HILL FARMING RESEARCH ORGANISATION

SEVENTH REPORT

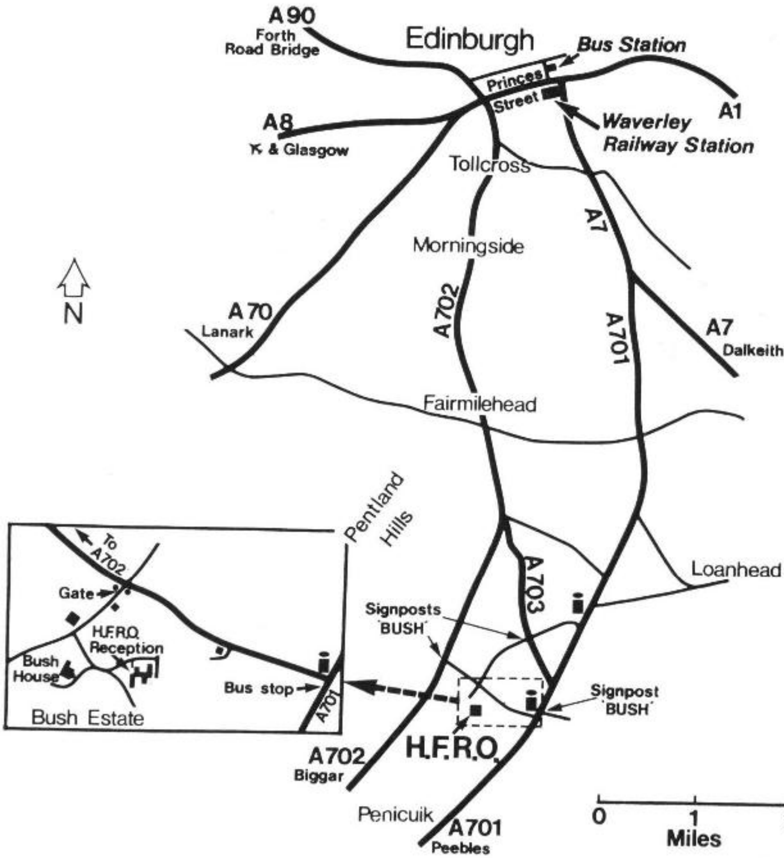
1974-1977

HILL FARMING
RESEARCH ORGANISATION

Hill Farming Research Organisation

7th Report
1974–77

Bush Estate,
Penicuik, Midlothian. EH26 0PY.
Tel : 031–445 3401



A90
Forth Road Bridge
Edinburgh
Bus Station
Princes Street
A1
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& Glasgow
Waverley Railway Station
Tollcross
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Morningside
A702
N
A70
Lanark
A701
A7
Dalkeith
Fairmilehead
Pentland Hills
To A702
Gate
H.F.R.O. Reception
Bush House
Bus stop
A701
Bush Estate
A703
Loanhead
Signposts 'BUSH'
Signpost 'BUSH'
H.F.R.O.
A702
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A701
Peebles
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2
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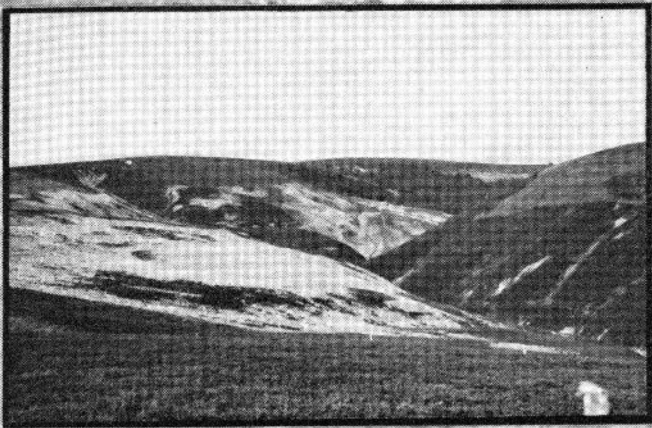

Deer farm

Glensaugh

House o' Muir

RESEARCH STATIONS

THE organisation has direct control of four farms, with a range of soils and climates, which provide the variety of conditions necessary for experimental work. They function under the guidance of their respective officers-in-charge, Mr W. J. Hamilton (Glensaugh), Mr D. C. Currie (Lephinmore), Dr R. H. Armstrong (Sourhope) and Mr A. L. Fairlie (House o' Muir).

Glensaugh, Laurencekirk, Kincardineshire

Glensaugh is situated at the eastern end of the Grampians. It consists of 832 hectares of rough hill grazings, dominated by heather and ranging from 135 metres to 485 metres, with 139·5 hectares of short- and long-term leys and 3·9 hectares of forage crops. Of the rough grazings, 200 hectares are devoted to the Red Deer Farm. Podsolised soils predominate with an extensive area of hill peat capping the summit plateau. The average rainfall is 10414 mm. The breeding stock consists of 1070 ewes (mainly Blackface and Greyface with some North Country Cheviots and cross breeds); 116 hill cows (Blue Grey and Hereford Friesian crosses) and 99 Red Deer hinds.

Lephinmore, Strathlachlan, Strachur, Argyll

Lephinmore is situated at the east side of Loch Fyne in Argyll. It consists of 1169 hectares of rough hill grazings up to 470 metres altitude, mostly over peat, and with a mixed herbage including heather, *Molinia*, *Trichoporum*, *Eriophorum* and hill grasses. There are 31 hectares of short- and long-term leys. Average rainfall is 1790 mm at sea level. The breeding stock comprises 1318 Blackface ewes and 34 hill cattle.

Sourhope, Yetholm, Kelso, Roxburghshire

Sourhope lies 15 miles south of Kelso on the western slopes of the Cheviots. There are 1051·5 hectares of rough hill grazings at 210 to 608 metres, consisting largely of grasses, such as *Agrostis* and *Festuca*, with substantial areas dominated by *Nardus* and *Molinia*. There are also 44·7 hectares of short- and long-term leys. Acid brown forest soils characterise the lower slopes while more acid peaty podsols and peaty gleys occur at higher elevation. The average rainfall is 9398 mm. The breeding stock comprises 2659 ewes (mainly

Blackface and South Country Cheviot with some North Country and South Country Cheviot crosses) and 58 hill cows.

House o' Muir, Midlothian

House o' Muir is located on Turnhouse Hill of the Pentlands, about two miles from the headquarters at Bush Estate. There are 220·1 hectares of rough hill grazing at 243 to 456 metres, consisting largely of *Agrostis/Festuca* pastures overlying brown earth soils, with 33·4 ha of short- and long-term leys. Average rainfall is 8382 mm. The breeding stock comprises 649 Blackface ewes and 27 hill cows.

LOCATION of RESEARCH STATIONS – SCOTLAND

INTRODUCTION

As is now customary, this Report presents reviews of only selected parts of the work of the Organisation. Since it is our aim to ensure that the findings of research are translated into practice through the Advisory Services as rapidly as possible, it is inevitable that new knowledge will become available to farmers and others between Reports by means of the on-going dialogue which is maintained through those appointed by ADAS as liaison officers and the specialist advisers in the Colleges. An example of this exchange of information would be the technique for the control of liver fluke which proved so successful at Lephinmore.

Regular contributions to the scientific literature are maintained and some aspects, for example work on red deer, have been described in a separate publication.

A substantial part of our efforts is devoted to sheep, and the problem associated with ensuring an adequate level of nutrition of the hill ewe throughout the year had been a central and continuing feature underlying the research programme of the Organisation from its inception. Scientific reports tend to concern themselves with recent advances and earlier work becomes forgotten. An attempt is made here to summarise in general terms the state of our current knowledge and also to discuss areas where we believe our understanding to be deficient. We certainly would welcome comments from those in the agricultural industry.

The improvement of heather-dominant farms presents unique problems about which we have hitherto been unable to propose any positive solutions. However, within the last six years effective collaboration of colleagues with an interest in plant and animal facets has lead to a much improved understanding of the nutritive value of the heather plant and how best it may be utilised. This work has now led us to the structuring of a new hill sheep system for heather-dominant hills which we propose to put to a practical test on our Glensaugh Research Station.

Now that the importance of improving the nutrition of hill sheep is better understood, the vital and key role that land improvement plays in achieving this aim is evident. Since fertilisers, particularly nitrogenous ones, are likely to become increasingly expensive we believe that in many cases the introduction of white clover, or perhaps other legumes, is a prime factor in the establishment and growth of improved pastures, not only because of nitrogen fixation but also because of the high nutritive value of legume herbage. Effective production from clover in many hill swards is not infrequently lower than desirable but achieving a satisfactory level is beset with many difficulties, many of which are not clearly understood. An active programme of research on several aspects of nitrogen fixation, clover growth, and utilisation is underway and a summary of much of the relevant knowledge from both HFRO and other sources is presented.

