lanatus*, *Festuca rubra*, *Holcus mollis*, *Agrostis tenuis*, *Anthoxanthum odoratum*, *Agrostis canina*, *Festuca ovina*, *Deschampsia flexuosa* and *Nardus stricta*. This order bears some resemblance to the frequency with which the species would be expected to occur in plant communities occurring in a fertility gradient from mull to mor soils i.e. the first named species would be more frequent in mull, the last named in mor soils. In January and in March winter greenness was assessed. A visual estimate of the proportion of dead or discoloured leaves was made and each plant allotted a score. There was an interaction between treatments and species and comparing winter greenness of regrowth following October cutting with the winter greenness of plants uncut at this date, the species fell into three groups:—

(a) *Holcus mollis* and *Festuca rubra*. Regrowth following October cutting remained fresh and green while the uncut foggage contained a high percentage of dead or discoloured leaves.

(b) *Festuca ovina*, *Deschampsia flexuosa* and *Holcus lanatus*. In this group the uncut foggage had a better score than the regrowth following the October cut. Indeed for the two first species regrowth was negligible, the cut presumably being at a date which was near the close of their growing season.

(c) *Agrostis tenuis*, *A. canina* and *Anthoxanthum odoratum*. In these species neither October defoliation nor the lack of it affected winter greenness.

Nardus stricta, though resembling the first group in that cut plants had a slightly better score for winter greenness, is not included in these groupings because of its overall poor performance. The species listed in order of winter greenness are:—

Holcus mollis

Festuca rubra
Festuca ovina

Agrostis tenuis
Holcus lanatus
Deschampsia flexuosa

Agrostis canina
Anthoxanthum odoratum

In March 1962, all the plants were cut back and re-allocated to new cutting treatments so that the effect, of the previous season's treatments on the plant's performance could be assessed. Data were collected on yield, the initiation of floral primordia and the time of anthesis. The order of the species as determined by the date of initiation of floral primordial from the earliest to the latest was, *Anthoxanthum odoratum*, *Nardus stricta*, *Festuca rubra*; *Deschampsia flexuosa*, *Holcus lanatus* and *Agrostis canina*; *Holcus mollis* and lastly *Agrostis tenuis*. Statistical analysis of yield data from cuts made in May and June showed that differences among species and among pretreatments were significant and that an interaction between treatments and species occurred. Differences among species in yield showed the same order as in 1961 the order of yield being, *Holcus lanatus, Festuca rubra* and *Holcus mollis, Agrostis tenuis, Anthoxanthum odoratum* and *Agrostis canina*; *Festuca ovina*; *Deschampsia flexuosa*. *Nardus stricta*, which could not be included in the analysis because losses had left insufficient replicates, was the lowest yielder. Treatment differences demonstrated the large effect that the previous season's management could have on the following season's growth. The biggest effect was that caused by the latest cutting treatment, *viz*., plus or minus October defoliation. In every case the plants which had been cut in October yielded less than those which had not been cut then, but the amount of the depression in yield differed from species to species. In some it was large and significant, in others it was small and non-significant. The species therefore differed in their degree of sensitivity to defoliation. *Holcus mollis* proved to be least sensitive, a group of three species, *Festuca rubra, Agrostis tenuis* and *A. canina* of intermediate sensitivity. *Deschampsia flexuosa* lies somewhat between this group and the last group of more sensitive species which is *Holcus lanatus, Anthoxanthum odoratum* and *Festuca ovina*.

These results were obtained from spaced plants and as doubt is often expressed as to whether results obtained under these conditions have a bearing on performance in sward conditions, in subsequent work it is intended to compare results obtained from spaced plants growing side by side with those under sward conditions. In some cases, e.g. yield, the absolute values would be different. This would not matter if the classification of the species in order of yield, maturity type, winter greenness etc., were unchanged. It may be that for some observations either method would be satisfactory, while for others sward conditions alone would be satisfactory.

A second line of study has been started to investigate competition among hill species. In the first instance competition between pairs of species will be studied but later it is hoped to extend the work to include more complex mixtures.

White Clover (J.K., A.D.M. in collaboration with the Department of Bacteriology, Edinburgh School of Agriculture)

The degree of improvement that is ultimately attained in the improvement of hill pastures will be to a large extent determined by the extent to which white clover can be made to grow productively in the hill environment. Indigenous white clover is a regular constituent of the better community types, mainly *Festuca-Agrostis* and related grasslands, on soils above approximately pH5 (see Fig. 1). A survey carried out in the Cheviot hill area showed that morphologically these clovers are smaller and more prostrate than the cultivated type of wild white clover. Leaflet size and petiole length were found to be 50% smaller than those of Aberystwyth S.184, while plant diameter and internode length were 26% smaller. Between grouped populations of indigenous clovers smaller differences correlated with environmental factors were found to exist. Leaflet length proved to be negatively correlated with soil base status, the smaller leaved clovers being found on the more mesotrophic sites. This was thought to be due to the higher grazing intensity usually associated with communities on the more basic soils.

Although there is evidence (Snaydon, R. W. (1962)) that indigenous clovers may be especially well adapted to soils of low nutrient level this may be of little direct importance if the yield of dry matter and of nitrogen are much less than those of a cultivated wild white clover type growing in the same soil. Little is known however of the productivity of indigenous clovers or their value as a source of nitrogen and a series of experiments have now been started to obtain information on these points.

At present only soils adequately supplied with nutrients and with an effective *Rhizobium* population are being used. Comparisons between clover/grass mixtures are being made in one experiment under various frequencies of defoliation and in another in relation to variations in altitude. Five altitudinal levels from 750 ft .to 1750 ft. are employed at each of which a uniform soil is provided in boxes. Grass/clover mixtures can be grown in these and their yields compared. Air and soil temperatures, rainfall and wind are being recorded at each level.

The effectiveness of the available *Rhizobium* population is another factor that may limit clover productivity and a survey of indigenous *Rhizobium* populations has been carried out. This showed that the mean effectiveness of the populations was positively correlated with soil base status, the more mesotrophic soils (pH 5·7) being associated with greater proportions of highly effective strains of *Rhizobia* than the more acid soils. However the proportions of the less effective grades showed no relationship with base status, the reasons for this not being apparent. Following this work it became evident that more information was needed on the factors influencing effective and ineffective strains of *Rhizobia* in soil and as a result the present programme of laboratory studies was started in the Bacteriology Department of the Edinburgh School of Agriculture. Although the work is still incomplete the results obtained so far indicate that pH *per se* in the range pH5-6 is likely to have little effect on *Rhizobium* survival in soil. On the other hand certain metallic ions appear to exert a marked influence in causing effective strains of *Rhizobium* to become ineffective. It is possible therefore that the principal way in which soil acidity influences *Rhizobium* populations is through the effect of low pH in increasing the availability of these metallic ions.

In addition to this work a joint programme of field and pot experiments is being carried out. As part of this programme a study has been made of the variation in the effectiveness of the *Rhizobium* population within a 20×8 m. plot in a flushed grassland community. The mean effectiveness of the *Rhizobium* population when tested on S.184 clover growing on agar was apparently low, although indigenous white clover occurred abundantly throughout the plot. Only 7% of the nodule isolates were highly effective while 50% were completely ineffective. No difference in effectiveness was found between *Rhizobia* isolated from small or large nodules. Within the plot a gradient of population effectiveness from one end to the other was found to exist, despite the low overall level of effectiveness. The reasons for this gradient are not yet known but it is suspected that variations in soil drainage may be involved. Such variations within what would normally be regarded as a single plant community may prove to be of frequent occurrence, especially in flushed grasslands.

The results of the survey already mentioned showed that 39 out of the 40 populations examined contained at least a small proportion of highly effective organisms, although the mean level of effectiveness, as measured in the laboratory, of many indigenous *Rhizobium* populations was not high. It is not known however what proportion of effective organisms must be present in the nodules to produce a satisfactory clover yield. In addition there is little information on the relationship between the *Rhizobium* population in the nodules and that occurring in the soil. Experiments in the field and in the glasshouse are being carried out to investigate these problems. Results obtained from clover plants growing on agar indicate that yields decline only slightly when the proportion of effective organisms in the culture is reduced from 100% to about 1%, but do so rapidly with further successive reductions. At the same time it appears that quite small proportions of effective *Rhizobia* in the inoculum can give rise to very much larger proportions in the population within the nodules. Since in this experiment nodule number was unaffected by varying proportions of effective strains it seems that a small proportion of effective *Rhizobia* in the medium is able to compete successfully with a large excess of ineffectives for the available nodule sites. Data consistent with these results were obtained from a pot experiment in which clover was grown on a brown earth soil containing no effective *Rhizobia* of its own and inoculated with varying proportions of effective and ineffective organisms. On this soil 1% of effective organisms in the inoculum produced a 78% effective nodule population, the yield being similar to that produced by a 100% effective inoculum. Different results were obtained however from a waterlogged hill peat similarly treated. In this case the yield declined steadily as the proportion of effective strains in the inoculum was reduced, the former being closely correlated with the mean effectiveness of the associated *Rhizobium* population in the nodules. The data suggest that conditions in the peat were in some way less favourable for the formation of effective nodules than in the brown earth soil and it is possible that the difference in drainage conditions between the soils may have been significant.

(Publications 70 and 76.)

Snaydon, R.W. (1962) *J. Ecol.* **50**, 439-447.

Water Relations (J.A.R.)

Although something is known, in general terms, about the soil moisture 'preferences' of many agricultural grasses and native hill species, very little is known about moisture requirement and tolerance in individual species, and about the effects of varying soil-moisture conditions on their growth and competitive ability. With this in mind, experiments under controlled soil-moisture conditions are being carried out at Glensaugh. The objects of these experiments are threefold, to examine the effects of different soil-moisture regimes on the growth pattern of individual species, to study the changes in competitive ability brought about by varying the soil-moisture regime and to relate soil-moisture tension changes with changes in the internal water balance of the plant.

In the experiments, large boxes lined with polythene film, and filled with soil are connected by pipes to reservoirs, where the water level is controlled by a system of adjustable ball-valves and an automatically controlled solenoid valve.

A 4 in. layer of washed gravel covers the bottom of each box, above this a layer of 'Terylene' cloth has been placed to prevent the soil above this from clogging the interstices of the gravel. Two soils were employed—a coarse sand with very free draining properties and a low moisture holding capacity, and a milled peat with high moisture retaining properties. The boxes were divided into compartments ('plots') by vertical partitions of oil-bound hardboard reaching down to one inch above the cloth barrier. The boxes are protected from rain by a movable roof of polythene film.

A preliminary trial was made in 1962 in which the following herbage species were grown:—

Festuca rubra	—Red Fescue	(S.59)
Phleum pratense	—Timothy	(S.50)
Lolium perenne	—Perennial Rye Grass	(S.23)
Dactylis glomerata	—Cocksfoot	(S.143)

In addition *F. rubra* was grown in combination with each of the other three species.

Two nitrogen levels were applied, nil and 35 lb. per acre.

Four water table regimes were employed:—

1. Continuously high.
2. 24 hours high alternating with 24 hours low.
3. 24 hours high alternating with 6 days low.
4. Continuously low.

The low water tables were below the level of the gravel and the high ones 1-2 cm. below the soil surface.

During the trial, weekly measurements of the plants' growth were made, and the final dry matter production determined. The root development was studied in those plants growing in the sand.

The effects of the water treatments varied somewhat with the species, and there was, with *P. pratense* and *L. perenne* a significant interaction (0·1% level) between soil and water treatments. *P. pratense* grown in sand showed a slightly, but not significantly better growth in the wetter treatments in the sand, whereas in the peat the best yield was shown in treatment 3. The growth of *L. perenne* was greatly reduced in the wettest treatment in peat, as compared with the drier treatments, but no effect of the moisture treatments was apparent when this species was grown in sand. Treatment No. 3 gave the best yield for *D. glomerata* in both peat and sand, whilst *F. rubra* showed no significant differences in yield in relation to the moisture regimes. *P. pratense* had the poorest root growth in the dry treatment and the best in No. 2. In the lower sections of the profile, 24-40 cm. below the surface, *P. pratense* showed the highest root production in the wettest treatment and the lowest in the dry, whilst the other three species showed a tendency towards increased root production with increasing dryness, *viz.*:—

Treatment	Total root weight in 5 cm. core from 24-40 cm. depth			
	F. rubra	*D. glomerata*	*P. pratense*	*L. perenne*
1	0·0183	0·0201	0·0657	0·0814
2	·0551	·0356	·0409	·2091
3	·0436	·0636	·0263	·0724
4	·0691	·1178	·0255	·2838

In this experiment, the range of soil moisture tensions obtained was:—

Treatment 1.	0 cm./Hg
Treatment 2.	0 cm. (high W/T) to 2·5 cm. (low W/T)
Treatment 3.	0 cm. (high W/T) to 3·5 cm. (low W/T)—Peat
	0 cm. (high W/T) to 4·0 cm. (low W/T)—Sand
Treatment 4.	Up to 8-10 cm.

This range was not as great as had been hoped for since the high relative humidity prevailing at the time retarded drying out of the soils.

In the following year, a similar experiment was conducted, using six single species of grasses, grown under eight soil-moisture regimes and in two soils. Different nitrogen levels were omitted. In that year moisture tensions in the driest treatments exceeded 40 cm. of mercury, the wettest again being completely saturated. Of the six species grown in this trial, all those growing in peat showed their poorest dry matter yield in the wettest treatment; the best growth occurred at mean moisture tension of 5 cm. Hg. (*Poa trivialis*) to 1·5-3·0 (*Festuca arundinacea*), with a falling off of yield towards the dry end of the scale. In the sand all the species showed better yields in the wetter treatments, although *Phleum pratense* and *Poa trivialis* did not give the highest yields in treatment 1 (completely waterlogged). This was possibly due to lack of soil aeration. Similar effects were noted on tiller numbers.

In order to obtain as full a record as possible of the environmental conditions affecting these plants, a multipoint thermograph and recording tensiometer were installed. A low relative humidity facilitates the drying out of the soils, a high humidity not only retards this effect, but may lead to an actual increase in soil moisture. This may be due either to condensation (dew formation) or to the hygroscopic nature of some of the soil constituents. The rate of drying of the soil is, as would be expected, directly related to the size of the plants growing in it. The thermograph records show that although there is little if any difference in the mean temperature between wet and dry treatments, or between peat (organic) and sand (inorganic) soils under the conditions of this experiment, there is a greater diurnal variation in sand, than peat. The flooding of a soil profile occasionally leads to a temporary lowering of the temperature.

In conjuction with the Agronomy Department tensiometers have been placed in a number of sites which have been selected to include different soil and vegetation types characteristic of the hill environment. These instruments have been read at weekly intervals but it is hoped to record, in addition to weekly spot readings from these instruments, the weekly minimum and maximum values. It was apparent that the rise in moisture tension occurs comparatively slowly, whereas a single heavy shower can rapidly reduce the tension.

Measurements of the internal moisture deficits of the plants both in the field and under experimental conditions are also being made.

The Effect of Altitude on Plant Growth (R.F.H., S.A.G. and G.L.)

To-day neither the national need nor the economic incentive is present which would result in a large scale programme of ploughing and reseeding upland pasture. Nevertheless the research worker has to study not only the problem of improving the existing method of land use but also the problem of other possible uses. In the future we may have to reseed large areas of hill land and should this prove necessary then a knowledge of which soil types to improve and the limitation imposed by altitude, aspect and slope on production will be of value.

As a research programme involving the simultaneous study of all these factors would be much larger than is feasible with present resources a start has been made on the effect of altitude on plant growth.

Observations are being made on the growth of clones of S.23 Perennial Ryegrass at 34 sites. These 34 sites are divided into 8 altitudinal transects, 4 at Sourhope, 2 at Glensaugh and 2 in Glenesk. For permission to establish sites at Glenesk we are indebted to the Dalhousie and subsequently to the Roxburgh Estates. Within each transect the sites are positioned at approximately 250 feet intervals of altitude. The number of sites within a transect range from 3 to 6. The lowest site in any transect is 500 feet and the highest 2250 feet. All sites face south. Observations began in 1962 and it is hoped to continue these through 1964, and possibly longer.

Experimental control is devoted to arranging that all sites differ as little as possible. At each site four cubic boxes, 16 in. inside measurement, were sunk to soil level, the boxes being paired and dug in one in front of the other, the pairs being 7 feet apart. The two rear boxes were allocated to one plot the two front boxes to another. Two different mixtures of soil, sand, and peat, were employed, the mixtures being allocated at random to the rear and front boxes separately. The ground surrounding the boxes was levelled the boxes themselves having a very slight downward fall to facilitate drainage. Each box was lined with polythene sheeting and each was individually drained with a polythene pipe. Nine clones of perennial ryegrass were propagated to give sufficient material in 1962 to plant all boxes with one small plant of these clones. In 1963 four clones were employed, nine small plants of each clone being planted to give four micro-swards within each box.

In 1962 and 1963 data were collected on number of tillers per plant, date of flowering, dry matter yield per plant, weight per tiller, etc. at various dates during the spring, summer and autumn.

In addition to the plant growth data maximum and minimum soil temperatures and soil moisture tension are recorded at eighteen sites comprising four transects. It is hoped to establish two tatter flags at all sites to assess exposure and to employ photo-chemical methods to measure 'light'.

These data, both plant and meteorological, are extensive and cannot be summarised in a short report.

The observations made so far do however suggest an explanation of the effect of altitude under our conditions. This explanation is based on the following assumptions:—

1. Within the temperature range encountered growth rate is linear in relation to temperature.

2. Temperature decline is linear in relation to altitude.

3. The march of seasonal temperature approximates to a sine curve.

4. Among the sites comprising an altitudinal transect and as a first approximation temperature is the only variant that need be considered.

5. The developmental sequence of the plants' seasonal growth is determined autochthonously, each aspect of development *viz.* flowering, tillering, leaf growth etc. occurring at different rates.

6. Growth and development are not synonyms but are different although interrelated processes.

Adopting these assumptions, the effect of altitude is best explained by following the suggested pattern of events throughout the growing season.

In early spring the mean temperature is near the critical temperature. For each 300 feet increase in altitude the mean temperature will drop 1° F. When the mean temperature reaches the critical temperature at the upper altitudinal limit the growth rates at equal altitudinal intervals of 300 feet below this will form a sharply increasing linear series. This sequence in growth rates may be written as:—

$$A^{0x}, A^{1x}, A^{2x} \ldots$$

When A = initial plant mass, assumed to be similar at all stations, x = growth rate.

The growth rate multipliers are directly proportional to the temperature differences at successive descending altitudinal stations.

The significance of the sequence becomes obvious when a similar sequence is written for mid-summer when the mean temperature at the upper altitudinal limit is assumed to be 20° F. above the critical temperature. This can be written as:—

$$A^{20x}, A^{21x}, A^{22x} \ldots$$

It will be seen that the ratio between successive multipliers of the growth rate in mid season has narrowed compared with early spring.