In the previous two Reports of this series a discussion of the general approach and philosophy underlying the development of new hill sheep systems and the techniques developed for economic appraisal of them were presented. Although progress reports of our development work have been presented on a number of occasions we here include a comprehensive report of the work at the Sourhope Research Station. We were much encouraged by the large number of farmers and others who attended our Open Days at Sourhope in 1973 and Lephinmore in 1975 and were stimulated by the interest shown in our work.

Although a wealth of detail is presented it is hoped that most of the questions which have been put to us by the many interested visitors who have seen this work will be answered more fully.

We have been further encouraged in the development of these systems by the work based on them initiated at the ADAS Experimental Husbandry Farms at Redesdale and Pwllpeiran and are grateful for the continuing exchange of information and experience which we have with the Directors of those farms, Mr J. Thompson and Mr M. Roberts.

In addition, through the auspices of the Scottish Agricultural Development Council and more recently the Council of the Scottish Agricultural Colleges, we have been able jointly to promote work with the new system on commercial farms, which many will argue is the only real and satisfactory test-bed. We appreciate this symbiosis of research and extension and the enthusiasm and dedication of those staff involved from the Colleges on whom the effective translation of science to practice is greatly dependent.

It is our belief that this work could well lay the foundations for change in hill farming and contribute towards increasing its competitiveness and ultimately its prosperity.

Board of Management

After nine years of extremely valuable service to the Organisation Mr. W. E. Cave and Professor A. T. Phillipson retired from the Board. Both took a great deal of interest in our work and their counsel and encouragement were greatly appreciated. It was with deep regret that we heard of the death of Professor Phillipson in January 1977.

We welcome to the Board Mr R. L. Ollerenshaw who farms in Derbyshire and Dr D. R. Melrose, Head of Veterinary Services, Meat and Livestock Commission.

Just at the point of going to Press we were shocked by the tragic death of Professor F. W. H. Elsley, a member of the Board since 1972. He did much to foster stronger links between research institutes and the advisory services and also with universities. His intense interest in all aspects of the work of the Organisation, coupled with his keen and enquiring and well informed mind, were a great stimulus to Board members and staff alike. His enthusiastic and wise counsels will be missed. A number of tributes to the wider aspects of his work and life have been published elsewhere.

SUMMARY OF RESEARCH

In 1976-77 financial provision was made for research in the following areas:

Title	*Objective*
Performance of sheep in hill and upland environments	Understanding of the biological factors affecting sheep performance, including nutritional factors, with a view to determining means of improving performance
The synthesis of hill and upland farming systems	The development of systems of animal production based on improved knowledge to attain optimal use of available pasture and animal resources
Beef cattle in hill and upland environments	Understanding of the biological factors influencing the performance and productivity of suckler cows, including their nutrition during pregnancy and lactation, and their intake and utilisation of pasture, with a view to improved performance
Hill and upland pasture production	Improved production through understanding of plant nutrition and nutrient cycling in hill soils; effects of utilisation; pasture establishment
Husbandry of red deer (with Rowett Research Institute)	To explore the potential of the red deer as a domesticated animal and to investigate the utilisation of and effect on hill pasture

CURRENT RESEARCH

(The abbreviations in brackets refer to members of staff and collaborating organisations)

Performance of sheep in hill and upland environments

The improvement of reproductive efficiency.

1. Pattern of ovulation rate early in the breeding season in Greyface ewes. (R. G. G., J. M. D., W. F. S.)
2. Time of mating and stocking rate on body condition at mating and fertility of Greyface ewes. (R. G. G., J. M. D., T. J. M., W. F. S.)
3. The effect of pre-mating nutrition on ovulation rate and embryo mortality in Cheviot ewes. (R. G. G., J. M. D., W. F. S.)
4. Nutrition prior to mating on body condition and ovulation rate in Blackface ewes. (R. G. G., J. M. D., W. F. S.)
5. Effect of pregnancy and lactation nutrition on subsequent ovulation rate and embryo mortality in Blackface ewes. (J. M. D., R. G. G., W. F. S.)
6. Plasma luteinising hormone (LH) in the prepubertal lamb. (R. G. G., W. F. S., J. M. D.)

The improvement of lactation and lamb growth.

1. Comparative studies of milk production and food intake of young crossbred and Blackface ewes. (J. N. P., J. M. D., W. F. S.)
2. Studies of the possibilities of extended lactation of ewes and its effect on lamb growth. (J. N. P., J. M. D., W. F. S.)
3. Interrelation of milk and solid food in lamb growth.

The assessment of nutrient requirements in pregnancy and the application of the findings to field conditions.

1. Effect of undernourishment in mid-pregnancy on subsequent production. (A. J. F. R., T. J. M., I. R. W.)
2. The objective assessment of feed inputs to pregnant hill ewes. (A. J. F. R., T. J. M., I. R. W.)
3. The objective assessment of feed inputs to pregnant upland ewes. (A. J. F. R., T. J. M., I. R. W.)

The effectiveness of improved genotypes in utilising better hill land resources.

1. A comparison of the performance of Blackface and crossbred ewes in improved hill conditions.
(J. M. D., T. J. M., R. G. G., W. F. S.)

Studies of wool production from Blackface and crossbred ewes under improved hill management systems.

1. Wool growth patterns, fleece structure and textile suitability of fleeces from crossbred genotypes.
(W. F. S., J. M. D.) (with WIRA)

Studies on the interaction of nutrition and body composition.

1. The effects of different levels of nutrition on changes in body reserves of ewes during lactation and post-weaning and on the body composition of lambs before and at weaning.
(J. Z. F.)
2. The effect of lamb nutrition post-weaning and of ewe nutrition in lactation on post-weaning lamb growth. (J. Z. F.)

The assessment of the nutritive value of heather to the sheep.

1. The effect of supplementation on the voluntary intake of diets containing proportions of heather and *Agrostis/Festuca.*
(J. A. M., A. M. S.)
2. To determine within two management systems the effect of stocking rate on the quantity and quality of the diet selected by sheep grazing heather hills in summer and winter.
(J. A. M., T. J. M., S. A. G.)
3. The effect of levels and patterns of utilisation of heather on the quantity and quality of the diet selected by the grazing sheep.
(J. A. M., L. B.)

Studies on the nutritive value of poor quality hill roughages.

1. Partition of digestion by sheep given poor quality *Agrostis-Festuca* and heather diets:
   (i) Nitrogen metabolism; rumen/caecal/plasma transfer of nitrogenous constituents. (J. C. M., S. W., J. A. M.)
   (ii) Carbon metabolism:
      (a) rumen/caecal/plasma transfer of carbon.
      (J. C. M., S. W., J. A. M.)
      (b) measurement of VFA production. (S. W., J. C. M.)

2. Comparative studies of the nutritive value of hill pasture (*Agrostis-Festuca* and heather) diets to the red deer and sheep.
   (i) Voluntary intake and digestibility. (J. A. M., J. C. M., A. M. S.)
   (ii) Production, absorption and utilisation of end products of digestion. (J. C. M., J. A. M., S.W.)
3. Protected lipid as a supplementary feed. (J. C. M., A. J. F. R., C. S. L.)

Mineral nutrition and animal performance.

1. The cobalt status of hill sheep on a grassy hill. (A. W., A. J. F. R.)
2. The copper status of hill lambs and its relationship to performance. (A. W., R. H. A., C. C. E., A. R. F.)
3. Long term effects of hypocuprosis on ewe performance. (A. W., R. H. A., C. C. E., A. R. F.)
4. Prevention of copper deficiency in the hill flock. (A. W., R. H. A., C. C. E., P. N.)

Quantification of the nutritional and productivity consequences of a range of hill pasture improvement techniques.

1. The nutritional and production responses to a range of improvement techniques on a range of hill soils and pastures. (3 sites). (J. E., R. A. H., T. G. C.)
2. The nutritional and production responses to a range of improvement techniques on blanket peat. (J. E., G. R. B.)

The improvement of hill pasture utilisation by grazing cattle and sheep.

1. Nutrient intake by beef cattle and sheep grazing a series of hill and upland pasture communities. (J. H., Rchd H. A., G. R. B., R. A. H., A. J. M.)
2. Voluntary intake by sheep of material cut from a range of hill and upland pasture communities, and the relationship between *in vivo* and *in vitro* digestibility within this material. (Rchd H. A., J. H., R. A. H., G. R. B.)
3. Diet selection by beef cattle and sheep in relation to pasture community and season. (J. H., S. A. G., G. R. B.)

The improvement of upland pasture utilisation by grazing sheep and cattle.

1. The prediction of clover intake in mixed diets of grass and clover. (J. A. M., Rchd H. A.)
2. The influence of sward characteristics and grazing management on grazing behaviour, diet selection and herbage intake by grazing sheep. (J. H., J. A. M., L. B., Rchd H. A.)
3. The effect of pasture availability on the herbage intakes of Greyface ewes when supplemented in early lactation. (J. A. M., T. J. M.)

The synthesis of hill and upland farming systems

The development and large scale testing of improved systems of sheep production from hill and upland resources.

1. Year-round grazing systems:
   - (i) Low capital input on a grassy hill. (R. H. A., J. E., T. J. M.)
   - (ii) High capital input on a grassy hill. (R. H. A., J. E., T. J. M.)
   - (iii) On blanket peat. (T. J. M., J. E., D. C. C.)
   - (iv) On heather moor. (T. J. M., J. E.)
2. Inwintering systems with and without land improvement on a grassy hill. (R. H. A., J. E., T. J. M.)

Sheep production systems studies in the uplands.

1. Sheep production from upland pasture; an examination of the relationships among pasture production, stocking rate and lambing date. (T. J. M., J. E., R. D. M. A.)

The development of simulation models of hill and upland sheep production systems.

1. The development of model components: (A. R. S., T. J. M., J. E.)
   - (i) Pasture availability, diet selection and intake on
     - (a) *Agrostis-Festuca* pasture. (Rchd H. A., J. K.)
     - (b) Heather/grass complex. (S. A. G., J. A. M.)
     - (c) Perennial sown pasture. (J. H., J. K.)
   - (ii) Lactation/lamb growth. (J. M. D., J. Z. F., J. N. P., A. J. F. R.)
   - (iii) Management decision model, upland sheep system. (T. J. M., A. R. S.)

2. Land use.
   (i) Agriculture/forestry integration. (T. J. M., A. R. S.) (with F. C.)

Control of records and preparation and use of computer programs for data handling and analysis. (A. R. S.)

Economic monitoring of development projects. (T. J. M., A. R. S.)

Veterinary monitoring of all systems studies.

1. Control of parasites. (A. W., A. R. F.)
2. Monitoring of trace element status. (A. W., A. J. F. R., A. R. F.)
3. Preventive veterinary programme. (A. W., A. R. F.)

The assessment of pasture production of improved pasture in the development projects.

1. *Agrostis-Festuca* pasture production. (T. G. C., R. A. H., J. E.)
2. Pasture production in reseeded pastures. (G. R. B., J. E.)

Beef cattle in hill and upland environments

The study of the nutrition of the beef cow in pregnancy and lactation.

1. The effect of nutritional state during late pregnancy on the production of beef cows. (A. J. F. R., J. N. P., A. W., A. J. M.)
2. Lactation studies with beef cows and calf growth rate. (J. N. P., A. J. F. R., A. W., A. J. M.)
3. Interactions between the effects of winter nutrition and grazing management on the herbage intake of beef cows and their calves. (J. H., A. J. M.)

Hill and upland pasture production

Plant nutrition.

1. Improved production of white clover.
   (i) Major nutrient requirements on hill soils. (P. N., A. R., G. R. B., G. T. B.)
   (ii) Inoculation with effective rhizobia.
      (a) Assess need in a range of soils and environments. Collaborative series of field trials with WSAC, NSCA, ESCA, ADAS, WPBS, MD-ESA and ARCUS. (P. N., A. R., A. H., G. R. B., G. T. B., C. M.)

(b) Assess the specificity of symbiosis between strain of *Rhizobium trifolii* and genotype of *Trifolium repens* growing in hill soils. (D. M. V.)

(iii) Selection of genotypes of white clover which will grow earlier in the season than existing commercial stocks. Collaboration with SPBS. Initial screening in progress by SPBS; HFRO will assist in subsequent assessments. (P. N.)

2. Increased efficiency of fertiliser phosphate usage on hill soils.
   (i) Assess method to determine short and long term needs.
   (ii) Assess responses of perennial ryegrass and white clover to added phosphate.
   (iii) Compare effectiveness of different forms of fertiliser phosphate. (M. P., M. J. S. F., P. N.)
3. Examination of the effects of hill pasture improvement on levels of copper and cobalt in soil and herbage, and determination of why currently recommended remedial treatments for low levels of these elements are unsuccessful on some hill soil types. (C. C. E., A. W., P. N., J. M.)
4. Improvement of the growth and nutrition of herbage plants by the use of earthworms.
   (P. N., G. R. B.) (with CSIRO)

Nitrogen fixation.

1. Factors which affect the fixation and transfer of nitrogen by white clover in hill pasture. (A. H., C. M.)
2. The relationship between nitrogen fixation and photosynthesis in white clover. (A. H., J. K., W. I. C. L., C. M.)

Nutrient interactions.

1. Soil/plant relationships of calcium, aluminium and phosphate in acid hill soils. (L. J. M.)
2. Understanding of the relationships between pH, soluble aluminium and organic matter, and the lime requirement of hill soils. (M. J. S. F., L. J. M., M. P.)

The influence of the grazing animal on nutrient cycling in hill soils.

1. Losses of nitrogen. (M. J. S. F.)
2. Redistribution of phosphorus. (M. J. S. F., A. J. F. R.)
3. Maintenance of improved pastures on peat and the diagnosis of causes of patchy establishment and growth.
   (M. J. S. F., J. E., G. R. B.)

4. Maintenance of improved pastures on mineral soils. (M. J. S. F.)

The effects of utilisation of moorland by grazing animals.

1. Effects of utilisation by grazing sheep:
   - (i) On the structure, stability and productivity of blanket bog. (S. A. G., G. R. B., L. T.)
   - (ii) On the structure, stability and productivity of heather moor. (S. A. G., G. T. B., L. T.)
   - (iii) On the production and utilisation of grass and heather in mixed swards. The effects of grazing pressure, the proportions of grass and heather and the pattern of utilisation. (S. A. G., J. A. M., T. J. M., G. T. B., L. T.)
   - (iv) On the structure, stability and productivity of both indigenous and sown grass swards. (S. A. G., G. T. B.)
2. Effects of utilisation by grazing hill sheep and beef cattle. The effect of season of grazing on species and pattern of plants selected from a range of communities. (S. A. G., J. H., D. E. S., Rchd H. A., L. T.)

The effects of utilisation of pasture by grazing animals.

1. Regrowth of defoliated pastures. The basis of differences in yield between grass species. (J. K., W. I. C. L.)

Conditions for optimum germination and establishment of selected grasses and legumes in hill pastures.

1. The effects of applied fertilisers, time of sowing and interactions between temperature and soil water; the physico-chemical nature of the seed bed. (J. A. R.)
2. The effects of resident vegetation: (a) washings from leaves; (b) undecayed aerial parts; and (c) litter and breakdown products; on germination of white clover and selected grasses in hill swards. (J. A. R.)

Bracken.

1. The determination of extra herbage production when bracken cover is reduced. (G. E. D.)

Responses of a range of hill soils and pastures to different improvement techniques.

1. A series of small-scale field experiments. (J. E., M. J. S. F., R. A. H.)
2. Monitor pasture composition. (J. K., M. J. S. F.)

Biological monitoring in development projects.

1. Soils; changes in levels of soil nutrients. (M. J. S. F.)
2. Pastures; changes in botanical composition. (J. K., J. A. R.)

Husbandry of red deer

The identification of the practical problems associated with the application of domestic animal husbandry methods to red deer kept under semi-intensive conditions.
(J. M. M. C., W. J. H., S. A. G.) (with RRI)

Key to abbreviations of organisations

ADAS	Agricultural Development and Advisory Service
ARCUS	Agricultural Research Council Unit of Statistics
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ESCA	East of Scotland College of Agriculture
FC	Forestry Commission
MD-ESA	Microbiology Department—Edinburgh School of Agriculture
NSCA	North of Scotland College of Agriculture
RRI	Rowett Research Institute
SPBS	Scottish Plant Breeding Station
WIRA	Wool Industries Research Association
WPBS	Welsh Plant Breeding Station
WSAC	West of Scotland Agricultural College

CURRENT KNOWLEDGE AND UNRESOLVED PROBLEMS IN THE NUTRITION OF HILL SHEEP

A. J. F. RUSSEL, J. M. DONEY AND J. EADIE

Introduction

In most hill sheep flocks nutrition is the most important single factor influencing production. This does not imply that other factors, such as breeding, are unimportant and can therefore be disregarded. Improved nutrition, however, offers the means of making the greatest and most rapid improvements in the efficiency of production from hill sheep.

The objective of nutritional research is to gain an understanding of how nutrition affects production and, in particular production per ewe and to quantify the responses in production to different levels of nutrition, i.e. to measure by how much production, be it in terms of lambing percentage, lamb birth weight, ewe milk yield or whatever, is affected by changes in feeding. It is, however, imperative that the results from these individual components of performance be brought together and considered as a whole before they are applied in practice. Indeed, one of the results common to all these individual areas of research has been a demonstration of the importance of previous nutrition, which highlights the need to consider nutrition, and particularly the nutrition of the ewe, on a year-round basis.

Food Supply and Demand

In any system of farming in which animals graze pasture for most or all of the year, they are confronted with large differences in both the quality and quantity of the herbage available to them as the season progresses. Not only will sheep eat more of a better quality forage than of a poor quality forage, but they will also obtain more nutrient from each kilogram of it. Thus, the changes in nutrient intake which take place throughout the year are even greater than might be supposed on the basis of changes in pasture quality.