These two contrasting sequences allow of a simple generalisation:—assuming the lapse rate shows no seasonal variation the effect of altitude is proportional to the difference between the mean temperature and the critical temperature, the smaller the difference the greater the effect. In brief the effect of altitude will be greater on growth and development in spring and autumn than it will be in mid-summer. It will also be realised that the effect of altitude will be related to the amplitude of the seasonal variation in temperature and the height of its peak above the critical temperature but this aspect has already been reported upon by Gloyne (1958).

It could be expected that altitude would affect in descending order of severity, seed yield (a developmental and growth process extending over the whole season and therefore including both the spring and autumn periods), flowering (a developmental and growth process taking place in the *Gramineae* in the early part of the year and generally completed before maximum temperatures are reached in July) and dry matter yield (a predominantly growth process rather than a developmental one and a process dependent on the mean growth period temperature rather than the temperature at any particular period during that season).

There is no doubt that the relationship between altitude and plant growth is exceedingly complex and this brief discussion omits many aspects. A most important factor affecting the rate of growth with increasing altitude, which has been omitted in this discussion, is wind speed. Future work is planned with the intention of separating the effects on growth of the decrease in temperature and the increase in wind speed which accompanies increasing altitude. It may be that the growth rate is determined by the sum of these factors and that their relative importance in that summation varies seasonally. Irrespective of the factors determining the growth rate, the general argument appears to fit the data collected so far and is also in accord with the observations made by Pearsall (1950) on the effect of altitude on the growth of *Juncus squarrosus* in the Pennines, 'however it seems certain that the effects of altitude are differential, affecting seed production most, flower production less and vegetative growth least'.

In the analyses, both the linear and quadratic regressions of the plant data on altitude have been calculated and it is of interest that some of the quadratic regressions are significant. This is not an unexpected result if the growth rates in the two sequences are studied, the ratio between successive rates within each sequence increasing with increasing altitude. Pearsall's data (1950 p. 50) also indicate an exponential effect of altitude on plant growth and development. If the altitudinal effect is exponential it is interesting to speculate on the effect small changes in mean temperature in the U.K., as have occurred post-glacially, would have on upland in comparison to their effect on lowland vegetation.

Gloyne, E. W. (1958) on the 'Growing Season'
Agric. mem. XVIII
Meteorological Office, Edinburgh.
Pearsall (1950) Mountains and Moorlands,
Collins

Sheep Behaviour (R.F.H.)

In the period 1956-59 the behaviour of hill sheep in relation to the various sward types found on their pasture was studied (Publication 72). The relation between sheep and their grazing is not, however, the only topic of interest in a study of their behaviour, the relationships which exist among the sheep themselves being also of importance. We might describe this as their social environment to distinguish it from their nutritional and climatic environments.

The social behaviour of two hefts has been studied, the Gairs heft (South Country Cheviots) 1959-60 and the Alderhope heft (Scottish Blackface) 1961-63. Of the two studies, that carried out on Alderhope was the more detailed and this is the one now described. None of the observations made on the Gairs heft contradict those made on Alderhope.

In May 1961 the number plates, carried round the ewes necks at lambing to make recognition easy, were retained after lambing. From that date until August 1963 the heft was visited at approximately weekly intervals and observers, equipped with maps of the heft, recorded the position of the ewes they could identify. The Alderhope heft extends to 350 acres and the stocking rate during the observation period was approximately 200 ewes and hoggets. There was an increase in the stocking rate during the period.

In addition to records of the grazing location of each ewe and hogget comprising the heft, the following data were available—weight of ewe and hogget at November, January, March, June and August; weight of lambs at birth (mid April—mid May), marking (early June) and weaning (mid August); dams of lambs born spring 1956 onwards; ewe lambs retaining as hoggets, and ewe and hogget wool clips.

As records of the location of individual sheep began to accumulate it became obvious that no sheep grazed over the whole area of the heft but that each sheep grazed within a particular area of the heft, this area being in the order of 100-120 acres and, in the case of many sheep, being less. While each sheep had its own area within which it grazed, the heft as a whole divided itself into groups of sheep sharing the same area of the pasture and these groups were called home range groups. The home range group adopted by a ewe is likely to be that of her dam and home range groups tend to be composed of a number of family groups. It, therefore, appears that two natural social groupings occur in hill sheep, the family group and the home range group. The attachment of a sheep to a home range group appears to be life-long there being very little, about 2% per annum, shift from group to group and this is possibly an overestimate.

The Alderhope heft extends from 900 to 1980 feet in altitude and, is botanically heterogenous, different plant communities occurring in a non-random manner throughout its area. This being so it follows that if sheep adopt different areas of the heft as their home range then these home ranges must differ in altitude, aspect and botanical composition. It also follows that these differences in the environment of different home range groups may be reflected in differences among them in performance measured by such indices as weight of lamb at weaning, growth of hoggets etc. This was indeed found to be the case. It was also found that in selecting ewe lambs for retention as ewe hoggets the preference for the larger lambs resulted in a higher proportion being selected from some ranges than from others. It would be expected that as a consequence of this the population of sheep in some ranges would increase while that in others would decrease. This took place, the stocking intensity in the two poorer ranges declining by 6% while that in the better ranges increased by 19% in the period 1961-63 a period in which the over-all stocking rate increased by 9%. If the 1963 hoggets remain in the range of their dams then it can be predicted that these differential changes in stocking rate will become, from August 1963 onwards, −16% in the poorer ranges, +27% in the better ranges, the over-all change in stocking rate in the heft being +10%. It is apparent that the average stocking rate on an extensive hill pasture and percentage changes in this rate is a measure which if used as an experimental or agronomic parameter could be an almost useless generalisation.

The social behaviour of hill sheep has a considerable effect on the experimental designs which can be adopted in studies of them. In August 1961 the number of ewe hoggets retained was increased in order to conduct an experiment on the effect of the juvenile plane of nutrition on the performance of ewes when adult. In order to vary the plane of nutrition some of the ewe lambs had to be removed from the heft for varying periods in the age range 11-52 weeks. Depending upon the age at removal and the conditions under which they were kept, social groupings were established among the ewe lambs which cancelled out the family and home range groupings to which they would have belonged if retained on the heft. When, aged one year old, these ewe lamb groups were returned to the heft, they acted as a social group, stayed together on the heft and in one case were forced by the social pressure of the resident ewe population to adopt, as a group, a relatively unoccupied and vegetationally poor part of the pasture. The effect of this behaviour was to question if not destroy the design of the experiment as required by statistical theory.

Most if not all hill farmers know that individual sheep have their own rake, that the lambs adopt the rakes of their dams and they also know that the sheep group themselves into sub-hefts or what we have called home range groups.

It is necessary, however, to work out the consequences of this behaviour in relation to normal farming practice.

Our observations have lead us to picture a hill sheep flock as split into sub-flocks or home range groups which are, without being fenced, effectively separated from each other in discrete groups by their social behaviour. Neither from day to day nor during their life-time do they normally graze out of their customary areas. Any practice which is applied at one point on the hill, the positioning of mineral boxes, feeding of hay, shelter belts, the improvement of small areas of pasture etc., may therefore be limited in their effect on the flock as a whole to those sheep which customarily graze the area in which the practice is sited. If the practice is to affect all the flock then it must be dispersed over the whole hill. Thus if mineral boxes or licks are positioned at a density of less than one per hundred acres on hills of this type then it is possible that some sheep will not utilise them.

Of some importance is the fact that sheep from different home ranges do not necessarily attain the same level of performance. Within the Alderhope heft in 1961 adjacent groups of sheep differed by 4·3 lb. in the weaning weights of lambs and by 8 lb. in the August weight of hoggets. Such differences imply that if improvements are to be carried out then the improvements may more profitably be carried out on one part of the hill where the response of the sheep is likely to be higher than in another.

The effect of home range behaviour on the procedure to be adopted when selecting ewe lambs for stock ewe replacement is a problem at once interesting and complicated.

Selecting the ewe lambs on the general basis of size and forward condition has resulted on Alderhope in the selection of the ewe lambs preferentially from what is judged, on the basis of vegetational composition, to be the better part of the heft. As a result of this procedure the population of sheep in that part has increased as has already been noted. When the sheep stock on Gairs was increased the population however increased disproportionately on what was thought to be the poorer part of the pasture.

It is possible that these opposite results, when stocking rate is increased, arise from there being two processes at work. One process involves the purely social behaviour of the sheep who will not tolerare more than a certain density of sheep within a home range the excess being forced out to under- or unoccupied parts of the hill. The other process involves the results of increasing the population within certain areas as more ewe lambs are retained from those areas than from others. As the stocking rate increases in these areas individual performance may decline and selection will then work against that group this point being reached before social pressure adjusts the population density.

There is as yet insufficient evidence to base a sound judgement on present methods of selecting ewe lambs. It does appear that some current practice could be improved and that selection should be based on a policy of maintaining the stock within separate home ranges at its optimum. This policy would require an intimate knowledge of a sheep stock and also a knowledge of what was the optimum stocking for the separate ranges.

(Publications 72, 78, 82 and 97.)

STUDIES IN MANAGEMENT PRACTICES

Muirburn (S.A.G. and R.F.H.)

1. *Heather Communities*

(i) *Long Term Burning Experiment.* In this experiment different burning rotations are being practised side by side in three localities, Glensaugh, Lephinmore and Sourhope. The driest habitat is Glensaugh where the heather community occurs on 8 in. of raw humus over freely-drained sandy loam. At Sourhope a wetter type of heather community occurs on an eroded deep peat hag. At Lephinmore the community grows on blanket bog on peat up to 2 feet deep. On both grazed and ungrazed plots the burning rotations practised are:—burned every 5 years, burned every 10 years, unburned, and cutting and removal of the vegetation at 5 year intervals. This last treatment was included because the main criticism of the practice of heather burning is that it leads to a lowering of the fertility of the underlying soils due to mineral loss in run-off immediately after burning. The removal of the heather crop treatment means that all the minerals in the vegetation are lost. Mineral balances are not however within the scope of this experiment where the concern is with the effects of the treatments on floristic composition. The experiment was commenced in 1956, and the 5 year treatments have already been administered at two of the sites. However on the Glensaugh grazed plots, where seven years after the initial burning, vegetation cover has reached only 50% on two of the plots and 70% on the third, the treatments have had to be delayed and at Lephinmore where late or wet springs during 1962-63 made burning impossible they have also yet to be carried out.

At the two sites where these treatments have been carried out, namely the Glensaugh ungrazed plots (treated in 1962 five years after the initial burning) and the Sourhope plots where ungrazed plots only are being observed (treated 1963, five years after the initial burning) heather regeneration has been quicker on the cropped than on the burned plots.

(ii) *Survey of Heather Regeneration Over a Wide Range of Conditions.* Observations on heather regeneration and other effects of

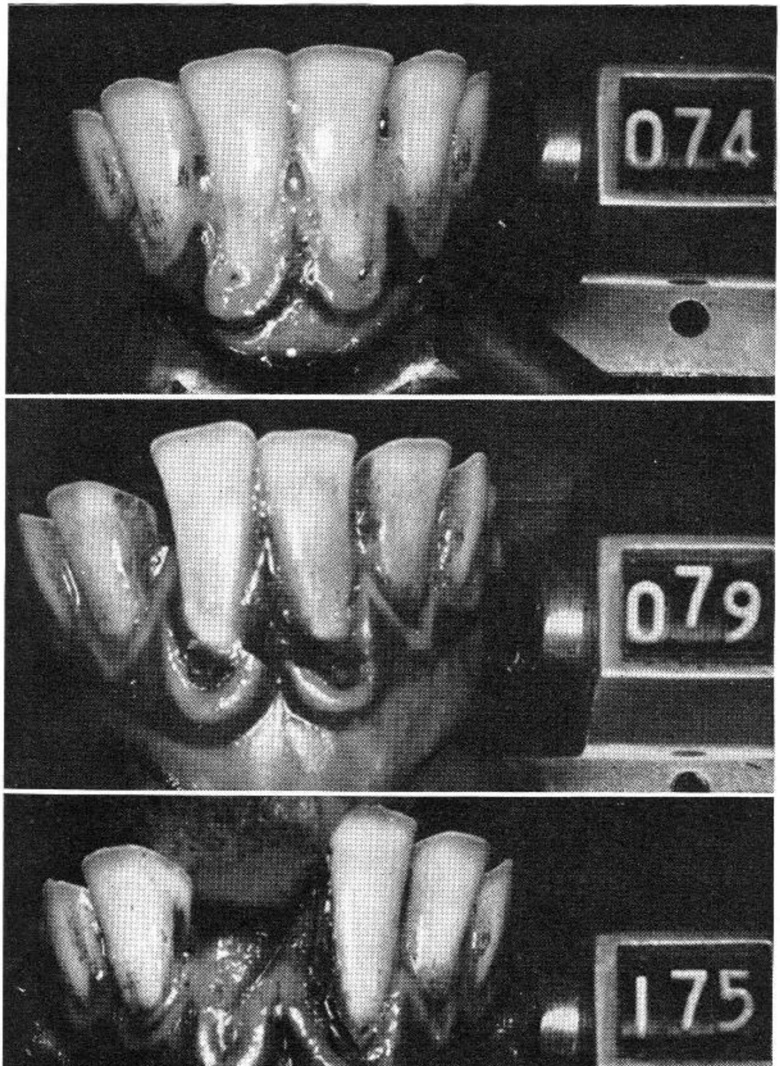


PLATE 1—Incisor teeth of Blackface ewe (V149) at Glensaugh showing the rapid deterioration that has occurred between $3\frac{1}{2}$ and $4\frac{1}{2}$ years of age. *Top:* 43 months (Nov.). *Centre:* 50 months (June). *Foot:* 52 months (Aug.)

PLATE 2A—Mixed group of North Country Cheviot, Merino and Soay sheep in the outdoor feeding pens at Sourhope

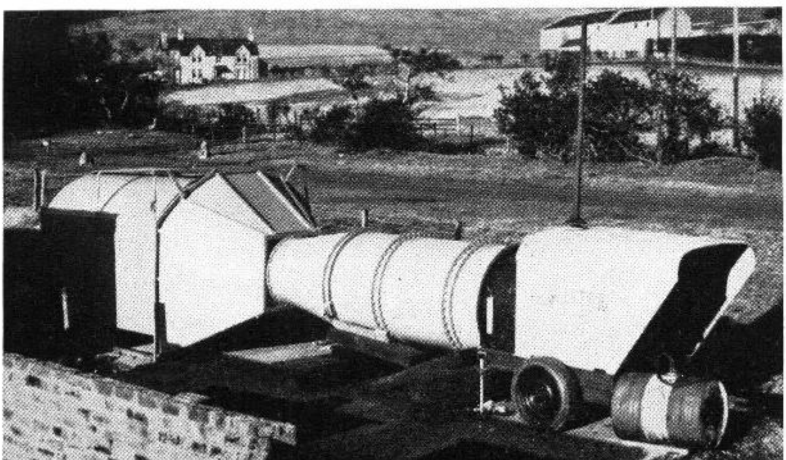


PLATE 2B—Home-made wind tunnel powered by a Lister hay drier. A controlled rate of air flow of between 8 and 36 m.p.h. can be achieved in the working section

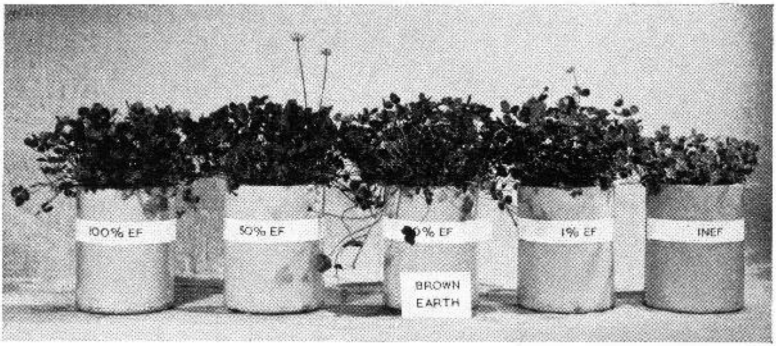


PLATE 3A—Showing the effect of inoculation with mixtures of effective and ineffective *Rhizobia* on S 184 white clover growing in a hill soil suitably manured. A mixture containing 1% of effective organisms gave a similar yield to that produced by a 100% effective inoculation. The indigenous soil *Rhizobium* population was wholly ineffective

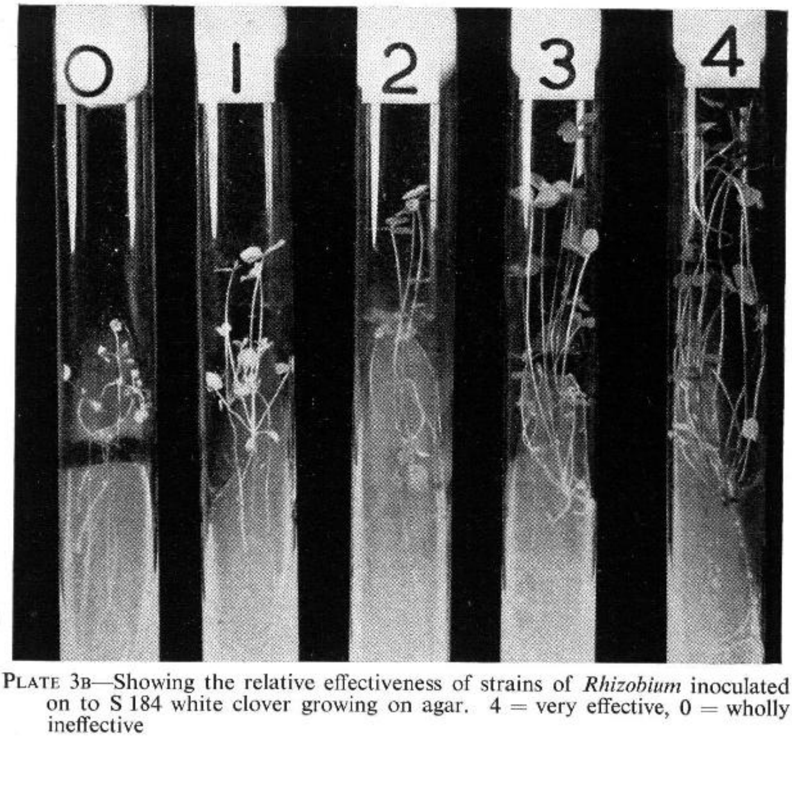


PLATE 3B—Showing the relative effectiveness of strains of *Rhizobium* inoculated on to S 184 white clover growing on agar. 4 = very effective, 0 = wholly ineffective

Fig. 1—Top home range group (40 sheep)