The animal's nutrient requirements also change throughout the year, depending on whether or not it is pregnant or lactating; 'requirements' being defined here in the strict sense as that quantity of feed or nutrient required at any particular time to meet the full needs of maintenance plus production without the animal drawing on its own body tissue.

In the ideal situation the cycles of nutrient intake and nutrient requirement would coincide, both in time and magnitude. In reality, however, the two cycles seldom match precisely, which leads to nutrient shortages at some periods of the year and to surpluses at others. The surpluses are conserved on the animal in the form of body reserves. These reserves are generally thought of as fat but it should be borne in mind that muscular tissue forms a valuable reserve of protein and that the skeleton also serves as a reservoir for certain minerals. Some essential trace elements and vitamins are stored in the liver.

Sheep are well able to utilise body reserves in times of nutrient shortage and, with certain provisos, are unlikely to come to any harm in doing so. The main provisos are that the reserves are adequate in the first place, that the rate at which they are used is kept within safe limits, and that the animal is given ample opportunity to replenish its reserves before the next period of nutrient shortage.

In practice the sheep is generally either mobilising or replenishing its body reserves to some degree. Although it is useful to measure both nutrient requirements and nutrient intake, it is the difference between these two which is important. The term 'nutritional state' is now commonly used to describe this balance between the animal's requirements and intake.

In this country the nutrient which is generally in shortest supply is energy and in common usage the term 'undernourishment' is generally taken to imply an energy deficit. It should be noted, however, that in certain situations protein may be the first limiting nutrient. In such cases the provision of additional energy will have little or no beneficial effect until the protein deficit has been rectified.

Undernourishment at any stage of the annual cycle will often affect production. In many cases the effect on production of moderate undernourishment for short periods of time will probably not be discernible; at the other end of the scale severe undernourishment may have severe effects on production. Between these extremes it is important to be able to assess the likely effects of varying levels of undernourishment in order that the potential loss may be balanced against the cost of providing the nutrients required to prevent that loss.

Nutrition and the Components of Performance

The sheep production year can be separated into recognisably different phases and it is convenient to begin with reproduction.

Premating phase

The premating phase culminates with successful mating. The characteristics involved are the onset of seasonal oestrous activity, the detection of heat by the ram, and the number of eggs shed after mating. Together these determine the maximum potential lambing rate.

Current and previous levels of nutrition as they affect body condition are both implicated, although to a different extent, in both onset of oestrus and in the determination of ovulation rate. Initiation of the regular breeding season and occurrence of regular heat periods appears to be unaffected by nutrition unless the animal is in an exceptionally poor condition. On many hill farms this level of condition might be found at the end of winter but considerable recovery would normally be expected through the summer, and failure to mate should not be a major practical problem.

Within limits set by the breed or individual genotype more significant variation in ovulation rate may be expected. It is not possible to make specific predictions of which animals may shed one, two or perhaps three eggs, but in more general terms, as the overall nutritional situation improves so too does the likelihood of an increase in the number of eggs and hence, on a flock basis, the potential lambing percentage. For example, in the Scottish Blackface breed it has been shown that the most important nutritional character is body condition and that this is directly related to the probability of multiple ovulation. Almost irrespective of nutrition at mating time itself, and provided she is not subjected to stressful management, a mature ewe of this breed may have one chance in ten of shedding more than one egg if she is in a relatively poor condition, rising to nine chances in ten if she is in optimum condition. The evidence to date suggests that other breeds may have quite different probabilities and may show much greater response to current nutrition. These different effects can not be predicted for different breeds without testing each and every one individually.

Where results are available, they may be used to describe the nutritional pattern most suited to the desired potential lambing percentage. Where direct knowledge is not available it is possible to apply the general principle that, whatever the breed, adequately fed ewes with sufficient body reserves and subjected to quiet non-stressful management are most likely to be successfully mated at the ordained time and to conceive up to the maximum expected from the breed. At this stage the terms 'adequate feed' and adequate body 'reserves' can not be precisely defined for all of the economically important hill breeds.

But onset of heat and release of eggs only sets the maximum potential lambing rate. If all the eggs released by a ewe fail to develop at any stage then the ewe may return to a later service or remain barren. Conversely, if only a proportion of the eggs shed as multiples are lost then pregnancy continues with the remaining egg or eggs, giving a reduction in final lambing percentage. This loss of eggs is largely determined in the next phase to be considered.

Early pregnancy

It has been shown that by far the greatest proportion of egg losses (up to 95 per cent of the total losses) occur during the first 4-5 weeks after mating. Studies on many breeds suggest that there must be a basic rate of loss (approximately 10-15 per cent of all eggs shed) due to unidentified factors which cannot be controlled. However, the actual rate of loss in many situations may be much greater. Wastage as high as 90-100 per cent of available eggs has been recorded in some especially severe experimental conditions.

The normal range found between seasons, flocks and experiments in hill sheep lies between 15 per cent minimum and a 35 per cent maximum. Some wastage is undoubtedly caused by seasonal factors such as weather, by stressful management practices and by other non-nutritional causes. It is certain that nutritional factors do play some role in regulating the losses but, due to different responses found in different breeds and to the effect of interactions amongst all the factors, it is not yet possible to make firm recommendations on nutritional patterns or on the likely savings associated with them. It can only be said that avoidance of nutritional extremes and of sudden changes between mating and the end of the first 35 days is likely to minimise wastage. Significantly higher losses have been found in both very fat and very thin, or in overfed or underfed ewes as compared with those in intermediate states. Highest losses may occur where thin ewes at mating are subsequently overfed or where fat ewes are on a rapidly declining plane of nutrition.

It can be concluded therefore that, within a breed or flock, the number of embryos passing this critical hurdle at the end of the first month of pregnancy will depend to a variable extent on the total nutritional state over the previous phases, and on achieved body condition and current nutrition. The better these are, within the bounds of what is practicable, the higher will be the potential lambing percentage.

Mid-pregnancy

The mid-pregnancy period is generally considered to extend from 30 to 100 days after mating, which with most hill ewes will cover the period from the beginning of January until early March. During this time the increase in weight of the foetus is relatively small; at 30 days it weighs less than 10 g, while weights at 100 days are around 900 g irrespective of whether the foetus is a single or one of a pair of twins. This 100-day weight represents only some 20-25 per cent of the ultimate birth weight.

In contrast to the foetus the other products of conception attain a very much higher proportion of their ultimate weight by 100 days. At this time the uterus and membranes associated with the foetus and the fluids surrounding the foetus weigh about 1·5 kg each.Thus the total weight of the pregnant uterus at 100 days is of the order of 4 kg in a ewe carrying a single foetus and around 5 kg in a ewe with twins.

The increase in weight of the gravid uterus of the hill sheep over this period is almost exactly offset by a decrease in the weight of the contents of the gastro-intestinal tract. This is due mainly to a progressive deterioration in the quality of the available herbage and hence to lower intakes of herbage. These compensating effects on live weight mean that over the early and mid-pregnancy periods apparent ewe live weight is a reasonably reliable index of changes in the weight of the actual tissues of the ewe. In traditional systems of management levels of winter nutrition are generally such that ewes lose some 4 to 5 kg live weight, representing the loss of an equivalent amount of body tissue, during the 100 days following mating.

Higher stocking rates in some of the Organisation's development projects have tended to lead to increased ewe body weight losses over this period. These have generally taken place against a background of improved early winter body condition, and of adequate nutrition in late pregnancy. To date there has been no evidence of any detrimental effects on birth weights or subsequent performance but it is not clear whether such effects have been averted by higher feed inputs in late pregnancy.

There has been little experimentation on the effects of nutrition during mid-pregnancy on subsequent production in comparison to that carried out on late pregnancy nutrition. Such evidence as exists suggests that some degree of weight loss over this period is physiologically desirable—and there is no doubt that in the practical situation weight loss at this time is economically desirable. Levels of feeding in excess of requirements can lead to embryonic or early foetal mortality and in some instances to the birth of small lambs. Although weight losses in mid-pregnancy are usual in the hill situation there is virtually no information available as to the magnitude of the losses which can be incurred without affecting production to a significant and measurable degree. There obviously must be a point beyond which the production penalty becomes unacceptable, but as yet is is not even clear as to what form this penalty would take—whether it would be manifest in terms of reduced birth weights, in general ewe debility or even in higher levels of ewe mortality.

A much better understanding of the effects of mid-pregnancy nutrition on production is required. Although the magnitude of weight losses over mid-pregnancy or any other period is undoubtedly of some consequence, the extent of the animal's body reserves, in terms of fat and protein, at the end of the period of loss is likely to be more important than actual weight. Studies on the possible effects of mid-pregnancy nutrition on production must take cognizance of the role of initial body reserves and quantify the use of these reserves during the period in question.

Work on this problem is now in its early stages, but until such time as a clearer understanding is achieved it would perhaps be prudent to adopt a nutritional strategy which limits weight losses during this period to not more than 5 kg, provided always that the initial condition of the ewes is sufficient to ensure that such a loss does not deplete reserves excessively. Restriction of weight losses over this period can be achieved using relatively small inputs of supplementary feeding—say 100 g (3 to 4 oz) per head per day. This will generally be least expensive given in the form of conventional concentrates, but when this poses practical difficulties the use of feed blocks should be considered.

Late Pregnancy

For present purposes late pregnancy can be considered as covering that period from 100 days after mating until lambing, i.e. from early to mid-April. During this time the foetus grows very rapidly, increasing in weight some four- or five-fold. There is also some further increase in weight in the other products of conception, and some development of udder tissue. Because of the rapid growth of the foetus all but the most severely undernourished ewes show an apparent increase in live weight in the weeks before lambing, although in reality all pregnant ewes on hill grazings are mobilising body reserves and therefore losing weight from their tissues. The extent to which body reserves have been used becomes apparent at lambing when ewes giving birth to single lambs generally lose about 7 kg and those producing twins may lose over 10 kg.

The growth of the foetus in late pregnancy is a relatively expensive process in terms of nutrients, and particularly energy. By the end of pregnancy the energy required by a single foetus is equivalent to that needed to maintain the ewe herself. Thus the energy requirements of a ewe carrying a single lamb immediately before lambing are approximately double that of a non-pregnant ewe, while a ewe carrying twins has a requirement of some two-and-a-half to three times that of a non-pregnant ewe. In practice, of course, these requirements are seldom if ever met in full, and ewes draw on their body reserves of fat and protein to meet the deficit between requirement and intake.

As has already been indicated, ewes are well able to mobilise their body reserves at such times. In contrast to the situation in mid-pregnancy where little is understood of the subsequent effects of undernourishment, it is now well established that one of the main consequences of undernourishment during late pregnancy is a reduction in lamb birth weight. Levels of undernourishment in twin-bearing ewes which result in reductions in birth weight of 25 per cent are not uncommon in many situations.

There are a number of reasons why it is important to prevent excessive undernourishment during late pregnancy. Although overweight lambs frequently die as a result of difficult births, very many more hill lambs are lost as a consequence of low birth weights. Ewes which have been severely undernourished not only produce lambs of low birth weight but many themselves have a poorly developed maternal instinct, thus putting the lamb at even greater risk. In addition to the now well established relationship between birth weight and lamb mortality, a further reason to seek to restrict reduction in birth weight is the relationship between weights at birth and weaning. An advantage of 0·5 kg at birth is likely to lead to a 1·5 kg greater weaning weight. Nor should the effects of excessive undernourishment on the ewe herself be overlooked. The incidence of ewe mortality is highest at the time when the ewe's reserves are least, i.e. around lambing time.

It is clear therefore that there are many factors which have to be assessed in deciding on a nutritional policy for the hill ewe flock in the weeks leading up to lambing. On the one hand there is the ewe's proven ability to draw on her body reserves and the saving in feed costs which this represents. On the other hand, and to be weighed against these, are increased levels of both ewe and lamb mortality, and reduced weaning weights of those lambs which survive. There is now sufficient information available to allow monetary values, albeit approximate ones, to be attached to the factors on both sides of the equation. Invariably the answer in the long term is that although some contribution can be expected from the ewe's body reserves, it is economic to provide sufficient supplementary feeding to keep the severity of undernourishment during late pregnancy within moderate levels.

Supplementary feeding stuffs are now more expensive, in real terms and in relation to product selling prices, than ever before, and it is imperative that such feeds can be used as effectively and efficiently as possible. In practice this means supplying feed to the ewes which need it most at those times when it is needed most. There are a number of ways in which this objective can be achieved. Firstly, the pattern of feeding should be matched as closely as possible to the pattern of foetal growth. This means starting at a relatively low level and increasing progressively as lambing approaches. Such a feeding pattern begins typically about six weeks before lambing with a level of feeding of about 100 g (3 to 4 oz) per ewe per day, and increases weekly, initially by perhaps 50 g and later by 100 g, to around 450 or 500 g (16 to 18 oz) per ewe per day.

Secondly, the main means of supplying feeding to those animals which need it most is to divide the flock, where possible, into groups of early and late lambing ewes, using ram harnesses and crayons at mating. These groups can then be fed separately according to their differing needs, feeding starting with the early lambing group perhaps 10 to 14 days before any feeding is given to the later ewes. If the season is such that there is some grass growth before lambing it may be possible to maintain the desired nutritional state in the later lambing ewes with lesser amounts of feed than were given to the early lambing group.

Where conditions allow further sub-division of the flock—and this may not always be possible—it is also worthwhile separating the gimmer age group and any particularly thin ewes from the main flock, and feeding these separately and somewhat more generously.

The only other area offering scope for making better use of expensive supplementary feeding stuff would be to identify barren, single- and twin-bearing ewes, and to feed these separately according to their needs. Although this is theoretically possible, and is in fact done to meet specific research requirements, present day technology has not yet produced a simple, reliable and relatively inexpensive method which could be applied on a commercial flock scale.

With flocks grazing grassy hills the principal demand is for energy; in such cases concentrates containing only moderate levels of crude protein (about 14 per cent) will generally be adequate. Recent research results suggest, however, that in situations where heather forms a significant proportion of the diet, higher levels of protein may be advisable. In these instances the supplement should provide between 20 and 30 g ($\frac{2}{3}$-1 oz) crude protein per ewe each day, and thus protein concentrates (of higher protein content) are required, particularly when the amounts fed per ewe are less than 200 g (7 oz) per ewe per day.

It is difficult in practice to assess the adequacy of feeding during late pregnancy. Monitoring changes in live weight and body condition can, however, serve as a useful guide. In general, ewes in moderate condition eight weeks before lambing can afford to gain less weight during the final weeks of pregnancy than the expected increase in weight of the gravid uterus. With ewes carrying single lambs an increase of about 3 kg from 8 to 2 weeks before lambing would indicate a satisfactory nutritional state; ewes expected to produce twins should gain some 5 kg over this same period.

Lactation

The number of live lambs at parturition is determined by the foregoing events. Subsequent production depends on the number of lambs which die during rearing and on the growth rate of the survivors. Survival of the new-born lamb depends on its own birth weight and vigour and on the maternal care and onset of lactation by the ewe. All of these factors are influenced by the nutritional state of the ewe in late pregnancy as well as by external events such as the weather at the time of birth.

The surviving lambs are entirely dependent on milk for 3-4 weeks and at 6-8 weeks of age milk still provides more than 50 per cent of the total energy intake. During this period the lamb makes use of between 5 and 6 g of liquid milk for every 1 g live-weight gain.

In general terms the factors which influence milk production are known. Higher levels of feeding support higher levels of milk production; suckling demand stimulates increased output; higher body condition can allow greater utilisation of reserves to maintain milk flow.

The characteristic pattern of milk production throughout lactation depends on many factors. In most cases the amount produced each day rises rapidly after parturition to reach a peak yield somewhere between 1 and 5 weeks. The peak may be sustained for a short period but declines rapidly after the fifth or sixth weeks. Depending on breed, body condition and number of lambs suckling, the nutritional level during the first period can have a very significant effect. An average daily production of 2½-3 kg/day would allow twin-suckling lambs to grow at up to 250 g/day and this level of production can be achieved without loss of weight on an energy intake of around four times that required for maintenance. At a lower level of effective production, growth rates of single lambs of less than 200 g/day would still require an intake by the ewe equivalent to twice maintenance.

In practice ewes are able to lose some live weight during early lactation whilst still meeting suckling demands in full which enables milk production to be maintained on a less than adequate feed intake. The mechanism by which this shift in partition of nutrients by the ewe is achieved, and the conditions under which it operates are not fully understood and therefore the ability to 'milk off her back' and produce a pre-determined milk output cannot be manipulated as yet by controlling nutrition. This is one of a number of unsolved problems which prevent full exploitation of potential production. These arise from the complexity of interactions amongst genetic, physiological, nutritional and environmental factors which control the level and pattern of milk production during the whole lactation and make it difficult to predict the effects of a specific level of nutrition or of management conditions on milk yield and lamb growth. In general, however, it can be predicted that increasing individual nutrition will result in earlier and higher peak yields. At higher levels of demand, that is if a ewe suckles two or more vigorous lambs, feed intake is almost certain to be the main factor limiting milk production.

After the first six weeks, when the daily rate of milk production begins to decline, improved nutrition has much less effect and even very high intakes will not sustain milk output beyond the potential of the breed. At constant and equal levels of nutrition the peak milk production achieved by twin-suckling ewes is higher than that of ewes suckling singles but the rate of decline is much faster. These effects of pattern of lactation have important consequences to the nutrition of growing lambs in respect of their developing appetite for herbage of differing quality.

The most important problem relating to nutrition and lactation derives from the fact that in most situations nutrient intake must be provided by grazed pasture although it can be supplemented in the early stages depending on the relation between the time of lambing and the onset of spring growth.

The nutrient intake of the grazing ewe depends in part on the quality and perhaps on the amount of the pasture feed on offer. Intake in the lactating ewe is also influenced by such factors as its previous nutritional history, its body condition and the magnitude of the suckling demand. As with lactation itself the salient effects are becoming known, but the precise consequences of the interactions between them in a situation where, for example, there is a changing relationship between the 'appetite drive' of the ewe and the nature and quantity of the available pasture, have yet to be elucidated.