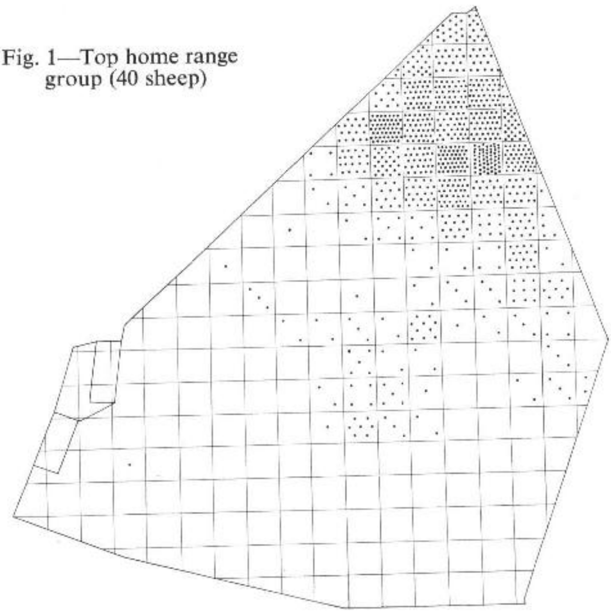
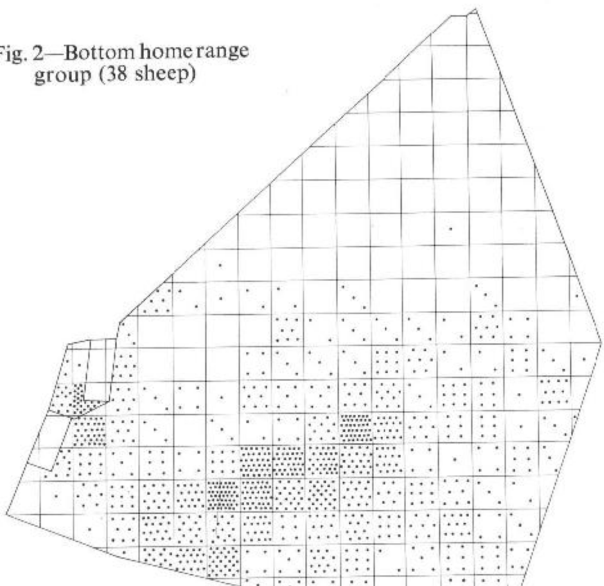


Fig. 2—Bottom home range group (38 sheep)



PLATES 4 and 5—Figures 1-4 show the location records of 4 home range groups occupying a 350-acre hill pasture. Each dot represents 2 sheep locations

Fig. 3—Mid home range group (52 sheep)

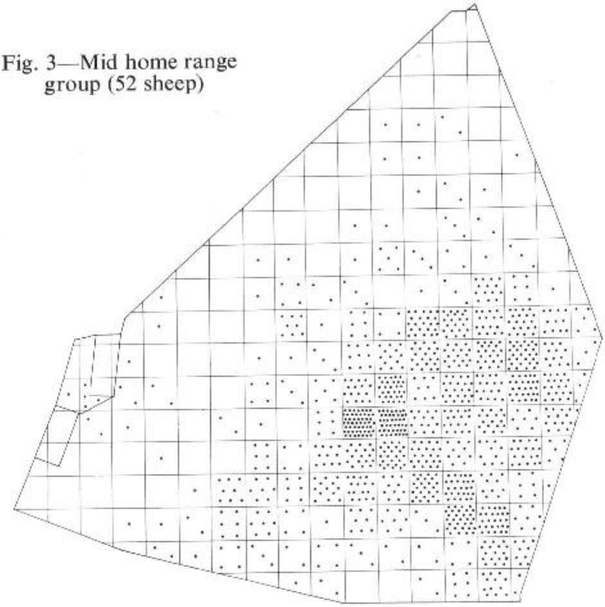
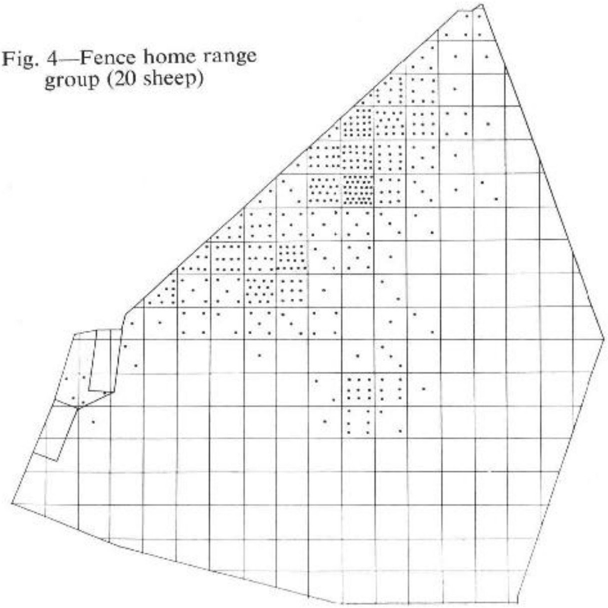


Fig. 4—Fence home range group (20 sheep)



recorded in the period May-December 1961. In constructing these figures the records for the sheep comprising the home range group were compiled on the one map.

a

b

PLATE 6—Effect of defoliation on the habit of heather plants. 6-year-old plants

a. Undefoliated plant—note open and leggy habit similar to that of aged heather in the field.

b. Plant defoliated annually during the winter, note compact and cushion-like habit

PLATE 7.—Members of a group of Soay rams in the village area, Hirta

PLATE 8—A view of the sloping plateau of Boreray looking towards Stac Li. The Blackface flock can be seen grazing as a single unit

burning are being maintained by annual visits to 30 areas, 14 in Perthshire and Angus and 16 in the Border counties. The sites include a variety of soil types varying in slope from level land to a steep scree, and in altitude, from a hundred feet above sea level to 2000 feet.

Records were collected prior to burning from all the sites and the study was commenced in autumn 1957. Six of the sites were burned in 1958, twelve in 1959, ten in 1960 and two in 1961. Within a week or two of burning a small grazing exclosure was erected at every site so that the rate of heather regeneration could be followed and the effects of grazing on heather return assessed. Grazing pressure varied from site to site. The exclosure was sheep proof only and did not interfere with hares or grouse grazing. Heather heights within the exclosures varied among the sites, soil type, altitude and exposure all contributing to the difference in rate of growth.

The areas where the heather has achieved the quickest growth rates are not necessarily those where heather cover is highest but this is complicated by such factors as floristic composition prior to burning, age of heather before burning, type of burn, etc. The numbers of species recorded on the burned areas has increased at every site, sometimes by one or two species only and sometimes being almost doubled. It is thought that this is not so much due to the incoming of new species to the area, though no doubt this has happened in some cases, but to an increase in the frequency of species which occur only as a trace or with a low frequency in mature heather stands—such species as *Trientalis europaea*, *Campanula rotundifolia and Sagina procumbens*. Observations will be maintained until regeneration has produced mature stands of vegetation showing little annual change in floristic composition.

2. *Grass Communities* (R.F.H. and S.A.G.)

Burning experiments on *Molinia*-dominant communities include a long term burning rotation experiment at Sourhope. Early observations made in this experiment on the effects of burning on a *Molinia* sward led to other experiments being developed. In these the effects of manures applied at rates equivalent to the amounts of chemicals being released by burning *Molinia* litter, the insulating effects of the litter layer on yield, the chemical composition of the *Molinia* leaves, and flowering vigour as effected by burning were studied. Two small pot experiments were also carried out in which the effects of different levels of insulation on development and flowering vigour of *Molinia* were examined (Publication 77). The only observation made since which may have bearing on the conclusions then made concerns the effects of burning on the yield of the sward. Measurements of tiller size of *Molinia* plants on the long-term burning plots made during late summer (July 25th) 1963 showed that the average tiller size on burnt plots was less than that on unburnt plots.

Tiller length (cms.) of Molinia caerulea *on burnt and unburnt plots measured 25/7/63.*

Burnt Plots				Unburnt Plots		
1	2	4	5	3	6	Control
33·92	32·17	30·33	32·58	45·67	42·92	43·18

These figures are the averages of twelve readings for the plots and twenty-eight readings for the larger control area ($P < 0{\cdot}01$).

The main conclusion reached on the basis of the work done so far is that the practice of burning *Molinia* has little to recommend it. If it produces more grazing it does so at a time when grazing is already adequate and it may diminish the amount available in winter when grazing is already short. Carried out to solve the agronomic problems raised by the pasture containing too much *Molinia* it increases the dominance of that plant. As an agronomic measure it may be dismissed as a relatively harmless form of pyromania. If the habit must be indulged then no more should be burnt than can be severely grazed in the summer following a spring burn.

(Publication 77.)

3. *The Effect of Grazing and Burning on the Regeneration of Heather Swards* (R.F.H., G.L. and S.A.G.)

The effects of different intensities and seasons of grazing on regenerating heather are being studied in this experiment sited on Finella Hill at Glensaugh. There are six main plots receiving different grazing regimes and each of these plots is split into four sub-plots burnt at two year intervals. These grazing regimes are, high or low intensity, in summer, winter or throughout the year. The burning programme was commenced in spring 1957 and completed in spring 1963. At the present time the ages of the heather on the four sub-plots are therefore 1, 3, 5 and 7 years.

Botanical analysis of the plots are carried out annually and records of the heights of the heather taken periodically.

The experiment is still in its early stages and no trend in changing botanical composition as affected by grazing regime can be detected

Calluna vulgaris

Chemical composition of separated leaf material from plants receiving different frequencies of defoliation (material raised from seed in 1957 plants 5 years old in 1962). Percentage of d.m.

Sampled in	Total Ash			Silica fice Ash			P			K			Ca			Mg			N		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1962	4·533	—	4·363	2·833	—	2·599	·131	—	·121	—	—	—	·393	—	·414	·178	—	·157	1·709	—	1·446
		N.S.			P< ·05			P< ·05						N.S.			P< ·01			P< ·001	
1963	4·153	4·069	—	—	—	—	·136	·124	—	·670	·511	—	·430	·426	—	·178	·153	—	1·67	1·45	—
		N.S.						N.S.			P< ·05			N.S.			N.S.			P< ·05	

Cutting Frequencies A = cut every year
(cutting commenced B = cut two out of every three years
December 1957) C = cut every second year

as yet. However the large effect that year of burning can have on heather regeneration has been amply demonstrated.

Heather Defoliation. The Finella experiment is accompanied by a box experiment, in which the effect of frequencies of cutting administered at two different times of the year on the yield and habit of growth of heather plants is being studied.

As previously reported, defoliation alters both the habit of the plant and the ratio of green or edible material to woody tissue. It is known that as heather ages the chemical composition of the leaves alters (Thomas, B., 1935 and 1956). Crude protein which declines consistently with age and ash, is highest in very young heather, and shows little or no variation with age after 3-4 years. Mineral content however, does vary with season, in general falling as the season advances. Samples of leaf tissue from some of the defoliation treatments were chemically analysed—see table on page 67.

The effect of cutting is apparently to maintain the leaves of the more frequently cut plants in a juvenile condition as measured by their chemical composition.

Thomas, Brynmor (1935) Agricultural Progress Vol. XII, pp. 82-89.
Thomas, Brynmor (1956) Herbage Abstracts Vol. XXVI, pp. 1-7.

4. *Loss of Mineral Nutrients Occasioned by Muirburn* (R.F.H., G.E.D. and I.A.N.)

The practice of heather burning has been criticised on the grounds that burning renders soluble the mineral nutrients in the plants and these could then be lost by leaching or surface run-off.

Interest in this problem extends beyond the H.F.R.O. and a committee was set up in 1961 composed of Nature Conservatory, H.F.R.O., Macaulay Institute and University staff to consider it. The committee was primarily concerned with the loss of mineral nutrients and restricted its deliberations to this aspect of the problem. From the outset it was understood however, that this aspect was neither the only one nor was it a decisive one. It was argued that if there were a substantial loss of nutrients this would condemn the practice but if this was not so this did not necessarily support its continuation as the rotational burning of a heather sward was not necessarily the best form of land use nor could other effects of burning be ignored.

Deciding upon the experimental procedure to adopt presented the committee with some difficulties. These arose from the fact that in metering the small quantities of mineral nutrients thought to be involved in a loss occasioned by burning, the experimental error was likely to be as large if not larger than the loss.

The procedure which was adopted was to construct a model of the chemistry of the moorland ecosystem, to argue which input and output pathways in the model were of significance and then to collect data relevant to these pathways in order that a first approximation towards quantifying the model could be made.

As a result of these discussions the following studies began or were continued:—

1. A study of the literature in order to assess the input of nutrients in rainfall, carried out by Mr. I. A. Nicholson (H.F.R.O.), Mr. R. A. Robertson (Macaulay Institute) and Dr. D. T. Crisp (Nature Conservancy).

2. A consideration of the mineral nutrient loss by the sale of livestock, carried out by Dr. R. F. Hunter (H.F.R.O.).

3. The collection of field data on the amount of mineral nutrients contained within the plant/soil system in a heather community, by Mr. R. A. Robertson (Macaulay Institute) and Mr. G. E. Davies (H.F.R.O.)

4. A laboratory study of the solubility of the minerals in heather plants after burning, their absorption by the soil complex, their volatilisation by different burning temperatures and their absorption by sphagnum, carried out by Mr. S. E. Allan (Nature Conservancy, Merlewood).

In addition to these studies, Dr. A. J. P. Gore and Dr. R. Elliot (both of Nature Conservancy) submitted to the committee reports on studies which they had already conducted.

It is hoped that some, if not all of this work will be published in due course by those who have carried it out.

The preliminary examination of the problem made clear what had not already been adequately realised. This is that mineral input in rainfall if entrapped by the plant/soil system is sufficient to replace the loss occasioned both by burning and by the sale of livestock.

The logical step in developing research in muirburn was then to study the entrapment of the nutrients in rainfall by the plant/soil system and studies of this are being undertaken by Nature Conservancy and H.F.R.O. staff.

A knowledge of the movement of ions in the highly organic soils found on hill pastures is fundamental to an understanding of both entrapment and leaching of nutrients. Preliminary discussions have been held on this question with the Agricultural Research Council Radiobiological Laboratory which is concerned with the movement both of fission products and of nutrient ions in the soil. In collaboration with H.F.R.O., A.R.C.R.L. has extended its investigations of the movement of Sr-90 and Cs-137 in undisturbed soil profiles to include peat and peat-podsolic soils from Scottish moors. It is considered that these results will assist in the planning of work on the movement of nutrient ions in moorland soils.

The Use of Herbicides on Hill Pastures (G.E.D. and R.F.H.)

By 1960 *dalapon* (2,2-dichloropropianic acid) had been tested on most plant communities at Sourhope and was found to be a very effective herbicide against most species, *Holcus* species however being highly resistant. Subsequently the newer herbicides, paraquat and diquat were tried against species resistant to dalapon. No valid results could be drawn from experiments carried out in 1960, which were designed to compare the three chemicals at three levels of spraying and two spraying dates, because heavy rain fell shortly after spraying. Under these conditions, however, dalapon proved better in suppressing *Molinia caerulea* and *Nardus stricta* whilst there was slight evidence that paraquat was more successful against *Festuca ovina* which had proved rather resistant to dalapon. Diquat gave very poor results and was not tried again. Experiments carried out in 1961 on different communities to those of 1960 and under good spraying conditions confirmed the results of 1960. In 1962 the only herbicide used was paraquat sprayed at 2 lb. and 4 lb./acre and at three spraying dates on two communities similar to those sprayed in 1961. At the two sites an excellent suppression of all species was obtained. There was no date effect and there was little advantage to be gained in spraying at the high rate of 4 lb./acre. *H. mollis* proved highly resistant and soon spread rapidly over bare ground.

It seems that paraquat is more sensitive to conditions at spraying time than dalapon and only in 1963 did it equal the overall performance of dalapon. An advantage of paraquat is its short-lived soil toxicity which reduces the interval between spraying and over sowing.

Hill improvement work started at Sourhope in 1963 is concerned with the up-grading of poor *Agrostis-Festuca-Nardus* pastures, by the use of fertilisers, the application of a herbicide to suppress *Nardus stricta* and finally the introduction of clover into the pasture. Because of the dense surface-mat and low rainfall numerous experiments at Sourhope and elsewhere have shown the difficulty of this last operation. Most workers agree that cultivation must be minimal otherwise the whole object in spraying is invalidated. A small scale experiment was therefore started in 1963 in an attempt to find the most suitable method of cultivation when combined with previous spray treatment to give reasonable clover establishment. (Publication 71.)

Bracken (G.E.D.)

1. *Chemical Control*

A series of experiments carried out at Sourhope since 1959 to test the effectiveness of herbicides as a method of bracken control have now been concluded. Experiments started in 1959 and 1960 compared the herbicide 4-CPA nonyl ester ('Weedone Brackontrol') with the recognised method of suppressing bracken by cutting twice a year for three years. The chemical was sprayed at the recommended rate of 1½ gals./acre and at two dates mid-July and mid-August. Plots were recorded for frond counts each year for three years after spraying and in 1963 height measurements were taken. Initial results differed between the two years: 1959 was an abnormally dry and hot summer and the critical time for spraying i.e. when the frond is fully expanded, may have been missed, a mid-August spray in 1959 reducing frond numbers by only 18% whilst a spray applied at approximately the same date in 1960 gave a 66% frond reduction. Three years after spraying and after annual cutting treatments had been applied frond counts, with the exception of the 1959 August spray treatment, did not differ significantly from one another and gave bracken frond reduction of approximately 40%. Vigour as measured by height of bracken was in all cases closely related to frond density.

In 1961 another experiment was started to compare 'Weedone Brackontrol' with amino triazole (activated) Weedazol-tl. The first was sprayed at 1½ gals./acre and the second at 3 gals./acre. There were two spraying dates, the beginning of August and the beginning of September. First year results were good and at the first spray date 'Weedone Brackontrol' gave a 70% reduction in frond number and 'Weedazol-tl' 80% but these differences were not significant. The following year, however, both showed only a 40% reduction. Early August was the best spraying date for the two chemicals with a reduction of almost twice that of September and this was significant in the first year after spraying but not in the second year. Height measurements taken in 1963 on all treatments did not differ significantly from each other.

In the above trials neither herbicides nor the recommended cutting treatments effectively controlled the bracken and until more is known about the effect of climate, soil type, and stage of growth in modifying the susceptibility of the bracken, it is difficult to predict results and hence explain the large variabilities encountered.

2. *Mechanical Treatment*

The trials set up in 1958 in conjunction with the Scottish Station of the National Institute of Agricultural Engineering, with the object of ascertaining the mechanical treatment necessary to keep in check bracken that had already been brought under control by 1954, continue.

Up to 1961 frond counts were made using a systematic arrangement of quadrats so that more precision would be gained through doing a covariance analysis of the data. After several analyses had been carried out it was obvious that this rather laborious method of sampling was not justified. Correlations between the same quadrats for different years was almost negligible and from 1961 onwards random sampling was used.

AGRONOMY

I. A. NICHOLSON

WATER IN HILL SOILS

THERE is no reliable estimate of the total upland area bearing peat soils, though in Scotland for peat two feet or more in depth the figure of approximately 1·7 million acres is generally accepted. There are many problems in the manipulation of peat areas for grazing purposes, but a clearer understanding of the water relations of peat soils and their associated vegetation is a necessary basis for proper use. Although a knowledge of the hydrological characteristics of hill soils, both organic and mineral, has broad implications, the studies developed over the last six years have been concerned principally with ecological and agronomic problems associated with pasture use, rather than with those of the supply and disposal of water. Some aspects of the work, however, may have relevance in these fields.