The requirements for a high level of milk production throughout lactation are most likely to be satisfied by high quality pasture. The degree of diet selection opportunity afforded the ewe has an important effect on the quality of the feed eaten on poorer quality pastures. Pasture management is concerned with controlling pasture quality and regulating the amount of pasture per unit area and per animal. These factors can profoundly affect intake and therefore ewe lactation performance, and these effects require to be quantified.

Recovery

Before the whole cycle is repeated when the ewes are again prepared for mating it is important that they should have replaced the body reserves which were depleted during pregnancy and perhaps even during lactation. Studies have shown that, in order to obtain the same potential reproductive rate in the following season it is the replacement of reserves which is important; how and when this recovery takes place is of much less importance. Under reasonable grazing conditions a good proportion of the depleted reserves can be replaced before lamb weaning after milk production declines from its peak. Provided that intake above maintenance level can be sutained after weaning the recovery process continues. Examination of ewes as late as a month before mating can allow for the construction of a suitable feeding programme to complete the recovery of any individuals which have not reached the desired level. The problems are largely tactical.

Conclusion

The prime importance of nutrition in determining the performance of the hill sheep has been confirmed. This is not to say that breeding and health are not important, but the general level of performance of hill sheep on the hill falls far below the potential and the reasons for this are primarily nutritional.

The work summarised here demonstrates the importance of improved body condition at mating to fertility, the need for adequate nutrition in late pregnancy to ensure satisfactory birth weights and to reduce lamb and ewe mortality, and the role of nutrition in the spring and summer months in increasing milk yields and lamb growth rates, and in replenishing the body reserves.

It must not be concluded however that the objective of research in sheep nutrition is aimed at maximising individual sheep output. The object is rather to learn how to improve it within the framework of the various physical, economic and operational constraints of hill sheep farming.

These constraints are such that without land improvement there is little prospect of improving sheep performance in a significant way. The role of improved pasture in increasing output from hill grazings, which includes increasing individual ewe performance, is currently being examined in the Organisation's systems development programme. But arising out of systems of sheep production which include an improved pasture component, where pasture management decisions have to be made, where stocking rates are higher and performance is better, much remains to be done.

The need for further work on nutrition in mid-pregnancy has been outlined, and a major change in emphasis from the earlier studies often necessarily involving pen-fed sheep and artificial diets, to work with grazing ewes and lambs, has taken place. This introduces many more problems of measurement, and a much more complex situation, arising out of the fact that feed intake, which is controllable in the pen-feeding environment, becomes a variable subject to many influences which must be understood and quantified.

BETTER USE OF HEATHER HILLS FOR SHEEP PRODUCTION

J. A. MILNE AND SHEILA A. GRANT

Introduction

Heather-dominant land has been estimated to occupy some $1\frac{1}{2}$ million hectares (3 million acres) in Great Britain. Such land carries a number of vegetation types varying with climate and soil type. In regions of low to medium rainfall (750-1300 mm; 30-50 ins) where soils are freely drained, dry heather moor with high heather dominance occurs. As drainage becomes impeded and/or rainfall increases the peat layer overlying the soils becomes deeper. The vegetation is more mixed with wet moorland grasses and sedges in addition to heather. In Scotland it is estimated that 30 per cent of hill sheep are found on farms with a significant proportion of heather-dominant land. However, there is great variation in the amount of inbye land associated with such farms and also in the extent and nature of the natural grass communities found on the hill. In view of these differences it is not surprising to find that both stocking rates and existing sheep production systems vary widely. Stocking rates range from about 1 hectare ($2\frac{1}{2}$ acres) per sheep to over 4 hectares (10 acres) per sheep. Farming practices vary from traditional set-stocked year-round grazing systems with mainly Scottish Blackface sheep to systems where the heather hills are grazed in summer only and where flocks producing crossbred lambs may be found.

In hill sheep flocks output is influenced by flock size and individual sheep performance. Lambing percentages play a major role in determining sheep performance. On hill sheep farms with a high proportion of heather and a small proportion of inbye land, lambing percentages are as low as 60 to 75 per cent and the level of output is such that net farm income is low. However, on farms where the proportion of heather is less and that of good native grassland higher, both the lambing percentages and the stocking rates are above average. The economic arguments in favour of the intensification of sheep production have been discussed in some detail by Eadie (1971).

It is the biological considerations which are discussed in this article based on five years of detailed research which has involved both nutritional and ecological studies of heather. Not all the issues have been resolved but an assessment of the practical possibilities of increasing the use of a potentially cheap source of nutrients is presented. The possibilities for increasing sheep production are likely to be compatible with other forms of heather moorland use such as their management for grouse and red deer. It is intended that the results of the research outlined below will be incorporated in a developmental project on dry heather moorland at our Glensaugh station to examine the level of animal production which can be achieved in improved systems and which will be of interest to farmers, advisers and landowners.

Factors limiting sheep production

Increased use of heather by sheep is likely to have two principal consequences. The first concerns the effect that increased grazing will have on the annual dry matter production of the vegetation and on heather dominance. The second concerns the quality of the feed selected by sheep and particularly the nutritive value of heather to the grazing animal.

Effects of grazing on heather

The dry matter production of dry heather moor varies from 1750-3250 kg/ha (1500-3000 lb/ac) with heather making up the bulk of the amount. On blanket bog, production is less, being of the order of 1250-1900 kg/ha (1100-1700 lb/ac), and heather only accounts for 20 to 50 per cent of the production. At current stocking rates sheep rarely eat more than 15 per cent of the total production that grows in a year when averaged over a farm as a whole. In the case of grassy vegetation, the ungrazed leaves and flowering stems die back, accumulate as litter and impede access to fresh growth the following spring. Heather plants which remain ungrazed build up their woody stems; such heather stands soon develop to a stage where they are no longer grazed by sheep.

The problems created by the uneaten herbage have necessitated the practice of periodic burning which removes the accumulated material and restores the hill grazings to a condition where the fresh young growth is both more attractive and accessible to grazing animals. The practice of muirburn when properly used is an important management tool. Recent public concern about muirburn has led to the production of a pamphlet 'A Guide to Good Muirburn Practice' by the Department of Agriculture for Scotland (1977).

The Guide covers both the theoretical and practical considerations of muirburn in some detail. Decisions about the proportion of a grazing to burn, the size and distribution of the burned patches and the frequency of burning require careful planning. The plan should take into account the vegetational make-up of the grazing; the fact that the various vegetation types contribute to production in different ways and at different times of the year and that their ability to regenerate after burning also varies.

The amount eaten of a particular vegetation type is influenced by the nature of the herbage, the proportions of the different vegetation types present and the time of year. Bent-fescue grassland and grassy flushes are grazed in preference to grass heath, moor or bog and it is only when herbage is deficient on the former that sheep graze the latter to any extent. Similarly recently burned patches of moor, bog or heath are grazed preferentially compared with unburned vegetation. Burning too small a proportion of heather can lead to damaging levels of grazing with all the new growth consumed and many shoots uprooted. On wet moors and bogs too frequent burning or burning combined with heavy grazing results in change to flying bent and deer sedge. Similarly, if the heather is too old when burned, it is possible to kill out the heather completely, also giving rise to flying bent or deer sedge moorland. These plants die back in the autumn and so provide no winter grazing. Thus particular care with both burning and grazing management is necessary on blanket bog or wet moorland.

Current grazing experiments at HFRO are investigating how heather reacts to both the removal of different amounts of new shoots and to the season of year in which it is grazed. On dry heather moor early results indicate that some 40-50 per cent of the new growth can be removed by grazing sheep without damaging young heather. Heather was grazed in mid-summer and/or autumn with sheep numbers adjusted to eat 40 or 80 per cent of the new seasons' growth. Heather which was grazed lightly in summer only, and particularly that lightly grazed in autumn only, was under-grazed in that this allowed the stand to make too rapid a build up of woody material. Heather grazed lightly in summer and again in autumn remained short and productive; flowering in autumn was reduced and regrowth took place at the shoot tips. However, where the heather was heavily grazed, shoots were frequently uprooted and bare areas were created. Heavy grazing by sheep near bare patches also caused damage around these patches even where the extent of grazing in surrounding areas was light. Heavy grazing in autumn, particularly where the heather had been previously grazed in summer, often resulted in the death of the aerial portion of the heather shoot with regrowth the following season coming from the shoot bases. These shoots were not readily accessible to the sheep.

Areas of young heather damaged by two years of heavy grazing showed rapid recovery when protected from further grazing. However, the longer the period of heavy grazing is, the more damaging it is likely to be; other species will have more time to establish and the continual removal of green shoots will deplete food reserves in stems and roots and ultimately kill the heather.

Where soils are waterlogged heather grows less vigorously and is therefore less tolerant of grazing. On blanket bogs the vegetation is mixed i.e. competitors are already present. In addition bogs are often grazed more heavily in autumn and winter when flying bent and deer sedge have died back and are not available. Thus where heather cover is low the heather may be quite heavily grazed so that harmful effects of grazing are likely at much lower stocking rates than with dry heather moor.

Feeding value of heather

On a well managed hill increased use of heather by increasing ewe numbers should be possible without causing a reduction in the productivity of heather or affecting its ground cover. However the increased use of heather will have important effects on the feeding value of the diet selected. Sheep graze principally the new season's shoots of heather and in most circumstances will eat more than half the length of the new season's shoot. Sheep eat a smaller part of the new season's shoot in the summer than in the autumn or winter and in autumn will select previously grazed shoots which have regrown in preference to those shoots with flowers on them. Sheep graze some areas of heather in preference to others. Younger heather, where the new season's shoots are more easily accessible is preferred to older heather where the stand may be tall or diffuse with the new season's shoots associated with older green material. Heather is grazed preferentially near grassy areas and in one experiment particularly heavy grazing took place around bare areas where heather had not regenerated after burning.

From feeding experiments where current season's shoots have been offered to sheep, the digestibility of the heather shoots declined from around 60 per cent in June to 50 per cent in August after flower initiation and thereafter dropped to 40 per cent by late winter. These digestibility values are lower than those of the better hill grasses in the summer and autumn. Also, at a given level of digestibility sheep eat less heather than grass of a similar digestibility and thus the feeding value of heather is lower than that of grass. For these reasons heather alone for most of the year provides a diet which does little more than maintain the weight of sheep; it is certainly inadequate to meet the nutritional requirements of ewes during lactation and for body weight recovery during the summer.

Other plants of the drier heather moors such as blaeberry and bell heather, are unlikely to be of a better value than heather. Summer nutrition in these hills is adequate because of the large amount of grass eaten from the associated patches of better hill grassland which are usually closely grazed. On the blanket bog areas these better grasses are found in smaller amounts and poorer quality pasture species such as flying bent, deer sedge and spret make up the diet in summer. It has been shown experimentally that a ewe in mid-lactation can eat up to 40 per cent of its diet as heather, the remainder being made up of grass, without depressing lamb growth rates. However ewe body weights were only maintained and this has importance in relation to the ability of ewes to recover body weight before mating.

During the autumn and into the winter the amount of heather in the sheep's diet increases as other plants grazed by the sheep are also of poor quality. On blanket bogs these include cotton sedge and stool bent and in drier areas grassy vegetation under bracken and in flushes. In winter the diet the ewe is able to select from predominately heather areas is such that substantial energy and protein deficits are inevitable.

Thus it can be concluded that attempts to make more use of heather by simply increasing ewe numbers are likely to have undesirable consequences on annual ewe performance. To achieve greater utilisation of what after all is a cheap source of nutrients for sheep requires the introduction of some improved areas of reseed. This would enable the overall quality of the diet to be at a level to support the productive processes of lactation and ewe body weight recovery prior to mating and also would allow for an increase in the use of heather.

Land Improvement

On a few farms, where the heather hill has larger than average bent-fescue patches, it may be possible to achieve the desired level of pasture improvement by manurial treatment and grazing management alone. However in the majority of cases pasture providing an adequate level of nutrition for improved animal performance will only be achieved through the establishment of sown swards. Surface seeding following minimal cultivation can be successful providing care is taken with ground preparation and choice of sowing date. The North of Scotland College of Agriculture's 'The Improvement of Hill Pastures' (1972) has discussed fully the variations in procedure in relation to a variety of natural vegetation types. The main differences between wet and dry sites in methods of land improvement are briefly detailed below.

The existing vegetation is normally removed by burning except on sites where the heather is very short or on bog sites where plant cover is sparse. On dry sites it is considered beneficial to apply lime and phosphate some months in advance of cultivation and sowing, while on wet sites, particularly where native plants which respond to lime and phosphate occur, application just prior to sowing is best. Dressings of 2 to 3 tons/acre (5000-7500 kg/ha) ground limestone and 10 cwt/acre (1250 kg/ha) high grade slag, or 6 cwt/acre (750 kg/ha) ground mineral phosphate in the wetter west, are considered necessary. Surface cultivations are usually carried out immediately before sowing using heavy disc harrows. On wetter areas such cultivations are not always possible. Fertilisers supplying nitrogen, potassium and trace elements are applied just before seeding. Early seeding (March) is best where there is little risk of spring frost or drought otherwise sowing should be delayed until late June. If possible it should be completed by early August. The improved areas should be fenced to permit grazing control. This is necessary to allow the pasture to be used to best advantage and to avoid damage to the sward by overgrazing or poaching.

The provision of suitable areas of improved pasture and their integration in a management system with the rest of the hill is being investigated both in the blanket bog and in the dry heather situations. The outputs and financial results from these studies have been encouraging and, provided that the increased stocking rates do not reach levels at which diet quality starts to decline, then this would appear a useful approach. The extent to which stocking rates can be increased on the hill without producing harmful effects on the vegetation is also being investigated.

Means of increasing sheep production

Heather is a cheap source of energy and protein for the sheep, and with present knowledge of the extent to which heather can be grazed without damage to the plant, there are considerable attractions in creating areas where reseeded improved species of grasses are associated with heather-dominant areas. This would particularly apply where only small areas of reseeds could be established because of slope or difficulty of access. The heather and grass mosaic areas would be grazed in the summer and autumn to provide adequate levels of nutrition during those periods for the ewe. To test these ideas experiments have been conducted to examine the proportion of grass by area required in the mosaic and how these areas could be managed to achieve adequate levels of nutrition. Results from these experiments have shown that the proportion of grass by area should be about 30 per cent and that grazing should be such that by late autumn about 40 per cent of the current season's shoots of the heather have been eaten. By removing this proportion of the current season's shoots the growth form of the heather plant can be maintained nearer the optimum for grazing for a greater length of time and the need for periodic burning will thus be considerably reduced.

The quality of the diet selected from these grass/heather mosaic areas during the summer would appear sufficient to support a ewe nursing a single lamb and in the autumn should allow small increases in ewe body weight. The proportion of heather in the diet, which has obviously a considerable effect on overall diet quality, has been found to be related to the quantity of grass available to the sheep. The more grass available to the sheep the less heather there will be in the diet. Further experiments have shown that grazing management which maintains the grass component between 500-1000 kg DM per ha (450-900 lb DM per acre) should provide a sufficient quality of diet. To obtain the advantages of a grass and heather mosaic that have been outlined above, the area containing the mosaic should be fenced off from the rest of the hill.

There is a further advantage in both grass and heather being present in the sheep's diet. Trace elements, particularly cobalt, are found in reasonable amounts in heather but not in grass species in reseeded areas. Sheep grazing reseeded areas for some time have been found to be suffering from sub-clinical deficiency of cobalt. The inclusion of heather in the diet would be one way of alleviating this situation.

One consequence of introducing reseeds to provide an acceptable level of summer nutrition is a change in the pattern of use of the hill vegetation. Increases in stocking rate made possible by the introduction of reseeds will inevitably put more pressure on the hill as a source of late summer–early autumn and winter feed. Experimental results show that the better grassy patches are hard grazed by the onset of winter and that the proportion of heather in the diet increases. Sheep on heather hills at fairly low stocking rates lose considerable amounts of liveweight during the winter. This is acceptable provided that the ewe is in good body condition in early winter and that supplementary concentrate feeding is given in the last 6 to 8 weeks prior to lambing. As stocking rates are increased heather forms a larger part of the winter diet and it is probable that weight losses in early and mid pregnancy will be higher. The importance of weight loss in mid pregnancy on subsequent ewe and lamb performance and in relation to supplementary feeding is at present being studied.

In experiments the addition of small amounts of protein or nitrogen, as urea, up to 3 g nitrogen/day, and energy in the form of sugars given by continuous infusion has increased the amount eaten and the digestibility of heather so that intakes of digestible dry matter have increased by at least 50 per cent. However when the supplements were given less frequently, akin to current block feeding or concentrate feeding situations, there was little increase in intakes of digestible dry matter from heather. Even at high stocking rates in winter the diet of the sheep contained only on average 60 per cent of heather with hill grasses making up the remaining 40 per cent. The responses to supplementation may be less when heather is a smaller proportion of the diet. Consequently considerable experimental work is still required before firm recommendations on supplementary feeding during the winter on heather hills can be made.

Conclusions

In most situations increased use of existing hill vegetation, particularly of heather, by increasing ewe numbers is likely to have damaging effects on individual animal performance before harmful effects on the vegetation occur. However, harmful effects on the vegetation are more likely at rather lower stocking rates on blanket bog vegetation than on dry heather moor. The introduction of reseeds together with increase in stock numbers leads to both changed patterns and increased levels of utilisation of hill herbage. This increase in use of hill vegetation is likely to be relatively small. By associating reseeded areas with heather in a mosaic, which is fenced off from the rest of the hill, further increases can be obtained in the use of heather within the mosaic. These mosaic areas would be grazed in the summer and autumn. Such mosaics could be used either alone or in conjunction with reseeds. The increased reliance on heather in the winter may lead to problems with winter nutrition. The means of overcoming these problems is currently under investigation.