Hill drainage was one of the problems considered by our predecessor, the Scottish Hill Farm Research Committee, and recommended as a subject for investigation, particularly with regard to on-site problems. It was recognised by the Committee, however, that the consequences of any practice in the uplands which might have a connection with water disposal on low ground could not be ignored. With other interests in view much of the experimental work has been developed with the active collaboration of the Peat Ecology Section of the Macaulay Institute and close contact has been maintained with the Hydrological Research Unit (D.S.I.R.) and with the Nature Conservancy.

A number of problems are of immediate practical importance but an *ad hoc* approach with these particularly in mind was rejected as earlier attempts along these lines had not been encouraging. The whole question of water and its relationships with land management is complex and involves a knowledge of income and loss through its various pathways, including drainage and evapotranspiration, and has important implications in soil fertility. Apart from an initial survey to establish the variation in drainage practices and to acquire some background information of their effects on vegetation and grazing habits, it was considered that the first phase of the programme should fall into three categories as follows:—

a. The significance of soil water regime to the growth of plants and the development of vegetation and soil under field conditions.

b. The relationship between various soil and vegetational treatments on an area and the characteristics of the water balance and balance of nutrients.

c. The moisture characteristics and permeability of soils and the behaviour of individual species in relation to soil moisture status.

Field and laboratory studies have been developed accordingly.

The Ecological Significance of Soil Moisture Regime in a Peat Soil (I.A.N., I.S.P.)

Owing to the paucity of experimental field data on the significance of the soil water regime in peat, a pilot study was carried out between 1958 and 1963. This work has been conducted co-operatively with the Peat Ecology Section of the Macaulay Institute for Soil Research. The site selected was in the south of Scotland on a raised bog bearing vegetation dominated by *Calluna vulgaris*, *Erica tetralix*, *Eriophorum* spp. and *Sphagnum* spp. Apart from limited drainage, periodic burning and occasional grazing by sheep, the area had suffered little disturbance prior to the introduction of the following treatments on two adjacent areas, the one bearing the natural bog surface and the other pre-treated by the establishment of a grass and clover sward:—

1. Control—water table fluctuations as in the untreated bog.
2. Continuously high water table.
3. High water table in summer; low in winter.
4. Low water table in summer; high in winter.
5. Continuously low water table.

The artificially high water tables were maintained by pumping into ditches surrounding the experimental plots and though water tended to be in short supply in long periods of drought, satisfactory differentials in water table heights were maintained throughout the experiment.

The experiment has taken the form of a general documentation of the consequences of different soil water regimes to soils and vegetation under the two systems of management. Peat shrinkage rates, soil moisture tensions, nutrient movement, soil temperatures, vegetational responses and herbage yields have been recorded and a number of avenues for more critical investigations have been opened up. Some of these problems are being investigated more critically in the Botany Department by Dr. Rogers.

One interesting feature was the relatively low values recorded for soil moisture tension even in dry periods when the water table was maintained at a continuously low level. Another feature of considerable agronomic interest was the performance of the three grass species timothy, cocksfoot and meadow fescue sown in the mixture on the improved series of plots. Under the conditions of the experiment, involving three cuts per annum (but no grazing), all the swards contained high proportions of meadow fescue though some modification in species balance did result from the water table treatments.

Hydrology and Nutrient Balance of Peat Catchments (I.A.N., I.S.P.)

A 70 acre raised peat bog having a maximum depth of about 20 feet and lying at an elevation of 750 feet in Lanarkshire was selected for experimental work which, as in the previous study, is being undertaken collaboratively with the Peat Ecology Section of the Macaulay Institute. An artificial catchment of 17 acres was delineated by a perimeter 'sheep' drain 14 inches deep. A meteorological station was established on the site and a metering station installed to measure the discharge of water from the catchment area. (Fig. 2).

Detailed recording began in 1959 and the study involves four phases namely:—

1. Characterisation of the water balance of the catchment in its comparatively undisturbed state to determine the relationship among precipitation, water table fluctuations and discharge of water in the drains.
2. Determination of the effects of increasing the drainage frequency on discharge characteristics.
3. Characterisation of the water and nutrient balances of seven 'micro-catchments' within the main one.
4. The application of seven different forms of grazing use, one on each 'micro-catchment' for comparative evaluation of their effects on the hydrological characteristics and loss of nutrients from the site.

The first phase of general characterisation over a three year period has been completed and for the last eighteen months preparations have been in progress for the subsequent assessments. Additional drains have been cut and seven 'micro-catchments' laid out, each with its own drainage system and equipment for the recording of water flow. Some difficulty has been experienced in the design of satisfactory instrumentation for the measurement of water flow because of the range of discharges encountered and the presence of suspended organic material in the run-off water. In collaboration

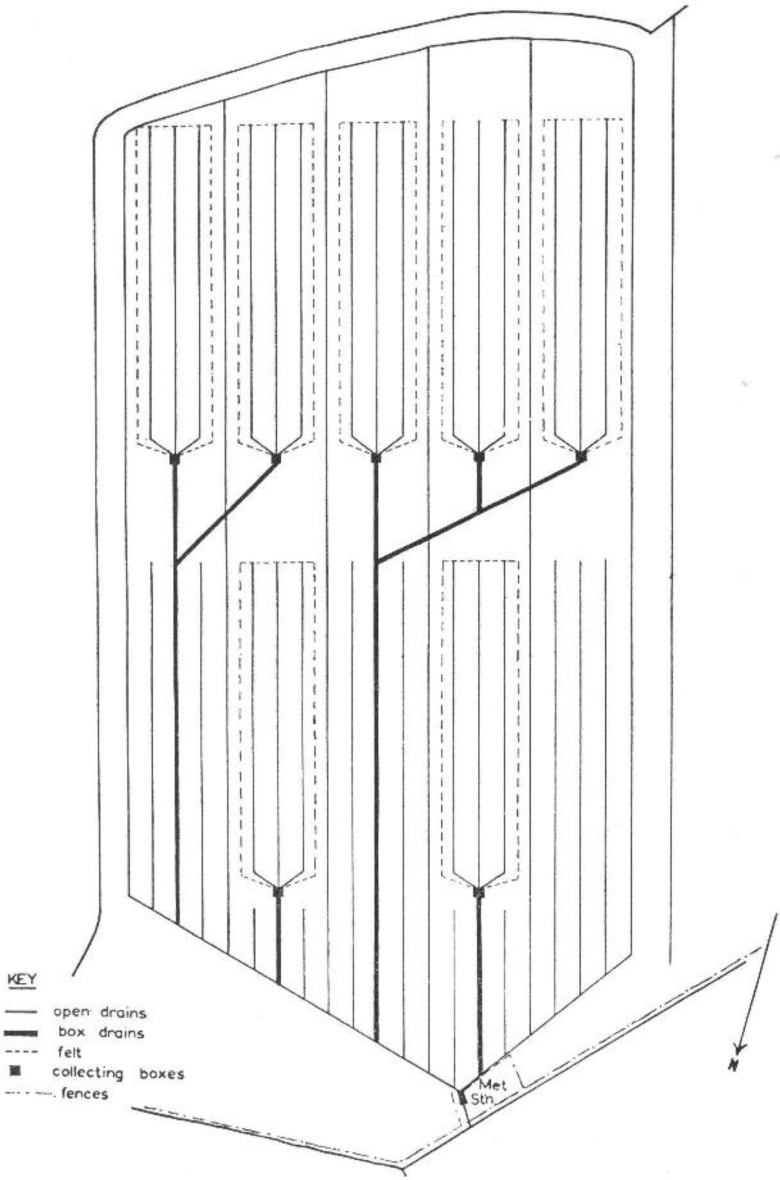


FIG. 2—Layout of catchment experiment, Blacklaw Moss, showing large catchment with seven internal ones.

with the National Institute of Agricultural Engineering, however, a suitable technique has been developed and the recording unit has been calibrated by them. Field tests of the equipment are currently in progress before the next stage of the work begins.

The establishment of the seven small catchments has involved the cutting of a considerable length of open drainage channel, thus enabling stages (2) and (3) to be accomplished over the same three year period by simultaneous recording at the main metering station of the whole catchment and at the seven internal ones. Some indications of the effect of additional drainage on the discharge characteristics from the catchment are already evident, but more data and considerable further analysis of existing data is still required.

An outline of the results for the first characterisation period has been published and an abstract of the findings is shown below.

Run-off as a percentage of rainfall for 1960 *and* 1961

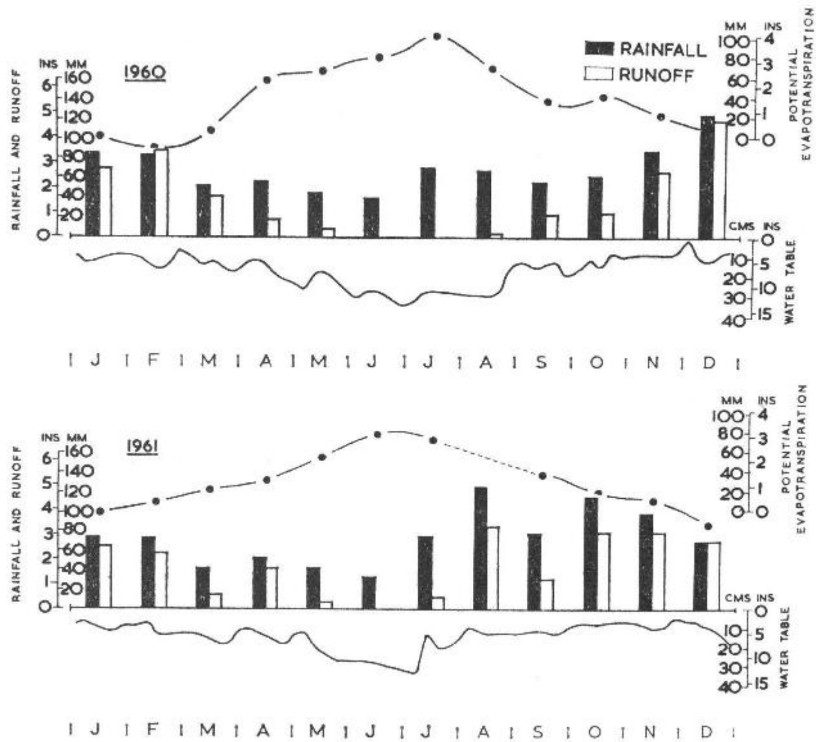
	J	F	M	A	M	J	J	A	S	O	N	D
1960	83·2	88·9	80·9	34·1	20·6	0·6	1·1	7·0	41·7	40·2	77·2	95·7
1961	87·2	77·5	35·5	79·4	16·5	1·5	17·2	66·9	38·4	67·9	80·9	101·1

There is no consistent relationship between rainfall and run-off without reference to the season of the year. High percentages of precipitation recovery occur in December, January, and February: low values occur in June in both years and also in July 1960 when run-off was only 1% of a total rainfall of 2·8 inches.

The relationships among monthly rainfall, run-off, potential evapotranspiration and water table height are shown in Fig. 3.

Run-off varies with all these factors. In both years the June run-off is considerably less than 0·1 inches of rainfall. Very low values are also recorded for July and August 1960 despite comparatively high rainfall (2·8 and 2·7 inches respectively) in these months, an effect resulting from the previous low level of the water table, a high level of evapotranspiration and the occurrence of rainfall as light intermittent showers. In winter, there are some anomalies which are attributed partly to the difficulty of accurately recording precipitation in the form of snow when drifting occurs, and partly to the delayed release of water due to low temperatures.

Further analysis of the data is continuing, to enable precise relationships to be established over short periods among the various parameters. Although no replication of treatments is possible, a detailed description of the performance of the catchment prior to



RAINFALL, RUNOFF, EVAPOTRANSPIRATION AND GROUND WATER TABLE RELATIONSHIPS

FIG. 3.

treatment will provide a basis against which treatment effects can be examined and compared. With a knowledge of the hydrological phenomena and an understanding of the mechanisms involved, it is intended ultimately to study the nutrient cycles associated with grazing systems from the extensive form of hill use to more productive and intensive alternative systems on the same soil type.

(Publication 94.)

Moisture Characteristics of Hill Soils (I.A.N., J.A.R., I.S.P. and G.L.).

The proposed study of the behaviour of different species in relation to soil moisture, mentioned in the last report, is being carried out by Dr. Rogers (Botany Department). A co-operative study on the moisture characteristics of different hill soils and the seasonal fluctuations in moisture status is also in progress (see Botanical Studies).

INTAKE STUDIES ON HILL PASTURE

AN important part of the Organisation's work is the elucidation of the processes of animal production from hill land. Studies of the grazing animal—grazed pasture relationship are fundamental to an understanding of the factors which influence animal production from hill pastures. Of particular importance are studies of the nutritional aspects of these relationships

For this work, means of measuring the nutrient intake of grazing sheep are required. A great deal of work in the last few years has been carried out both in the United Kingdom and overseas on the development of intake measurement techniques. The accuracy of measurement attainable still leaves something to be desired, but since hill pastures and management systems present their own peculiar problems in intake measurement, it was thought desirable, early in 1961, to initiate work in this field.

Annual Cycle of Nutrient Intake (J.E., J.S.B. and A.C.)

As a first step, it was decided that an attempt should be made to document the annual cycle of nutrient intake of the sheep on one of the hefts at Sourhope. This kind of study has the merit that differences in intake can be expected to vary quite widely as between winter and summer and techniques can be assessed within this framework.

It was hoped that a study of the seasonal nutritional pattern would pin-point those periods in which nutrition is tending to limit individual animal performance, and provide information on the need for, the timing of, and possible nature of any required supplement. A knowledge of the levels of nutrition which sheep obtain on the hill would be useful in relating to hill conditions the results of more closely controlled experimentation and would be of value in coming to decisions on levels of nutrition to adopt in future experiments. It was also hoped that a contribution could be made to our understanding of the factors controlling intake under grazing conditions on the hill.

The intake of grazing animals is calculated from a knowledge of faeces dry matter outputs and the feed/faeces ratio (which is dependent on the digestibility of the intake). Faeces outputs can be measured either by total faeces collections using harnesses and bags, or by the use of an inert marker substance such as chromium sesquioxide which is fed in known daily quantities.

In choosing the method of faeces output measurement there are characteristics of hill pastures and the management system which are of some importance. The management system on the experimental heft is free range and the sheep show a diurnal pattern of movement, downwards from the hilltops in the morning, and upwards again in the evening. This diurnal movement occurs against a markedly variable vegetational background and might therefore be considered to have some nutritional significance. The aim must therefore be to interfere as little as possible with the natural 'rake' of the sheep. This consideration eliminates the possibility of using marker substances which require a preliminary dosing period of some days prior to faeces output measurement, and would probably require twice daily gathering of the sheep for dosing and faeces sampling when the measurements were being made. Very much less interference is introduced by total faecal collections, using harnesses and bags. The sheep are penned near the bottom of the hill once a day on their downward journey in the morning, and this procedure has in no way interfered with their normal grazing behaviour. The decision to use harnesses and bags, in the absence of a satisfactory means of separating faeces and urine in female grazing sheep, has required that wether sheep be used in this work.

The measurement of the digestibility of the intake in most recently published work has been done by faecal index methods, in which the digestibility of the grazed herbage is estimated from a constituent of the faeces, usually nitrogen. Regression equations relating faeces nitrogen concentrations and digestibility are obtained from digestibility trials on herbage derived from the herbage types under study. The greatest precision is generally obtained when the regressions are derived from a single growth of herbage from one pasture type. Bearing in mind that relationships to be of any value in intake studies on hill pastures would have to be applicable to, and therefore derived from, a fairly wide range of hill pasture types, the prospect of obtaining sufficiently precise relationships was not encouraging. For this reason, and because of the necessity of extending intake studies to mixed grass and heather hills in the future, it was decided that it would be worthwhile to begin the current study by using an internal plant indicator ratio method. For various reasons lignin was chosen.

In ratio methods, the digestibility of the intake is calculated from the ratio of the indigestible indicator in an 'as-grazed' herbage sample to that in the faeces. Two major problems arise. Firstly, there is the difficulty of obtaining a satisfactory 'as-grazed' sample, and an attempt has been made to solve this problem through the use of oesophageally fistulated sheep. The second problem arises out of the possible partial digestibility of the indicator substance.

A series of digestibility trials was begun in 1962 with the combined objectives of looking at the question of the partial digestibility of lignin, of assessing the possibility of deriving satisfactory faeces—N digestibility regressions, and of evaluating Owen's 'dissolved faecal fraction' method of estimating intake. It is recognised that it is impossible to cut hill herbage identical to that eaten by sheep. The available herbage on the hill at any one time is composed of uneaten material accumulated from previous seasons' growth and uneaten current season's growth. Areas from which herbage is to be cut for digestibility trials are therefore pre-trimmed and cut, as far as possible, from herbage grown in the previous 4-6 weeks. The low yields and unevenness of the terrain make the collection of digestibility study material laborious and time-consuming, and it is generally only possible to gather enough herbage for two sheep per digestibility trial.

Ten wether lambs were retained from the 1960 lamb crop and have been run continuously with the ewe stock on the Gairs heft at Sourhope ever since. Once a month, for three consecutive days, total daily faeces collections have been made since January 1961. Prior to, and during each collection period the position of each grazing wether is recorded every half-hour from dawn to dusk, and from an analysis of these records and their relationship to the various hill pasture types on the heft, decisions are made as to the areas from which 'as-grazed' herbage samples are to be taken. These samples are collected by means of oesophageal-fistulated sheep and also by a hand sampling technique.

It is possible to calculate digestibility values using a faecal index technique, by lignin ratio using both hand and oesophageal samples, and on the same samples using the *in vitro* digestibility procedure developed at the Grassland Research Station, Hurley.

Some 50 digestibility trials relating to a range of hill pasture types have been completed. Regression equations relating faeces N contents to D.M. digestibility have a seasonal bias and the calculation of seasonal regressions has considerably improved the accuracy obtainable.

Digestibility values calculated by the faecal index method, to the extent to which this is currently possible, and those estimated by both lignin ratio and the *in vitro* procedure on the hand taken samples show reasonably good agreement. The samples collected by the oesophageally fistulated sheep have *in vitro* digestibility values significantly lower, particularly in May and June. This is probably a function of the way in which these animals have to be used on the hill, and since, in indoor trials, the quantity of herbage extruded through the cannula has varied from 40%-70% of the herbage ingested, it is likely that ingested and extruded samples also vary in quality. These questions have been examined in trials recently completed, but for which analyses are not yet available.

Pending the completion of the digestibility trial programme any conclusions must be tentative. It appears that the digestibility of the intake on the hill varies from just below 50% in January-February and rises to around 73-74% in May-June. Intakes of digested energy rise from around 125-130 kcals/per $Kg.^{0\cdot73}$ to about 275-280 kcals/per$Kg.^{0\cdot73}$ bodyweight.

Faeces outputs remain relatively constant throughout the year when correction is made for differences in body size. If this tendency is confirmed it would indicate that intake is controlled, under the conditions of this investigation, by the digestibility of the ingested herbage the year round. A consideration of the implications of this finding is, however, thought to be premature at this point in time.

(Publication 79.)

Digestibility Assessments of Hill Pasture Species (J.S.B., J.E., A.C.)

The Botany Department has been studying the nature of vegetational variation in hill pastures and a classification of the bent-fescue grasslands has been proposed. Little however, is known about the nutritional significance of the various hill pasture types. Such information is necessary since vegetational change is only of consequence in terms of animal production to the extent to which it is reflected in the quantity and/or quality of the herbage eaten by the grazing animal.

Studies of the digestibility of the economically important hill species are of interest in this context and small plot trials have been started with a view to investigating the variations in the digestibility of five hill species under three management treatments during the grazing season, using the *in vitro* digestibility procedure.

Hill sheep select their winter diet from herbage conserved *in situ*, and this fund of conserved herbage is depleted as the winter advances by grazing and by plant senescence. Plant senescence results in both losses of dry matter and in a lowering of the digestibility of the available dry matter. An attempt is being made to measure these sources of loss in a number of hill species in another small plot trial, again using the *in vitro* digestibility procedure.

The intention is not to extrapolate the findings of these investigations to hill pasture types, but rather to use the information as a background to an investigation of the problem of hill pasture evaluation which it is hoped to begin in 1964, based on intake measurement.

MANAGEMENT STUDIES

Hill Pasture Upgrading Study—Lephinmore (I.A.N., I.S.P. and D.C.C.)

THE objective of this study is the creation of a system of hill pasture use which incorporates the idea of active vegetational control and which is operated at a higher level of productivity than in normal practice. This will provide useful data for more critical research on various aspects of a pasture system which is theoretically superior to that previously operated on the same area. The technique of improvement is based on the following four principles:—

1. Stocking rate must be high enough to initiate plant successions on a comparatively short time scale.
2. To achieve the soil's optimum potential to produce pasture at a given fertility level, there must be a capacity to manipulate grazing to initiate and control plant successions of the most desirable kind. This involves the ability to apply periods of grazing and periods of rest.
3. A rapid rise in stocking rate without detriment to livestock requires (on this herbage background) pasture conversion by reseeding or top dressing on a proportion of the area.
4. The uniform application of fertiliser or reseeding over a large area of hill is inefficient because of soil variability and impracticable for economic reasons. It may also lead to grazing concentration on a part of the hill. These problems can be mitigated by the selective application of treatments on small scattered areas.

The experimental area rises from the downfall between two forestry plantations on Mid Hill, and connects with the grazings above. Several phases are envisaged in the scheme to provide ultimately two or three enclosures of approximately 100 acres each, in addition to the larger area of untreated hill. The first phase involving about 80 acres was commenced in 1957 and the second, incorporating 100 acres, was begun in 1963 by fencing a contiguous area above. These enclosures, and perhaps one other will provide the basic units for the control of grazing.

In the first enclosure, 14 acres or approximately 18% of the whole were selected for upgrading by direct fertiliser application or reseeding according to the condition of the selected areas. Areas for improvement were chosen so as to form an 'improvement mosaic' distributed throughout the enclosure. This procedure encourages livestock to range widely. It also enables soil types to be selected with the greatest potential for pasture growth, combined with a suitable distribution in relation to shelter and proximity to a variety of natural plant communities.

Cultivations were employed only where necessary and in all cases they were confined to surface treatment. Peat areas received no cultivation. Lime and fertiliser treatment was based on soil analysis and varied accordingly. Several different seeds mixtures were sown, but the components regarded as most important were white clover and red fescue (S.59). Red fescue has proved particularly successful for this kind of work as it is highly competitive when closely grazed; it does not require high fertility and it persists despite considerable management abuse. Its capacity to withstand heavy and continuous grazing has been a particularly valuable attribute in this experiment owing to the marked tendency of stock to graze heavily on the improved areas.

It is intended to apply similar treatments to the second phase. Owing to the existence of the first enclosure next to it, there will be considerably less difficulty in arranging grazing and rest periods than in the case of the first, when the unrestricted hill offered the only alternative grazing.

The objectives of the scheme have been attained so far with considerable success. On the first enclosure the intensity of sheep grazing has been increased tenfold, in addition to heavy cattle stocking which was formerly negligible. Taking the hill as a whole the ewe flock has been increased by 40% since 1957, an increase from 200 to 280 Blackface sheep. There has been no attempt to use the enclosures to develop a separate enterprise, in fact the essential feature of the technique is that improved areas should be used for the benefit of the hill as a whole and integrated with it in management to facilitate grazing control. Costs and returns have not yet been fully analysed but the indications are encouraging.

After six years the experimental area is beginning to show marked changes in the vegetation and offering some valuable opportunities for critical studies on components of the system. Such studies are now to be developed.

Controlled Grazing (J.N.P.)

In 1954, the Park Law heft of 184 acres at Sourhope was divided into two similar areas for the purpose of comparing a system of controlled grazing with traditional free range grazing management. Until 1962, the facility for grazing control was provided by fencing off about 25% of the control grazed area, and in practice, controlled grazing consisted of reserving this enclosure for use during tupping and lambing and to provide a change of diet for ewes and lambs in summer. Cattle grazing in summer only is applied equally to each grazing system. Using a New Zealand type of permanent electric fence the controlled grazed area was further divided in 1961 to give an additional three enclosures. With this increased opportunity for grazing control the system now adopted is based on set stocking of the enclosures with ewes and lambs from lambing until weaning, with rotation of cattle through the enclosures as required to remove surplus vegetation. After weaning the ewes are run as one flock and rotated through the enclosures at intervals. This permits each enclosure to be rested for periods during the autumn. The free grazed flock continues to be managed under the traditional system.

These two management systems are being compared against a background of increasing sheep grazing intensity. Since 1956, sheep numbers have been increased by 85% and the stocking rate is now 0·7 acres per sheep—about double that of the rest of the farm. Allowing for variation due to season, which is similar to that of other flocks on the farm, there is no evidence that increased stocking rates have been detrimental to the level of individual ewe performance.

Skeletal measurements show the control grazed sheep to be larger animals and their live-weights have become consistently greater throughout the year. This is being reflected in greater production from the control grazed flock.

The study is continuing.

Wintering of Hill Ewes (J.N.P.)

From the point of view of improving the productive capacity of certain hill swards there may be advantages in removing sheep from their grazing during winter and early spring. This raises problems of sheep management during this period and the relative merits of possible alternatives require investigation.

In the winter of 1962-63 the production and performance of 24 North Country hill ewes wintered indoors from mid-January until after lambing in April was compared with a similar group wintered on their hill grazing. Each group consisted of 12 old ewes and 12 young ewes. Feeding of the indoor group consisted of 2·5 lb. of medium quality hay plus 1 oz. of White Fish Meal per head per day. The hill group consumed 96 lb. of hay per head plus 28 lb. of concentrates. Due to the abnormally severe winter this quantity of feed consumed by the hill group was very much above average; in a more normal winter, this would be about 32 lb. of hay per head. Originally it was intended to winter a third group in a confined area outdoors on the same ration as those indoors. Unfortunately, the severe snowstorms obliterated the fences and this part of the experiment had to be abandoned.

Each group of ewes had similar average live-weights in November 1962 and again at the beginning of the study, but at the pre-lambing weighing in early April the indoor ewes averaged 11 lb. more than the hill group. However, ewe live-weights were again similar in June but at weaning time in August the hill group were slightly (2 lb.) heavier.

There were no abortions in the indoor group, but two abortions occurred in the hill flock. However, both groups lost two lambs at birth and five between birth and weaning. Thus there was little difference in lamb survival and mortality.

The average live-weights of single and twin lambs are presented in the following table.

Average Live-weights of Lambs

Group	Birth lb.	Marking lb.	Weaning lb.
Indoor Single	9·4	27·5	55·1
Hill Singles	7·7	24·1	48·7
Difference	1·7	3·4	6·4
Indoor Twins	8·5	21·6	44·7
Hill Twins	7·1	19·4	44·2
Difference	1·4	2·2	0·5

Immediately after lambing the indoor ewes with single lambs were returned to the same hill grazing as the hill group. Ewes with twin lambs from both groups were grazed on reseeded pasture until mid June; this probably accounts for the similar live-weights of these lambs at marking and weaning.

The average production of weaned lamb per ewe mated was 44·3 lb. from the indoor group and 39·3 lb. from the hill group, a difference of 5·0 lb. per ewe.

Ewe Reactions to Grazing Management and its Effect on Lamb Growth (J.N.P.)

This experiment was designed as a pilot study under low ground conditions, to investigate certain aspects of grazing control prior to the development of future work involving sheep on hill pasture with controlled access to improved grassland.

The study was made at Glensaugh during 1963, using 44 Blackface ewes and their Greyfaced lambs. The treatments were:—

a. Ewes and lambs set stocked and grazed in four plots of 0·8 acres each.

b. Ewes and lambs grazed as one flock and rotated twice weekly through four plots similar to (a).

c. Ewes and lambs allowed free range.

All plots were within the same field which had not been sheep grazed since ploughing, but all ewes and lambs were given anthelminthic treatment to further reduce any effect due to helminthiasis.

Blood samples were taken periodically from the ewes and analysed by the Glasgow University Veterinary Hospital. A significant fall in blood calcium and magnesium took place in all groups within 24 hours of being put into their experimental plots. Thereafter, the set stocked and free range ewes made a steady recovery, but movement of the rotation flock between plots produced variations in the blood content of these two constituents.

No significant differences were found in average ewe live-weights between treatments at any time during the study, but considerable differences in lamb growth rates emerged between treatments.

Statistical analysis of live-weight of twin lambs showed that significantly greater gains were made by the set stocked and free range lambs. Although the set stocked lambs made the greatest gain this was not significantly greater than that of the free range group. Similar differences in live-weight occurred with single lambs but these were not significant. However, only 4 or 5 single lambs per treatment were available for comparison.

Herbage samples were taken to estimate quantities available to the sheep and also for chemical analysis. These analyses are not yet complete but the contents of calcium and magnesium were similar in the herbage taken from each grazing treatment.

It is intended to repeat this study in 1964.

OTHER STUDIES

Response of Surface Seeded Pasture to Applied Nutrients (I.A.N. and I.S.P.)

AT the lower end of the fertility scale there are a variety of problems of pasture conversion and maintenance which it is proposed to investigate . There is, however, very little critical data on the minimal requirements for major nutrients and the importance of trace elements for surface seeding. Some information on the responses to these nutrients is a necessary preliminary to further work. A series of experiments has therefore been planned to cover a variety of soil conditions with the aim initially of studying responses during the establishment period. The first experiment was laid down at Lephinmore in 1963.

Genetic Selection for Milk Yield in Cheviot Ewes (J.N.P.)

A selection experiment at Sourhope in collaboration with the Animal Breeding Research Organisation is designed to study the response of the South Country Cheviot ewe to genetic selection for milk yield under hill conditions. In 1954, the sheep stock of 180 ewes plus 50 hoggets on Auchope hill was divided equally into a selection and a control line, both flocks being grazed together. Four tupping groups were used in each line, there being approximately 23 ewes to each ram. One ram lamb was selected from each sire group and used in the next group in a cyclical fashion to reduce in-breeding.

Selection was on the basis of live-weight gain of single born ram lambs up to 8 weeks of age, the first rams being selected in 1955. By 1959, the experiment had run as planned for four years and no consistent difference had yet been demonstrated between the selection and control lines. It appeared from preliminary analysis of results that under the environmental conditions, the heritability of milk production was fairly low.

In order to improve the efficiency of selection more emphasis was placed on milk production as a maternal character. To this end, selection was based on the ewe's average performance in three seasons. Only very small numbers of such ram lambs were available within the selection line of 90 ewes. To offset this, the scope of selection was increased to cover all ewes at Sourhope. Rams for the control line were similarly selected.

The results in 1960 and 1961 gave reason for optimism but results for 1962 did not confirm this, the control line being superior. Part of this may be due to the use of a ram from the selection line being used in the control flock and part possibly due to differential feeding of the two flocks in the spring of that year. However, 1963 results were favourable and the overall effect suggests that some slight degree of success has been achieved in improving 8 week weight. The birth weight of single and twin lambs and the weaning weights of singles also suggest a trend. A relative decline in fleece weights in the selection line may also be significant. However, all these effects so far achieved are slight.

Daughter-dam correlations are about 30%, but the heritability based on sire progeny groups is, however, effectively zero. Ewes tend to have successive lambs with similar 8 week weights and to produce offspring which have similar 8 week weights to themselves. Under the conditions of the study the 8 week character is essentially a maternal character.

Further modifications in the method of selection are being made in 1963 when mass selection of ram lambs from the selection line will be used. Ram lambs from the control line will continue to be selected as in the past and used in a cyclical fashion within the existing breeding groups.

Progeny testing of rams to test the efficiency of the selection method is being undertaken in 1963.

The Effects of Different Wool Staple Length Remaining after Shearing (J.N.P.)

At shearing 1961, half the Cheviot ewes and hoggs of the Rigg heft at Sourhope were shorn bare. This was done by machine so as to leave a minimum length of wool staple. The remainder were shorn by hand so that approximately 0·5 in. of wool staple remained. Sampling the two groups six weeks later to record wool growth showed no significant difference between treatments. Since 1961, the trial has been continued, the sheep receiving the same shearing treatment each year.

In 1962 the longer staple group produced 0·6 lb. more wool per head than the bare sheared group. This difference was statistically significant, but again there was no significant difference in wool growth during the six week period following shearing.

1963 results were again in favour of the longer staple group, but by only 0·26 lb. per head which was not statistically significant. However, it is possible that this result was influenced by the severe winter storms of 1962-63, as in 1963 average fleece weights were reduced in both treatment groups. It is noteworthy that before shearing in 1963, 35·7% of the bare shorn group wholly or partly cast their fleeces, compared with only 6·6% of the other group.

Winter Coats for Hill Sheep (J.N.P.)

Recent reports suggest that the production and performance of hill sheep can be improved by providing them with 'protective clothing' during winter. This practice is not new and during the successive winters of 1954-55 and 1956-57 trials were made at Sourhope and Glensaugh to assess the effects of this treatment using Blackface hoggs. The coats consisted of jute sacking sheets which were fitted to the hoggs so that they extended from neck to tail and reached well down the flanks. In each year the sheets were fitted in mid-November and removed early in April. Similar groups of hoggs without sheets were maintained under identical conditions, to act as controls.

The Sourhope hoggs were wintered on an exposed hill with little natural shelter at an altitude range of 1000-2000 feet. They were given no supplementary feeding except hay during periods of snow cover. At Glensaugh, the hoggs were wintered on reseeded pasture at an altitude of 600 feet and were given supplementary feeding. The trial period covered winters of different severity. Adverse conditions prevailed in 1954-55, but the winter of 1956-57 was followed by an early spring.

As judged by average live-weights and fleece weights, there was no evidence that any benefit was derived from this form of protection under the experimental conditions.

PUBLICATIONS

(*Reprints not available)

58. ARMSTRONG, R. H. and CAMERON, A. E., 1961. Further studies of hexoestrol implantation of Blackface wether lambs. (*Anim. Prod.*, **3**, 295-300).

The implantation of up to 15 mg. of hexoestrol in Blackface wether lambs at weaning resulted in a significant increase in live-weight gain over untreated lambs in the subsequent fattening period. Twenty mg. hexoestrol failed to give a response superior to that obtained with 15 mg., nor was there any significant advantage in substituting three 5 mg. tablets for a single 15 mg. tablet. In neither of two successive years was overall gain in live-weight significantly increased by implanting part of the hexoestrol dose prior to weaning. Each group of lambs receiving hexoestrol showed an increased average carcass weight.

59. DONEY, J. M. and MUNRO, JOAN, 1962. The effect of suckling, management and season on sheep milk production as estimated by lamb growth. (*Anim. Prod.*, **4**, 215-220).

Mean daily live-weight gain of lambs to marking was used to estimate the milk production of their dams. Flock records over a number of years showed that ewes rearing twins produced more milk than those with singles in all environments. It was found that the difference between single and twin rearing ewes increased with the available feed. Twin lambs, ewed as singles, grew at the same rate as single born lambs ewed in the same environment. It was concluded that the milk yield of the ewe was not normally a limited factor in the growth of a single lamb under conditions pertaining to the hill farm of Glensaugh. These conclusions were confirmed by a small scale experiment involving the artificial rearing of one member of 27 twin pairs.

60. DONEY, J. M. and SMITH, W. F., 1962. Multiple medullae in wool fibres. (*Nature Lond.*, **195**, 723).

An unusual form of fibre medullation found in wool samples from Blackface sheep at Lephinmore and Glensaugh

is described. Double medullae were found in both fine wool and coarse hair fractions of the fleece.

61. HAMILTON, W. J. * Observations on the sheep stock of Hirta, St. Kilda, 1961. (Unpublished report.)

62. KING, J., 1962. The *Festuca/Agrostis* grassland complex in South-East Scotland. (*J. Ecol.*, **50**, 321-355).

The complex of biotic *Festuca/Agrostis* grasslands and grass-heaths in a part of the Cheviot Hills of south-east Scotland has been analysed and described in relation to the environment. The chief factors contributing to environmental variation were soil base status, soil moisture regime, grazing pressure and the effects of selective grazing among species. The soil data were used as a basis for an axis of environmental variation along which the stands were ordinated using their floristic characteristics for this purpose. A series of *Nardus*-dominant communities were found derived from the *Festuca/Agrostis* communities as a result of selective sheep-grazing, and floristically similar to the parent communities of which they could be regarded as *Nardus*-rich variants.

63. MUNRO, JOAN, 1962. A study of the milk yield of three strains of Scottish Blackface ewes in two environments. (*Anim. Prod.*, **4**, 203-213).

Milk yields of Lewis, Lanark and Newton Stewart strains were recorded over periods of eight weeks on reseeded and hill pasture. There were no differences amongst strains within one environment but significant differences between the environments in effect on yield in all three strains.

64. MUNRO, JOAN, 1962. The use of natural shelter by hill sheep. (*Anim. Prod.*, **4**, 343-349).

Observations on a small flock of Blackface ewes has shown that sheltering behaviour was largely dependent on wind speed exceeding 24 m.p.h. Sheltering increased markedly at temperatures below freezing. Above freezing there was very little effect unless the temperature fell rapidly by more than 4° F. No relationship could be found between sheltering behaviour and any other climatic factors which included rain, relative humidity, wind direction and season of year. It was concluded that the sensitivity of sheep to exposure is influenced more by wind speed than by any other climatic factor.

65. DUCKWORTH, J., BENZIE, D., CRESSWELL, E., HILL, R. and DALGARNO, A. C. with ROBINSON, J. F. and ROBSON, H. W., 1961. * Dental malocclusion and rickets in sheep. (*Res. Vet. Sci.*, **2**, 375-380).

66. ROBINSON, J. F., CURRIE, D. C. and PEART, J. N., 1961. Feeding hill ewes. (*Trans. Highl. Agric. Soc. Scot.*, **6**, 31-46).

For six successive winters large scale field trials were undertaken at Glensaugh, Lephinmore and Sourhope to assess the effects of supplementary feeding hill ewes during late pregnancy. No worthwhile response to feeding was obtained at Sourhope, but at Glensaugh and Lephinmore a satisfactory response to feeding was obtained in terms of lamb survival. On both these farms lamb numbers were increased by about 10% at weaning. However, there was little difference in wool production and increases in average lamb weaning weights were not more than 3 lb. in any one season. Variation occurred between seasons, age of ewe, and single and twin bearing ewes and these are discussed.

67. The late DUCKWORTH, J., HILL, R., BENZIE, D. and DALGARNO, A. C. in collaboration with ROBINSON, J. F., 1962. * Studies of the dentition of sheep. I. Clinical observations from investigations into the shedding of permanent incisor teeth by hill sheep. (*Res. Vet. Sci.*, **3**, 1-17).

68. WANNOP, A. R., 1961. Report on visits to Falkland Islands sheep stations. (Unpublished report.)

69. NICHOLSON, I. A., PATERSON, I. S. and CURRIE, D. C., 1962. Electric fencing for hill land. (*Scot. Agric.*, **42**, 73-76).

The availability of cheaper fencing for hill land has made it possible to consider a much greater degree of grazing control than is practised to-day. The New Zealand electric fence, used on H.F.R.O. farms, has introduced a new conception of fencing on hill land. This is not so much because of the means of wind charging the batteries, but because of the methods adopted to ensure a physical barrier in itself effective in retaining stock during short periods of power failure.

70. HOLDING, A. J. and KING, J., 1963. The effectiveness of indigenous populations of *Rhizobium trifolii* in relation to soil factors. (*Plant and Soil*, **18**, 191-198).

The *Rhizobium* strains nodulating indigenous clover plants

in Scottish hill pastures are predominantly of low effectiveness. The effectiveness of the population from each of the 48 sites examined was positively correlated with soil base status. The correlation was due to an increase in the proportion of the most effective class of *Rhizobium*, the less effective classes individually showing no relationship. The agronomic implications of the findings are discussed.

71. KING, J. and DAVIES, G. E., 1963. The effect of dalapon on the species of hill grassland. (*J. Brit. Grassl. Soc.*, **18,** 52-55).

The effect of dalapon is described on pastures of *Agrostis/Festuca*, *Festuca ovina/Deschampsia flexuosa* and related *Nardus*- or *Molinia*-rich hill grasslands. The results are discussed in relation to the technique of surface sowing and the choice of vegetation types suitable for treatment.

72. HUNTER, R. F., 1962. Hill sheep and their pasture: a study of sheep-grazing in South East-Scotland. (*J. Ecol.* **50,** 651-680).

The grazing preferences of Cheviot sheep were studied on a 251 acre hill pasture stocked at 1·76 acres per ewe or hogget. The sheep showed marked preferences among the nine sward types comprising the pasture and these preferences varied seasonally.

Grazing intensity was more clearly related to CaO and crude fibre content than to any other factor. The observed disproportion between grazing intensity, the yield of herbage dry matter and the faecal return indicated that where sheep alone graze a pasture there is probably a trend towards pasture degeneration.

Two qualitatively different classes of pasture were recognised. The first comprised the bent-fescue and bracken-infested swards, the second the *Molinia*, *Nardus*, heather and draw-moss swards and the relationship of the sheep towards these two classes was qualitatively different. The first class, described as the mull swards, were intensively grazed and were more heavily grazed in summer than in winter, the converse being true for the second class described as the mor swards.

The relationship between these observations and the ecology, carrying capacity and improved utilization of hill pastures is discussed.

73. GUNN, R. G. and ROBINSON, J. F., 1963. Lamb mortality in Scottish hill flocks. (*Anim. Prod.*, **5,** 67-76).

Records on lamb mortality from birth to marking are summarised for four seasons on each of the Organisation's three farms. The effects of level of ewe production, multiplicity, sex, weight at birth, age of ewe, and type of management are studied on the degree of mortality. Season and farm interactions are discussed.

74. DONEY, J. M., 1963. The effects of exposure in Blackface sheep with particular reference to the role of the fleece. (*J. Agric. Sci.*, **60**, 267-273).

The effect of shelter from winter conditions was studied in terms of body weight change of dry sheep individually fed a maintenance ration. Over two winters the exposed groups lost weight relative to the sheltered group. Attempts to relate individual differences within treatments to fleece type were not conclusive. A method of measuring the insulation provided by the fleece in dry environmental conditions was developed. It was shown that exposure to moderate winds could increase the heat loss from the fleece covered areas by between three and five times.

75. PEART, J. N., 1963. Increased production from hill pastures. Sourhope trials with cattle and sheep. (*Scot. Agric.*, **42**, 147-151).

Following the introduction of cattle to two hill sheep grazings, total livestock production increased by 182% and 73% respectively. Most of these increases were due to the contribution by the cattle, but sheep production from the existing flocks increased by 37% and 18%. Production from a similar area grazed by sheep only remained virtually unchanged during the experimental period.

The comparative stability of sheep production from the sheep only grazing and the extent of the improvement shown by sheep on the cattle grazed areas suggest that at present stocking rates sheep are unable to exploit the potential of their hill grazings, implying that within the limits imposed by their environment the sheep are already producing near to their inherent capacity. Hence, in general, on many hill farms increased production is dependent on the output from additional grazing animals rather than from improvement within existing stocks. The significance of this is discussed in relation to grazing management under hill conditions.

76. KING, J., 1961. Ecotypic differentiation in *Trifolium repens*. (*Plant and Soil*, **18,** 221-224).

The indigenous white clover (*Trifolium repens*) of *Festuca-Agrostis* pastures in South Scotland is shown to be characteristically small leaved, prostrate and of small diameter in comparison with the cultivar S.184. Within the indigenous type, leaflet size was found to be differentiated in relation to soil base status. This was attributed to the effect of grazing intensity which in these pastures varied with soil base status.

77. GRANT, SHEILA A., HUNTER, R. F. and CROSS, C., 1963. The effects of muirburning Molinia-dominant communities. (*J. Brit. Grassl. Soc.*, **18,** 249-257).

A number of experiments investigating the effects of muirburning *Molinia*-dominant communities are described. The weight of burnable litter was assessed and its chemical composition and insulating properties determined. The chemical composition of *Molinia* leaves on burned and unburned plots was determined. Data was also collected on the total yield, the proportion of this yield due to *Molinia* versus other species and the flowering vigour of *Molinia* growing on burned, unburned, raked and manured plots. Changes in botanical composition of the sward as affected by different frequencies of burning are also reported. The agronomic value of muirburn is discussed and the conclusion is reached that the practice of muirburn is not to be recommended unless followed by close grazing.

78. HUNTER, R. F. and DAVIES, G. E., 1963. The effect of method of rearing on the social behaviour of Scottish Blackface hoggets. (*Anim. Prod.*, **5,** 183-194).

Four groups of Scottish Blackface ewe lambs were reared in the period 11-52 weeks old under different regimes. The regimes differed in the age of the lambs at which they were separated from their dams and whether having been separated they were together in a field and/or penned together in a sheep shed.

These regimes caused differences in social behaviour among the four groups and also resulted in the groups adopting different parts (home ranges) of an enclosed 350 acre hill pasture. The various home ranges within the pasture are dissimilar environments and it is argued that home range and method-of-rearing effects will be confounded making statistical comparisons between the different rearing treatments impossible.

79. HUNTER, R. F. and EADIE, J., 1962. Botanical research at the Hill Farming Research Organisation. (*Proc. European Conf. for Forage Production on Natural Grassland in Mountain Regions*).

The hill pasture system of the U.K. has no parallel in any other country. It is both extensive and primitive and our research is aimed at modifying rather than supplanting it. Such a research policy leads to a study of the system as it is in order to find the factors limiting production and the point at which capital may most profitably be used in improvement.

80. DONEY, J. M., 1963. The fleece of the Scottish Blackface sheep. III. The relative importance of the fleece components. (*J. Agric. Sci.*, **61**, 45-53).

The relative importance of variation in the components of wool production to variation in wool production itself was estimated by two methods of analysis. About 30% of the attributable variation in total fleece weight was found to be due to variation in surface area and 70% was due to differences in wool production per unit area of skin. Between 50 and 60% of variation amongst sheep in the latter character was due to fibre weight and the rest to fibre number. The variation in fibre weight was further partitioned into between 50 and 70% to cross-sectional area and the remainder to length.

81. NICHOLSON, I. A. and HUGHES, ROY, 1963. A method for the characterisation of range-type vegetation. (*J. Range Mgmt.*, **16**, 293-299).

In ecological studies on extensive pasture areas, established methods of vegetational analysis are not always applicable. The method developed at H.F.R.O., and described in this paper, was designed for use in large scale grazing studies on areas having a pronounced vegetational mosaic. The method enables a 'point' map to be drawn from a series of point samples derived from parallel transects, and also provides data from which association amongst species can be determined. Changes both in the floristic make-up of plant communities and in their relative areas can be followed readily over a period of years.

82. HUNTER, R. F. and MILNER, C., 1963. The behaviour of individual, related and groups of South Country Cheviot hill sheep. (*Anim. Behav.*, **11,** 507-513).

Individual members of a flock of 150 South Country Cheviot hill sheep on a hill pasture extending to 251 acres, do not graze the same area of the pasture but each is restricted to a part of the pasture. The distribution of the flock within the pasture is therefore the sum of dissimilar distributions of its individual members. Matrilinearly related sheep tend to graze the same parts of the pasture, the implication of this behaviour being that offspring adopt the grazing area of their dams. The activity of the sheep during the hours of daylight varies seasonally as does the degree to which they flock together.

83. BOYD, J. M., DONEY, J. M., GUNN, R. G. and JEWELL, P. A., 1964. The Soay sheep of the island of Hirta, St. Kilda. A study of a feral population. (*Proc. Zool. Soc.* Lond., **142,** 129-163).

A general introductory paper. The history and origins of the Soay breed are examined. Methods of study are described and details of the present day population, in terms of their numbers, life span, growth rates, behaviour, and habitat, are outlined.

84. DONEY, J. M., 1961. The effects of inbreeding on four families of Peppin Merino. IV. Heterosis and material effects. (*Aust. J. Agric. Res.*, **12,** 362-369).

Inbred ewes were more variable than non-inbred contemporaries in fertility, live-weight and size. Wool production, which was also depressed by inbreeding, showed an increase in variance. It seems that the changes are not direct responses to the excess homozygosity but result from the disturbance to underlying physiological mechanisms. Outcrossing between two inbred lines or between an inbred line and normal flock ewes gave a reversion of the progeny to the level characteristic of the original random bred population.

85. DONEY, J. M., 1962. * Inbreeding in Blackface sheep. (*Anim. Prod.*, **4,** 293 (summary)).

86. DONEY, J. M., 1964. The fleece of the Scottish Blackface sheep. IV. The effects of pregnancy, lactation and nutrition. (*J. Agric. Sci.* **62,** 59-66).

Pre-mating, pregnancy and lactation periods correspond approximately with summer, winter and spring and the effects of the physiological state or of nutrition during these periods are confounded with the natural rhythm of wool growth. Under hill conditions barren ewes produced slightly more wool than in lamb ewes in winter and considerably more in the lactation period. Improved nutrition in winter had no effect on wool growth although it had a marked effect on live-weight maintenance. During lactation, improved nutrition resulted in an increase in wool production. The interaction between nutritional and climatic control of wool growth are discussed in relation to the adaptation of the breed to its environment and the effects of artificial selection for total annual wool growth.

87. DONEY, J. M., 1964. * Genetic effects on feed intake and efficiency of feed utilisation. (*Anim. Prod.*—in press (summary)).

88. DONEY, J. M. and SMITH, W. F., 1964. Modification of fleece development in Blackface sheep by pre- and post-natal nutrition. (*Anim. Prod.*, **6**, 155).

Wool production and fleece structure were studied by fibre analysis in six groups of lambs subjected to different pre- and post-natal levels of nutrition. Samples were taken at 6, 12, 28 and 48 weeks of age. Pre-natal limitation (twin pregnancy) had an effect on the number of secondary follicles active at birth but had no permanent effect. Severe post-natal restriction of intake had a marked effect on the rate of development of the secondary fibre population, on wool production and on the shedding cycle. The effects persisted beyond the period of nutritional limitation but had disappeared by 12 months of age.

89. GRIFFITHS, J. G., 1962. * Observations on the use of natural shelter by sheep according to weather conditions. (*Anim. Prod.*, **4**, 298 (summary)).

90. GUNN, R. G., 1963. * Effects of treatment during first winter on performance of Cheviot ewes. (*Anim. Prod.*, **5**, 224 (summary)).

91. GUNN, R. G., 1964. Levels of first winter feeding in relation to performance of Cheviot hill ewes. I. Body growth and development during treatment period. (*J. Agric. Sci.*, **62,** 99-122).

Over three years, different levels of first winter nutrition were imposed on groups of North and South Country Cheviot ewe hoggs. In 1956-57, three levels, high mid, and low, were fed indoors. In 1957-58, only two levels, high and mid, were fed indoors, with the low level being represented by hill wintering. In 1958-59, two levels were represented by away wintering and hill wintering.

Low plane feeding was designed to simulate average hill wintering, creating a 10% loss in live-weight. Mid plane feeding was designed to maintain live-weight at approximately the same level throughout the winter. High plane feeding was designed to produce a live-weight gain of 15-20% in 1956-57 and the maximum gain possible in 1957-58.

The effects of these treatments on growth and development during the treatment period have been studied, from changes occuring in live-weight and seven live measurements, both on the total treatment groups and also on the heavy and light hoggs within the groups prior to treatment. Both within and between treatment effects were considered in this latter case.

92. GUNN, R. G., 1964. Levels of first winter feeding in relation to performance of Cheviot hill ewes. II. Body growth and development during the summer after treatment, 12-18 months. (*J. Agric. Sci.*, **62,** 123-149).

A continuation of the above. The effects of season on growth subsequent to treatment were considerable. They were, however, strongly influenced by the stage of growth reached by 12 months which in turn was influenced by the relationship between the level of treatment and the stage of growth reached prior to treatment. These season and stage of growth interactions are discussed with regard to their overall effect on the weight, size and conformation of the animal at 18 months of age.

93. NICHOLSON, I. A., 1963. The influence of management practices on the present day vegetational pattern and developmental trends. (Paper read at the *Brit. Ass. for the Adv. of Sci.* as a contribution to a symposium on 'Land use in the Scottish Highlands', Aberdeen, 1963).

94. ROBERTSON, R. A., NICHOLSON, I. A. and HUGHES, ROY, 1963. * Run-off studies on a peat catchment. (Paper presented to the *International Peat Congress*, Leningrad, 1963).

95. KING, J. and NICHOLSON, I. A., 1964. *The grasslands of the forest zone. Contribution to book 'Vegetation of Scotland' edited by Professor Burnett. Oliver and Boyd, Edinburgh.

96. HUNTER, R. F., 1963. Land use in the Scottish Uplands. (Paper read at the *Brit. Ass. for the Adv. of Sci.* as a contribution to a symposium on 'Land use in the Scottish Highlands', Aberdeen, 1963).

The best use of our upland areas is a problem which concerns ecologists and their advice is based on determining the present trends in the upland ecosystem and extrapolating these into the future. The nature of these trends as described at present, is open to some criticism and they require continuing and extended study. In particular the rate of change in the ecosystem has been inadequately studied as valid predictions depend on both accurately describing and accurately timing these trends.

It is doubtful if any except short-term predictions are of value. The future status of the uplands cannot be predicted in the long-term as the prediction must be based on what is unpredictable, technical advances and future social attitude and needs.

97. HUNTER, R. F., 1962. Home range behaviour in hill sheep. (*Brit. Ecol. Soc. Symposium 'Grazing'. Bangor*, 1962—in press).

At intervals throughout one day in each week in the period May-November 1961, the location of the members of a flock of 160 sheep grazing a ring-fenced 350 acre hill pasture was recorded on a vegetation and topographic map of the pasture. The sheep could be individually recognised, their pedigrees and live-weights being known.

The 350 acre pasture was not a common environment for the sheep who split themselves into sub-flocks, composed of families of sheep, the sub-flocks being restricted to parts of the pasture which differed in altitude, aspect and vegetation.

While the possibility cannot be excluded that the differences among the sub-flocks in both lamb and hogget weights was of genetical origin, it is more likely that these differences arise from the home ranges, adopted by the sub-flocks, being different environments.

The relevance of home range behaviour in hill sheep to hill sheep management and to experimental work with hill sheep is discussed.

THESES

'A study of the effect of different levels of winter feeding of North and South Country Cheviot ewe hoggs on their growth, development and subsequent performance'. R. G. GUNN. Thesis presented to the University of Edinburgh for the degree of Doctor of Philosophy. 1962.

'The diet and behaviour of hill sheep'. C. MILNER. Thesis presented to the University of Edinburgh for the degree of Doctor of Philosophy. 1963.

SOME RANGE AND WATERSHED PROBLEMS IN THE UNITED STATES

I. A. NICHOLSON

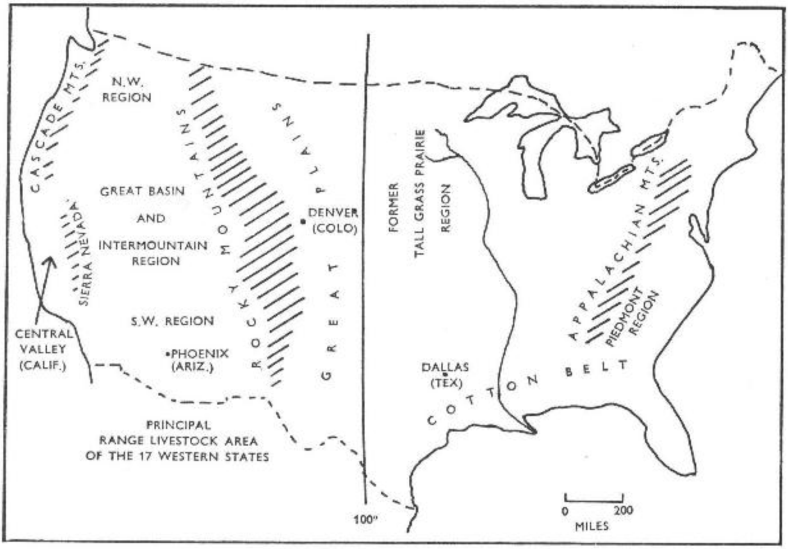
DURING 1963 the writer had the privilege of visiting the United States for the purpose of studying range and watershed problems. This provided only a background knowledge of what is a large and diversified territory and in presenting this article no claim is made to write with authority on land use problems in North America. A review of some salient features, however, may be of interest to those concerned with British upland problems which in certain fundamental respects are essentially the same.

Vegetational Background

The eastern part of the United States was formerly dominated by natural forest: coniferous forest was distributed in the north and south-east while deciduous and mixed woodland extended across the Appalachian Mountains and occupied the region between the northern and southern forests. Though the greater part of this natural woodland has been cleared for agriculture or cut-over and greatly modified, there still remains an extensive area of forest cover. Between the eastern woodlands and the Rocky Mountains, two great belts of natural graslasnd originally extended from the Canadian border southwards to the state of Texas. The tall grass prairies which formed the eastern belt are now mainly under cultivation, but westwards the more arid short grass plains are still grazed. The plains, in fact, represent the eastern extension of the western range whose boundary is marked approximately by the hundredth meridian.

Between the plains and the Pacific Ocean there is a great complex of rugged and mountainous territory. Except on the coast and at higher elevations inland, much of this area receives little rainfall and there is considerable variation in its seasonal distribution. These factors, together with the rapid changes which occur in elevation over short distances, are associated with a remarkable diversity of vegetation.

The western coniferous forests are distributed along the north-west coast and inland at higher elevations. Between the Sierra Nevada and the Rocky Mountains, in the region known as the Great



Basin, desert shrub is widespread and the same general type extends into the south-west where it merges with desert grassland. Other western grasslands include the Pacific bunchgrass vegetation of the north-west and the annual Mediterranean type which occurs in parts of California. The latter are much modified rangelands formed by the replacement of the original native bunchgrass cover through the influence of heavy grazing combined with the introduction of many species from the borders of the Mediterranean.

Though the altitudinal zonation of vegetation is a universal phenomenon, there is in the south-west a particularly interesting and striking sequence of types, associated with increasing precipitation and falling temperatures, from the deserts to the mountain summits. Above the desert plains which bear sparse cover of cactus and other species, desert grassland is distributed between 3000 and 5000 feet. This is followed in altitudinal sequence by 'chaparral' (a term applied to scrubby vegetation with evergreen leaves) and woodland communities of low stature composed of pinyon pine and juniper. These give way to stands of western yellow pine (*Pinus ponderosa*) which occur at about 7000 feet. Above this level there is Douglas fir, and finally the uppermost woodland belt, dominated by spruce, lies between 10,000 and 11,500 feet. With a further increase in elevation the trees are replaced by arctic-alpine vegetation of grasses, sedges and herbs. This altitudinal sequence provides a variety of range and cover types and is indicative of the diversity which may occur in both range and watershed problems in a comparatively small area.

There are about 630 million acres of non-forested pasture and range in the 48 contiguous states and 639 million acres of forest land (1). As a high proportion of this is grazed, there is often no clear distinction between forest and grazing land. Indeed, the grazing of domestic livestock, timber production, water, wildlife and watershed protection are aspects of use which frequently must be considered together in the management of semi-natural areas.

Consequences of malpractice

The destructive and spectacular effects of agriculture in the so-called Dust Bowl area of the southern Great Plains before the war are well known. In the Piedmont region of the east, the destruction of forests in the early days and the former prevalence of continuous cotton growing led similarly to widespread soil degradation. The annual average soil loss under this system has been estimated as 22 tons per acre, while the associated increase in surface run-off resulted in an average water loss equivalent to 10% of rainfall (2). Even as late as 1953 it was estimated that more than three-quarters of the total farm field acreage was eroding faster than the rate of soil formation. The destruction of forests by 'wildfire' has frequently caused devastation by soil erosion on steep slopes, and many cases are on record of disastrous floods in consequence of accelerated run-off from unprotected watersheds.

On the western range the history of mis-use is perhaps less well known. Between 1870 and 1886 cattle numbers in the seventeen western states rose from under eight million to over twenty-one million. It was in this period that the vast cattle enterprises were floated and it was the first period of intensive use. A combination of over-use, drought, severe winters and other factors caused the collapse of the boom between 1886 and 1900 in various parts of the west (3). At about the same time, however, an increase in sheep numbers took place on ranges already seriously depleted. By 1890, for example, there were twenty million sheep in the western states compared with just over five hundred thousand in 1850 (4). The problem was further aggravated by a later boom with the coming of the first world war. In a report of Congress in 1936 it was estimated that the grazing capacity of the western range had been reduced by more than 50% compared with that of its virgin condition.

Deterioration in ranges is represented by the replacement of nutritious and palatable plants, the ingress of brush and reduction of plant cover leading to lower grazing value and to erosion and gulleying in parts. Great strides have been made in the definition of scientific principles for the conservation management of ranges and watersheds, but much remains to be done both in research and in the adoption of non-destructive practices.

THE MANAGEMENT OF WATERSHEDS

A WATERSHED has been defined as (5), '. . . a body of land bounded by a ridge or water divide and below by the level at which water drains from it." In a broad sense, therefore, all land lies within some watershed.

Water is received as precipitation. Some is stored within the watershed as snow, in the soil profile or deep underground, while the balance is lost by evaporation and transpiration, by underground flow or in streams. The water yield, which might be described as the water crop, its quality and timing of release are influenced by many factors such as climate, the geology and soils and the characteristics of the vegetation and its management. The manner of land use is associated with the maintenance of a stable and productive soil and is also linked with various problems of water yield, the suitability of water for fish habitat and the occurrence of flooding and sedimentation at lower levels. Watershed management is therefore concerned with both on-site and off-site effects. As an example of this in Britain the current problem might be cited concerning the effects of hill draining on the quality of the grazings themselves and on the occurrence of floods at lower elevations.

A great deal of research is now being conducted on watershed problems. Work began at the well known Coweeta Hydrologic Laboratory in the southern Appalachians in 1934, though other experimental areas had been established before this date. During the first phase at Coweeta, spanning more than twenty years, the effects of many management procedures ranging from different timber cutting techniques, forest grazing to complete tree removal and farming were studied and documented. This work has provided much valuable information for the guidance of watershed management over large areas of similar land. It has also established a firm basis for the development of more recent basic studies on the factors influencing the water cycle and on the integration of timber production with water resource management. Field laboratories with related objectives have been established on other land categories, for example, in the Rocky Mountains and in the Sierras where problems of snow pack management figure prominently in the programme. In other cases the effects of range management practices are being studied. A feature of special interest in all this work is the emphasis placed in the overall direction on the problems of integrated management of all resources contained by the watershed.

The problem of adequate water supply is becoming acute in many parts of the United States. In some areas, some or all of the water needed is obtained by pumping from deep underground sources, but as the supply is not inexhaustable great emphasis is placed on the manipulation of watersheds to increase the supply for direct consumption, or to replenish the underground reserves. Demand is rising rapidly: in 1954 demands for withdrawal from waterways were about 27% of streamflow, a figure which is expected to rise to 51% in 1980 and to 81% in the year 2000. Although much of the water extracted is eventually returned, a use such as irrigation involves a high 'consumptive loss'. Care must be taken to maintain streamflow sufficient for navigation, for electricity generation and for the maintenance of an acceptable standard of purity. In 1961 a select committe reported to Congress on the problem of national water resources (6) (a report which deserves to be widely read in this country by those concerned with British hill resources) and amongst some far reaching recommendations it stressed the need for further research work on the re-use and the cycling of water, on the relation between cover type and water yield and on the effects of changing the vegetation on the characteristics of the watershed. It has been estimated (6) that opportunities exist for improving water yields on about 15% of the area covered by the seventeen western states. Some indication of the importance of vegetation in this respect is given in the following table.

Present and potential water yield of land supporting contrasting vegetation types

	Range in precipitation (ins.)	Average present water yield (ins.)	Potential increase % of present
Forests in snow pack zone.	20-100	20·0	20·0
Interior Ponderosa pine	20-30	4·0	5·2
Interior Douglas fir	22-35	7·0	14·0
California woodland grass	12-40	7·0	14·0
Arizona chaparral	12-25	1·5	33·0
Semi-arid grass and shrub	5-20	0·4	0

A number of forest types in the high level snow-pack zone offer considerable scope for water yield improvement and controlled release. Studies indicate that this may be done by adopting certain cutting patterns and other management practices which reduce interception and evaporation losses and increase the accumulation of snow.

Where the climate is arid, or in other areas at time of drought, a deep rooted tree cover depletes the soil moisture to a greater depth than more shallow rooted shrub or grassland vegetation. Thus, by changing the vegetation there may be an improvement in water yield. Heavy grazing of rangeland may further restrict rooting depth, but taken too far this leads to a reduction in plant cover, loss of litter and exposure of the surface. Associated with this there is usually a decline in the rate of infiltration causing surface run-off. This may enhance the water yield (7), but soil eroison and sedimentation downstream is usually the result. Though the estimated percentage increase in water yield of some arid types is quite substantial the actual gain is small. In the more arid types therefore the aims of management are usually to achieve optimum efficiency in the on-site use of water for forage production and to control the ingress of useless grazing plants, especially the deeper rooted ones, which may seriously reduce the moisture available for the better forage species.

These examples illustrate the complexity of watershed management and demonstrate the importance of achieving a correct balance in relation to use and capability of the watershed, and of reconciling the often competing requirements in management of the resources to be utilised. Very frequently rangeland is one of these resources.

RANGELAND PROBLEMS

Range in the American sense is described as '. . . naturally vegetated, mostly unfenced lands of low rainfall . . . that are grazed by domestic livestock and game mammals' (4). The term 'range' has a meaning distinct from that of 'pasture.' This is applied to grasslands which are usually fenced in the mid-west and east in areas of abundant rainfall, or to irrigated grasslands in the west which are fertilised and seeded to domesticated forage plants.

A characteristic of rangelands is their relatively low productivity and associated with this is the limited control which can be exercised over the growth and use of forage. The system of production is a semi-natural one, depending on the utilisation of a more or less natural forage background by domestic livestock. The depletion of rangelands in the early days was a natural consequence of this unbalanced situation. The pioneer graziers may have had a basic understanding of livestock management, but they had little or no knowledge of the management requirements to ensure the maintenance of range resources in a productive and stable condition. It is noteworthy that in management of the American range, as in the British upland sheep grazings, basic principles of sound use failed to emerge as a result of early experience in their management. Since an outline of such principles for the management of more intensively used pasture did develop in western Europe, prior to or at the beginning of the scientific era, it is of interest that a corresponding evolution failed to take place on grazings of a more extensive nature. In the former case, however, a combination of favourable soil conditions and the absence of a serious climatic impediment to high production, and often the opportunity to grow crops and grass in alternation, formed a suitable context in which considerable experience of management effects could be accumulated in the span of a single lifetime. In this way the ecological principles underlying management were more readily assimilated into comparatively well-based agronomic practices. On the American range, conditions were relatively unfavourable for the recognition and adoption of such guiding principles of use before the period of intensive scientific effort. As already indicated, bad use led to a reduction of the better species and often to the gradual incursion of shrub or it caused erosion. Even where the grazier had some understanding of how to mitigate these effects, they were often recognised too late to be reversed with available resources. It was not until the ecological studies of Clements (8) on climax vegetation and succession and that of Sampson (9) on rangeland plant successions that a scientific basis for management was established.

Condition and trend of rangeland

Since the pioneer work of the early American ecologists a great volume of research has contributed to an understanding of what constitutes good range management and how this can be achieved. Good range management according to Parker (10) '. . . entails harmonious manipulation of grazing so as to provide for the growth requirements of forage plants, prevent soil deterioration, and allow for sustained maximum animal production.'

For the description of ranges and as a guide to their management, two concepts have been developed, namely 'condition' and 'trend'. These enable the range to be evaluated firstly, with respect to its existing state and secondly, from the viewpoint of its dynamic tendencies, i.e. whether changes taking place in its character and productive capacity are proceeding in a desirable or an undesirable direction.

The expression 'condition' includes two concepts, one short term and the other long term. The former is concerned with the amount of forage present at a given time and thus reflects preceding climatic conditions and in particular rainfall. This evaluation does not take into account the state of the range in other respects and gives no indication of its current status relative to its potential. It is the aim of the long-term or successional approach to do this. In this case each condition class corresponds to a stage of succession which is determined mainly by past grazing use. Thus, condition is related to the idea of climax and in terms of Dyksterhuis' definition (11) it is 'the percentage of the present vegetation which is original vegetation for the site.' There is an alternative though similar procedure which is probably more generally applicable, especially when reference to a former perennial grass climax is impracticable. This aims to relate the present vegetation and general state of the range to a hypothetical optimum which the site is considered capable of supporting under long-term grazing use. In this case many characteristics of the range appear to be given greater weight than in the climax approach, but the condition classes still relate to stages of succession.

Five classes are generally employed in classifying ranges according to condition. These classes are 'excellent', 'good', 'fair', 'poor' and 'depleted'. In terms of carrying capacity on the short grass range of the Great Plains, for example, a range in 'excellent' condition might provide enough grazing for one cow for one month on 2½ acres (12). Lower down the scale, the same range in 'poor' condition might require 10 acres to support one cow for the same period.

It is clear that the two concepts, 'condition' and 'trend,' are closely linked. In practice they assume considerable importance and are widely used. A proper assessment of the long term trend, and the identification of causal factors, is necessary if any needed corrections to management are to be made in time to avoid a progressive decline in range condition.

Burning

Vegetation fires caused by lightning or deliberately by the Indians, occurred periodically before European settlement. 'Wildfire', or uncontrolled, accidental or indiscriminate burning is a constant hazard and great care is now taken to avert it. Controlled burning, however, is a common practice in the management of a number of cover types. Burning may have beneficial or destructive effects according to conditions and owing to the great variety of effects documented by American studies, combined with the differences of opinion where critical data is lacking, it is difficult to generalise on the effects of fire or to summarise them in a short account.

In some range areas fires have been virtually eliminated and the increase in brush is sometimes attributed to this. In the desert grasslands during the last few decades mesquite (*Prosopis* spp.), a tall shrub, has spread extensively on many ranges and though this plant provides some browse, it competes strongly with forage species. Other invaders of the arid grasslands of Arizona and New Mexico are acacias (*Acacia* spp.), cacti (*Opuntia* spp.) and juniper (*Juniperus* spp.). There is considerable controversy as to the true status of grassland. Some writers regard the grasslands as climax in the sense of Clements (13) while others consider them to be sub-climax, held in their present condition by recurrent fires. The absence of periodic fires due to overgrazing which reduces the fuel, is said to be the factor responsible for shrub invasion (14). According to one view on these arid areas; 'shrubs grow where there is not enough rain to grow enough grass to carry fires to kill the shrubs'. Parker and Martin (15), however, consider that the delicate balance between shrub and grass has been upset by a variety of factors associated with range use.

Fire is used in coniferous woodland both in the east and in the west under closely controlled conditions at certain seasons (prescribed burning) to remove the understory vegetation and excess of litter. This is done to encourage the growth of better forage in forest ranges and in timber forests to reduce the amount of inflammable material before sufficient has accumulated to cause complete destruction to the stand in case of accidental fire.

Grazing practices

Over-grazing has had such destructive effects in the history of range use, and the process of upgrading depleted ranges is so slow and expensive, that there is great emphasis on the avoidance of over-use. One therefore got the impression that while the advantages of protection from grazing on non-forested ranges were well appreciated, it was not so clear what positive benefits to the range might be imparted by the act of grazing. On forest ranges, as for example in the pine forests of the south-east, careful management is necessary to avoid damage where the site is also valued for its timber. The needs of the different forest types vary considerably in this respect, but it is recognised that judicious grazing may contribute to good forest management.

Many ranges are used seasonally, for example, the high level Ponderosa pine stands and alpine grazings above the tree line. Various techniques have been devised to encourage desirable trends in ranges used seasonally or throughout the year. The systems aim to achieve the harmonious integration of use with the physiological phases in the growth and development of the component species. Parker (10) defines proper use as '. . . the degree of grazing that will allow the more desirable forage plants to maintain their stand and vigour, prevent undue run-off and erosion and minimise damage to tree reproduction.' The key to the manipulation of plant communities lies in an understanding of the physiological rhythm of individual species and their responses to grazing influence and rest. Parker also states (10) that '. . . complete herbage removal is most injurious after the date when substantial regrowth is impossible but before maturity'. Continuous early spring grazing is also recognised as deleterious (9).

Various systems of deferred and rotational grazing have been developed. Rotational grazing is essentially the same as we know it, though applied on the range to very much larger units. Deferred grazing, on the other hand, has the specific function of re-vegetating ranges through seed establishment by delaying grazing until after seed maturity. Both procedures, or a combination of the two in deferred-rotation systems, have done much to maintain ranges in good order and to restore depleted ranges to higher condition classes.

American problems and British conditions

The application of climax and succession concepts to range management is not without its critics. In an article published in the Journal of the British Grassland Society (16), Love, an American agronomist, posed the question, 'The Range—Natural Plant Communities or Modified Ecosystems ? ' and proceeded to criticise severely the traditional American approach to range use. Briefly, Love contends that the application of climax and succession concepts to range management is misleading, that the evaluation of range condition in terms of climax vegetation is fallacious and serves to obscure the potential productivity of range land. Few would argue that a century or more of use has failed to modify the former climax, but from the recognition of this point it does not necessarily seem a logical step to condemn the whole structure of American range philosophy as the author evidently does. The concept of climax when sensibily applied is 'nothing more than a guide for organising man's mind concerning ecological processes that occur in natural plant communities' (17) and this seemed to be the way most range workers applied the idea in practice. Though certain situations were somewhat confusing when viewed from the climax standpoint, e.g. the annual ranges of the Californian foothills which have superseded the former bunchgrass climax, even this did not appear to invalidate the general approach. Love further asserts that 'the climax vegetation (even if we could define it) need no longer be the goal in range and wild land management any more than it is with other crops,' and that research is opening up the possibility of manipulating soil, herbage and other factors. Moreover, he states that it is wrong to consider rangeland use as a problem essentially different from that of agricultural production at more intensive levels involving considerable environmental control.

While much of this discussion requires careful consideration in its application to the British upland 'ranges,' the latter point in Love's argument has obvious significance to our own problem. It must be accepted that there is no *fundamental* difference between extensive pasture utilisation and other forms of agricultural production, but there would appear to be a discontinuity. Indeed, the failure to recognise the existence of this is one reason why I suggest we have not made more rapid progress in the development of hill grazing management in Britain, despite the fact that we have a good deal of knowledge of how to reclaim small areas and raise them to much higher productivity levels, thus creating at considerable cost much modified 'ecosystems'. The discontinuity is created partly by the state of technical knowledge and partly by economics. In the absence of a technical break-through enabling effective physical and chemical manipulation of the environment to be widely and economically applied, we are largely limited to the manipulation of grazing, its intensity and timing. It is in our failure to fully understand the importance of applying controls of this kind in extensive systems that our approach can be criticised. Through the accumulation of scientific knowledge we may expect to achieve a greater degree of control of all the main components of the system, physical, chemical and biological, thus extending the area to which more conventional agricultural approaches are appropriate. While this represents an incursion into the region of range and wild land management it eliminates neither the problem nor the discontinuity, but merely advances the frontiers of agricultural control.

There are few areas in the United States where soil erosion is not either a real or a potential danger. Erosion occurs in the British uplands and it cannot be disregarded. However, by comparison with the American predicament it can only be regarded as of marginal significance in the usual grazing systems. To think in terms of American experience may serve to divert attention from what is likely to be a problem of more consequence to us, namely the effect of vegetation and its management on the insidious process of the soil's 'chemical depletion,' rather than its physical removal.

American environments differ in many respects from those in the British uplands and there are few areas which approach the oceanic conditions of moderate temperature and abundant well distributed rainfall as we know them. On many occasions I was asked what benefit I expected to derive from a study of rangeland and watershed areas under markedly different climatic conditions, such as in the semi-arid western region in particular. There are two answers to this.

Firstly, the occurrence of drought is not the monopoly of arid areas. The occurrence and significance of periodic moisture deficits in British hill soils has never been closely studied, presumably because of the apparent dominance of problems associated with water in excess. However, as Green (18) has pointed out, 'the most fundamental dividing line in land use, natural or otherwise, may prove to be that between localities which have a period of water deficit at all, and those which have not.' There is such a line of division under British conditions and therefore a study of the ecological significance of moisture deficits and associated problems assumes considerable importance.

Secondly, the ecological approach to land use in America is firmly established, in fact modern range management practices are based on a great deal of ecological work under a variety of conditions. One can only appreciate the significance of this by comparison with the attitudes which, in the past, have too frequently prevailed in relation to the British uplands where the management of vegetation is not based on principles established by scientific study. In general, practices have been adopted in response to what has been considered to be the requirement for proper animal husbandry. In fact, on the extensive grazings the pastoral system has tended to be overweighted towards an expertise in the husbandry of livestock in adversity. The development of modern range management in the United States is the best example there is of the way successful grazing systems on extensive pastoral areas can be built up on the basis of an understanding of the vegetation and its environmental background.

Perhaps the most important lesson to be learnt from the American approach is the evident appreciation of the need to manage to best advantage the natural resources of the country. Whether it is water, rangeland or wildlife the principle is to take a crop yet conserve the system which produces it.

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THE SHEEP OF ST. KILDA: LESSONS FROM FERAL POPULATIONS

R. G. GUNN AND J. M. DONEY

The Environment

THE group of islands known collectively as St. Kilda lies about fifty miles to the west of the Outer Hebrides and consists of four islands and numerous Stacs. Three of the islands now carry self-contained sheep stocks completely unmanaged by man.

Climatic conditions are governed largely by the location within the Gulf Stream. Mean daily temperatures range from 7° C. (44° F.) in January to 13° C. (55° F.) in August, with a diurnal variation of less than 5° C. in summer and winter. The prevailing wind is from the south-west with a high annual average of over 20 m.p.h. (force 5) and with gale force winds (force 8), or more, occurring on an average of twenty-three days a year. There is an annual rainfall of 50 inches and the islands often create their own cloud canopy giving chronic hill fog. Snow is uncommon and does not usually lie for long.

The islands are almost completely cliff bound. Only Hirta, which rises to nearly 1400 feet above sea level and is the largest island (1575) acres, possesses a favourable beach for landing purposes. Both Soay (244 acres) and Boreray (190 acres) rise to over 1100 feet above sea level. Hirta consists of two broad valleys set into an S-shaped ridge with many steep terraces on the outward-facing cliffs. About three-quarters of the surface provides sheep pasture. Of this approximately 600 acres are mixed grassland dominated by *Festuca* and *Agrostis*; a further 250 acres are dominated by either *Molinia* or *Calluna* and the remainder, covering the cliff terraces and the lower slopes, have a maritime type of vegetation including a salt tolerant *Plantago* sward (McVean 1961). Soay consists of a flat plateau with steep terraced cliffs and a mixed grassland community which is probably similar to that on Hirta. On Boreray, the main grazing area slopes steeply from 1200 feet down to the cliff tops at 250 feet and there are again many fertile terraces.

Recent History of the Sheep Stocks

The early origins of the islands' sheep stocks are unknown, but at present both Soay and Hirta are occupied by a primitive breed known as the Soay, while Boreray has a breed derived from the Scottish Blackface. Until 1930, when the human population of Hirta was evacuated, the Soay breed was restricted to the island of that name and may have existed there with little change since Norse times. The islanders ran commercial sheep on Hirta and Boreray which are believed to have been of similar breeding to contemporary Hebridean stocks. These would have been equivalent to the Lewis strain of Blackface but might contain some residual genetic influences from earlier populations such as the so-called St. Kilda four-horned sheep. At the evacuation, the sheep on Hirta were taken off, but the Boreray stock were abandoned. In 1932 a small flock of about 100 Soay sheep from Soay itself were established on Hirta and the present population is descended from this introduction.

Population Studies

These self-contained and self-maintained flocks of sheep provide unparallelled opportunities for a study of ways in which individual animals and the population as a whole are adapted by nature to the free-ranging conditions in which they live. A knowledge of natural adaptation can assist in the understanding of factors influencing the management and selection of domesticated hill breeds which exist in similar climatic and nutritional environments. The isolation and difficulty of access to these islands, which are responsible for the existence of those conditions, also contribute to the difficulties involved in the study. Observations must be restricted to relatively short visits at fairly specific times of the year. Such limited observations as have been carried out in the past few years have been possible through the co-operation of the Army who have provided transport to and from the Outer Hebrides. Expeditions to Soay or Boreray are much more difficult, involving landing on cliffs from small boats and have therefore been limited.

Extensive studies of all aspects of the biology of these islands were initiated by the Nature Conservancy in 1957. Prior to this, sporadic visits between 1932 and 1955 made by various agencies, provided a little recorded information on the sheep stocks. A first census was made on Hirta in 1952 (Boyd 1953) and systematic annual counts began in 1955. The Blackface sheep on Boreray were counted in 1951, 1956, 1959, 1960 and 1963. Only three brief visits have been made to Soay itself and there is very little information available, so, unless specified, all subsequent references to Soay sheep apply to those on Hirta. More critical studies were started in 1959. About one tenth of the total population have been caught annually, individually identified, and had several physical characteristics recorded.

Only a few of the individual Blackface sheep on Boreray have been captured for examination.

Population size and performance

In a normal commercial hill flock the ewe stocking rate is determined directly by the farmer on a basis of his assessment of the carrying capacity, and males are separately maintained in small numbers. On St. Kilda there is no such human intervention and the population numbers and sex ratios can fluctuate in response to other pressures. Data given in Fig. 4 have been abstracted from Fraser *et al* (1957), Boyd *et al* (1964) and from unpublished observations by the authors and their colleagues. As can be seen, the population density on Hirta in May has increased from the original small number and now appears to be fluctuating at a high level. Much of this apparent fluctuation is due to differences in the numbers of lambs surviving beyond the yearling age. As the normal lambing season ends in April, the period of greatest lamb mortality, at and near birth, is effectively past by May and the recorded numbers provide the equivalent of a marking percentage. In 1959 the ewe stocking rate had reached a high value of over 700. These ewes had produced more than 450 living lambs despite the fact that at least 150 of the sheep recorded as ewes were only yearlings and no nursing yearlings were found. Following normal wastage and replacement there could have been nearly 900 ewes in 1960. This number entered the winter of 1959-60 which followed a summer drought. Most of the ewes survived the winter but were in poor condition and about 55% of them died, probably from enterotoxaemia. The remaining ewes produced only 86 lambs alive in May giving a lambing percentage of less than 10% of ewes going to the ram. By 1961, with no replacements available, the ewe stock remained at about 400 but these reared more than 400 lambs. Unlike 1959, when no nursing yearlings were found, the majority of the surviving ewe lambs from the 1960 drop took the ram in the same year and were found with lambs at foot in 1961. In such natural populations some compensating mechanisms permit the younger members to take a much greater part in flock replenishment than would be the case at higher densities. The rapid accession to sexual maturity was presumably influenced by the temporary abundance of feed available in the summer following the drastic reduction in numbers. By the following May the yearlings, despite having borne a lamb, were bigger and heavier than similar aged sheep in previous years. The suggestion could be made that greater flexibility in the age at which commercial hill sheep are first bred might be useful in the regeneration of optimum flock numbers, without reducing the genetic potential, following losses such as occurred in the winter of 1947.

In spite of quite marked fluctuations in population density and in the availability of feed the study has so far shown that such characters as the size of the adult sheep and their growth of wool are fairly constant. This could lead to the conclusion that, providing measures were taken to alleviate disasters such as occurred on St. Kilda in 1960 and to ensure the adequate development of young stock, the sheep density of many Scottish hills might be raised to give a greater flock productivity, without any decrease in individual adult performance. In spite of the uncontrolled changes in population size on St. Kilda with the consequent alternation between heavy and light stocking rates, there is no evidence of a significant change in the pastures since the evacuation (McVean 1961). Without a detailed knowledge of different ecological systems, it is difficult to isolate certain characteristics from one and to extrapolate them into other situations. However, it might be argued that both increased production and long term maintenance of more desirable pasture conditions could be achieved in some mainland hill areas by a combination of heavier stocking together with some form of grazing control which seems to be inherent in the natural situation.

This discussion has been based on the results of extensive observations on Hirta. The more limited observations on Boreray (Figure 4) suggest that the Blackface sheep there may have followed the same sort of cycle over the same period. Individually these sheep are bigger than the Soay and a count of 400 animals in 1963 on an estimated 150 acres of grazing is high even in relation to Hirta.

Breeding Structure

Under commercial management the number and type of males retained for breeding are regulated by the policy of the enterprise and have no effect on the ewe stocking rates. In a wild population the males are in active competition for food and space with the ewe flock and with each other. A natural system of male culling would be to the advantage of the population as a whole. The situation on both Hirta and Boreray has resulted in a very unequal sex ratio (see Figure 4) with approximately four breeding ewes on Hirta and eight on Boreray to every adult ram. This imbalance is derived from a selective mortality. From birth up to the age of one year there are about the same number of males as females. After this age there seems, in most years, to be a much heavier winter death

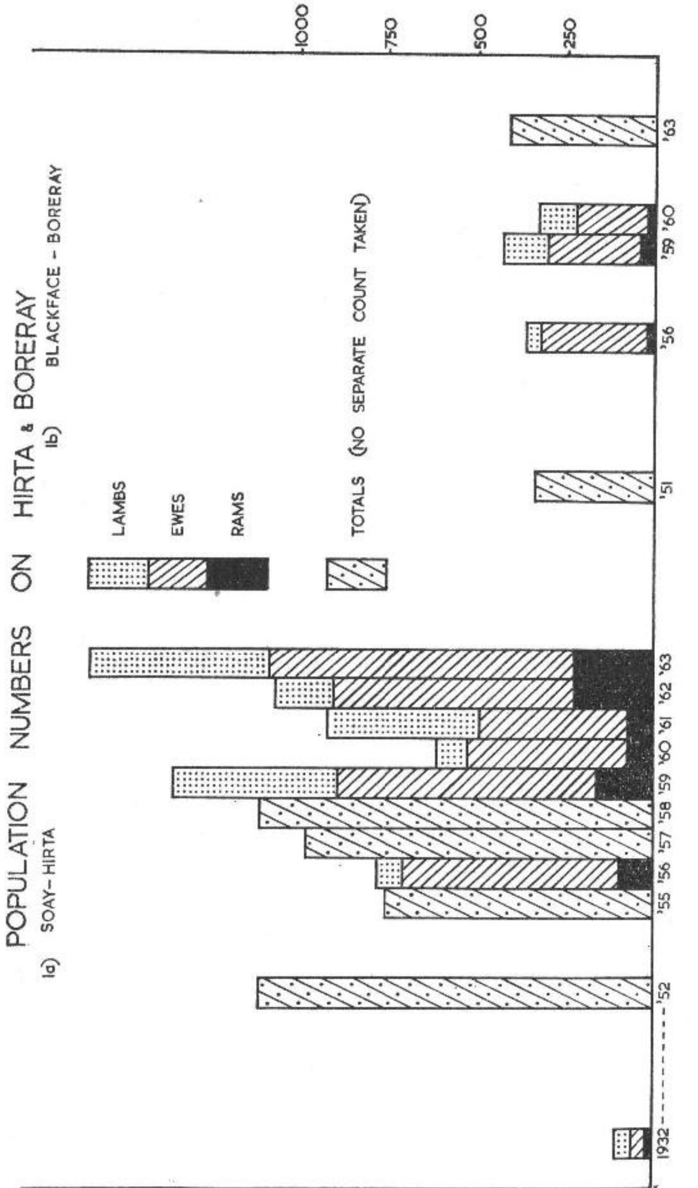
POPULATION NUMBERS ON HIRTA & BORERAY
Ia) SOAY-HIRTA
Ib) BLACKFACE - BORERAY
LAMBS
EWES
RAMS
TOTALS (NO SEPARATE COUNT TAKEN)
1750
1500
1250
1000
750
500
250
1932
'52
'55 '56 '57 '58 '59 '60 '61 '62 '63
'51
'56
'59 '60
'63
1000
750
500
250

FIG. 4.

rate of males. This is shown in Table 1, in which the sheep caught in one locality on Hirta over five years are listed according to age. Because of differences in behaviour, the catching technique tends to provide a less random sample of the male than of the female. In

TABLE 1

Age distribution of male and female Soay sheep (Compiled from the records of sheep captured for examination on Hirta from 1959 to 1963).

	Lambs	Yearlings	2 year olds	3 year olds	4 year olds	5 year olds and over
Male	114	72	57	10	5	10
Female	113	40	40	22	20	110

May the rams congregate in groups, often of a similar age and either the whole group or none of the group tend to be caught. Thus in 1962, when the total population stood at over 700 ewes and 280 rams, 34 ewes and 55 rams were caught, many of the latter being from one large group of yearlings and two year olds. In most other years the capture was much closer to the overall proportion. The five year total clearly indicates the relative decline in numbers of rams with increasing age. On all visits, the sex distribution on Boreray has been found to be even more extreme but, without close examination, an age distribution could not be obtained.

Very little is known of the breeding structure as distinct from the sex ratio. There is some evidence that the male groups break up in the autumn and smaller mixed sex groups are formed. These may range from a single pair to a group containing several rams and many more ewes. One reason which has been suggested for the winter kill of males is that the energy loss through mating and fighting leaves the animal in poor condition to face the stress of winter. It is not known whether the few surviving aged rams represent the dominant males in the breeding system or whether they are simply individuals who play no part in population maintenance. During the breeding season, some groups have been seen consisting of a young ram and one or two females, while on the other hand, groups of a single female followed by a line of rams led by the oldest and biggest have also been noted, as well as groups of rams of all ages without any females. Whatever the system is, the observations indicate that, through all its ups and downs, the population is maintained in a fairly constant level genetically. The Soay sheep in their present form are distinctly dimorphic for hair and wool colour and this appears to be due to the segregation of a single gene. Light brown appears to be recessive to dark brown. Records from Hirta suggest that over the period of observation the proportion of each colour type has remained constant and that this proportion agrees closely with long distance counts made on Soay itself. The recorded colour combinations in dam-lamb pairs could be explained by the segregation of a single pair of alleles with random mating, equal gene frequencies and little differences between the alleles in survival value. This latter situation is unusual in a wild population but is supported to some extent by the fact that the colour distribution in the half of the flock which died in 1960 was identical with that of the survivors. Colour variation might be expected to influence survival value in a situation where heavy predation occurs but on these islands there are very few predators. This colour dimorphism may not be the original condition as several nineteenth century observers (e.g. Sands, 1878) have described the Soay sheep as being uniformly 'light brown'. Furthermore a recent close study of the sheep on Soay itself has disclosed a marked difference in the ratio of horned to polled ewes compared to that on Hirta.

It can be concluded that a natural management system has evolved which allows a greater number of productive females to survive and yet retains sufficient males to maintain the general adaptation of the population as a whole to its environment. Whilst the breeding system has little of relevance in itself to the commercial farmer, the adaptive mechanisms, which would be called 'hardiness' by hill flockmasters in Britain, may be of considerable interest.

Adaptation to Environment

The study of behavioural and physiological adaptation is made difficult by the shortness of visits to the islands and information so far pieced together can do no more than suggest parallels with hill sheep and indicate research projects.

The grazing behaviour of the Soay sheep shows very markedly the type of territorial pattern described for sheep as 'home range' behaviour (Hunter, 1962). On the 1500 acres of Hirta there are five fairly distinct topographical regions and each of these is occupied, in the spring and summer at least, by a permanent ewe flock. Marking of individuals has shown that sheep rarely stray from group to group. Location of corpses in 1960 suggests that this pattern may change in winter as the sheep concentrate in more favourable areas. By May, however, the discrete flocks are again apparent. Within a group the sheep have a markedly constant daily rake in spring and summer, moving down to low ground in the morning and slowly working upwards to their camp areas by nightfall. Their morning descent is spectacular—they have been observed to run down as a flock, even when quite undisturbed. They tend to graze and rake as a flock although they may be scattered over quite a wide area. Individual preferences within the flock territory can also be seen by following specially marked animals. The home range behaviour is very like the situation described for unshepherded Cheviot ewes by Hunter (1962) and the rake pattern is very similar to that imposed by Border shepherds in their daily management of sheep stocks. This suggests that the basic grazing management of many hill flocks has been derived in the past from the natural behaviour of the sheep. Such systems may be capable of maintaining a balance between animal and plant components but do not necessarily allow for maximum productive output. As has been noted previously, the males tend to form social groups of their own during summer (Plate 7) and these do not seem to be restricted in pattern of territory. One group may be found grazing quite different localities on successive days but they do seem to retain constant night camps. On the much smaller island of Boreray there is less room for the Blackface stock to separate into discrete flocks (Plate 8) but a similar pattern of raking has been seen.

A study of physiological adaptation cannot be carried out in the field. Certain observations and measurements which can be made on characters such as live-weight and skeletal growth suggest that the Soay sheep fit the specifications given by White (1931) for the ultimate in 'hardiness'. They are, as White pointed out, of very little commercial value. The Blackface sheep on Boreray are closer in physical appearance to the almost extinct Lewis strain than to any other contemporary type. We have no records of their characteristics in 1930 but they now appear to be closer to the unimproved, uneconomic but hardy type than the present day survivors of the Lewis strain. An expedition was mounted to bring back some of these sheep to allow close study of their physiological responses to climatic and nutritional stress and, by comparison with commercial sheep, to discover the changes produced by selective improvement. Because of bad weather conditions no sheep were removed from Boreray but a small flock of Soay sheep were brought from Hirta. After acclimatisation at Lephinmore half of these were transferred to the London Zoo and half to Edinburgh Zoo. Some measurements have been made under these conditions and it is intended that the progeny will be studied in greater detail. One point of interest which has so far emerged is that the winter rate of wool production from the sheep at the Edinburgh Zoo was extremely small. It was estimated that maximal production occurred in July and August and that growth in January was only 5% of that in autumn. This indicates a much more extreme growth cycle than occurs even in the Blackface breed (Doney and Smith 1961) and gives some support to the hypothesis suggested by one of the authors (Doney 1964) that a low ratio of winter/summer wool production is a primitive characteristic, allowing a more useful partition of intake in conditions of nutritional and climatic stress associated with winter in the Northern Hemisphere. Examination suggests that the Soay sheep have very little superficial fat. In winter and spring they appear to be emaciated and yet they retain remarkable agility and activity and the ewes can produce viable lambs of up to 10% of their own liveweight and suckle them adequately. By a study of these primitive adaptive mechanisms and growth forms we hope to learn more about the consequences and requirements of improvement in stock breeding and management systems.

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