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TRIFOLIUM REPENS (WHITE CLOVER): ITS ROLE, ESTABLISHMENT AND MAINTENANCE IN HILL PASTURES

P. NEWBOULD AND A. HAYSTEAD

Introduction

The importance of white clover in hill land improvement is widely accepted and publicised in scientific circles (Munro, 1970, 1973; Newbould, 1974; Mytton, 1975) and yet there are still farmers who are reluctant to depend on it because of uncertainty about its role and its unpredictability in establishment and production (Wright, 1975). A few scientists and advisers have also expressed concern about its possible impact on animal health. Some of the questions farmers and others ask about white clover are:— "Why should I grow it?" "What variety should I grow?" "Which grass should I grow with it?" "How much seed should I sow?" "Is all my land suitable for it?" "How do I obtain predictable and rapid establishment and growth?" "What is nitrogen fixation? "What is inoculation?" "Do I need to inoculate my seed and, if so, what is the best method?" "Do I need to fertilise my white clover/grass swards with nitrogen?" "How do I manage my white clover/grass swards to maintain a high proportion of clover?" This article attempts to answer these and other questions by briefly describing the key role of white clover in hill land improvement and present knowledge of the biological processes which underpin its growth and which affect the establishment and maintenance of clover-rich pastures in practice. Many detailed aspects of knowledge on this subject up to 1969 were reviewed in the proceedings of a symposium edited by Lowe (1970). In conclusion research work presently in progress which might result in the further development and refinement of procedures for the growing of white clover in hill pastures is briefly described.

The Role of White Clover

1. *Source of nitrogen—why needed?*

Hill soils rich in organic matter contain large quantities of nitrogen (up to 10000 kg/ha) but only a small part of this (approximately 30 kg N/ha) is available for absorption by plants (Floate, 1971).

Organic residues of plant and animal origin must all undergo breakdown or mineralisation before becoming available to plants. This is a slow process, especially in hill conditions, due mainly to low temperature and high acidity. Nitrogen in inorganic fertilisers, urine and rain is readily available to all plants, while the fixation of atmospheric nitrogen in the nodules of clover plants, a process to be described in more detail later, supplies nitrogen directly to the clover but only indirectly to the companion grasses. Soil nitrogen in available form moves readily into plants and when the latter are consumed by grazing animals the nitrogen is utilised in the animal almost immediately. However, the nitrogen returned to the soil of grazed hill pastures as unconsumed plant material or as faeces only slowly changes into an available form. This slow change forms a bottleneck in the cycling of nitrogen from soil to plant to animal and back to soil again and so creates the need for substantial inputs of nitrogen if more pasture is to grow. The amount of available nitrogen required to increase herbage production cannot always be provided by regular annual dressings of fertiliser in hill sheep farming systems because of the high cost. In many circumstances, because of the relatively poor response of grasses growing in the hill environment to additions of nitrogen, there is often a bigger boost to pasture production, and hence a more favourable financial return if money is spent to improve a new piece of hill ground rather than spending the same amount of money on annual dressings of fertiliser nitrogen (Eadie, 1973). The only economically viable alternative is to grow white clover, and to manage it in such a way that it grows vigorously and fixes nitrogen from the atmosphere throughout the growing season, so that as much as possible of the fixed nitrogen is transferred to the grasses in the sward whilst maintaining a good proportion of white clover.

White clover producing about 30 per cent of the total annual dry matter of a mixed hill sward has been shown to contribute about 100 kg nitrogen per hectare to the sward (Munro and Davies, 1974; Haystead and Lowe, 1977). If the clover is well managed, as described later, this contribution of nitrogen can be obtained for a number of years. Full replacement of clover by nitrogen fertiliser would require an average annual application of at least 200 kg fertiliser nitrogen per hectare since the average efficiency of use of nitrogen fertiliser is only about 50 per cent because of losses in drainage and by bacterial denitrification. At present prices this would cost £20 per hectare and this amount would have to be expended each year. Thus, over a ten year period the total amount spent per hectare would be £200. If the same amount of money was invested in land improvement to establish white clover, just less than three hectares of clover-rich pasture could be produced. Although the total yield of dry matter per hectare might be somewhat less for the clover (say 4500 kg/ha) than the nitrogen (5500 kg/ha) based sward there would still be a marked production advantage per pound invested in the former system. In addition to this very significant bonus the system based on white clover has additional benefits which are described below.

2. *High quality herbage for animals*

Compared to grass, white clover herbage has a higher crude protein content, a higher level of digestible energy, a higher mineral content of magnesium, calcium and iron, and is high in carotene. When clover is a component of the diet the voluntary intake of all feed by the animals is increased (Thomson and Raymond, 1970) and some recent experiments indicate that the efficiency of utilisation by lambs of the digested organic matter is enhanced (Armstrong and Eadie, 1973).

These arguments might suggest that it would be preferable to grow white clover alone. However, it is extremely difficult to keep white clover weed free because of its growth form. A further disadvantage to the sole use of white clover lies in its relatively short growing season. Thus, the need for consistent yields of herbage spread over the season and for a companion plant that can benefit from the nitrogen transferred from the white clover and take some of the treading pressure on the sward means that mixed swards of clover and grass must be used despite some difficulties inherent in their management.

There have been no reports, even from lowland situations, that there are sufficient oestrogens in white clover of a type to interfere with reproduction in animals. A very different picture to the marked effects found with red and subterranean clover, particularly in Australia (Adams, 1975).

Nitrogen Fixation, Symbiosis and Transfer

1. *Nitrogen fixation*

Fixation is the process by which nitrogen gas present to the extent of 75 per cent by weight in the atmosphere is changed to a form which can be utilised by green plants. This change can be brought about by chemical means as in the manufacture of fertilisers or by the action of living micro-organisms either by themselves or in association with green plants. The underlying reaction, whether chemical or biological, is a joining together of gaseous nitrogen from the air with hydrogen gas derived from oil or water to form ammonia, as summarised in the following equation:—

$$\underset{\text{nitrogen}}{N_2} + \underset{\text{hydrogen}}{3H_2} \xrightarrow[\text{Industrial chemical reactions}]{\text{Nitrogen fixing organisms}} \underset{\text{ammonia}}{2NH_3}$$

The chemical process is mediated by special metal catalysts while the biological one depends on the presence of a biological catalyst or enzyme called nitrogenase. Catalysts are substances which accelerate or promote chemical actions without themselves being changed. From an economic standpoint, however, the value of the biological process lies in the fact that it can function and fix nitrogen efficiently at normal temperature and pressure using sunlight as the energy source. The chemical process, on the other hand, requires extremely high temperature and pressure, both expensive to maintain in these days of high cost energy, if a good yield of ammonia is to be obtained.

The utilisation of sunlight to drive the chemical changes that go on in green plants takes place in the leaves. As the leaves absorb sunlight they take up or **fix** carbon dioxide from the air around them and use it to manufacture sugars. These sugars, manufactured, or **photosynthesised**, in the leaves are used to make all the carbon-containing components of the plant and also act as fuel to drive chemical transformations in the plant. After being transported to all parts of the plant the sugars are re-converted to carbon dioxide, releasing the energy they contain, to carry out processes like nitrogen fixation and nitrate assimilation in the roots.

There is no similarity between fixation of nitrogen and carbon and the term phosphorus fixation which describes the process by which soluble phosphate from fertilisers is rendered unavailable to plants by precipitation or attachment to exchange sites in the soil.

2. *Symbiotic nitrogen fixation—white clover and Rhizobium trifolii*

The ability to convert gaseous nitrogen into a form which can be assimilated by living organisms is limited to microscopic organisms, amongst which the bacteria are by far the most important in temperate regions. Although many bacteria fix nitrogen as they grow in the soil, organisms of the genus *Rhizobium* usually only fix nitrogen after they have infected the roots of a legume to form root nodules. These nodules contain both plant and bacterial tissue and are the site of nitrogen fixation. Inside the nodule the bacterium (*Rhizobium trifolii*) is provided with the correct environment and a suitable energy source to enable it to fix nitrogen. In turn some of this nitrogen is made available to the plant. An association of this type, in which both partners benefit, is called a symbiosis and although the ability to fix nitrogen is exclusively a bacterial characteristic nodule fixation is described as symbiotic nitrogen fixation.

Some rhizobia which do infect and nodulate white clover do not form associations that fix nitrogen efficiently; they are described as 'ineffective'. 'Effective' rhizobia form active nodules, often large, multi-lobed and red in colour, while 'ineffective' rhizobia form inactive nodules which are frequently small and white. Nodules can also be of intermediate 'effectiveness', ranging on a scale between the two extremes.

The larger effective nodules are often found on the main roots of the clover plants near to the soil surface while the smaller ineffective nodules tend to be distributed throughout the root system. Recently, it has been found that associations between some selected strains of *Rhizobium* and particular varieties of white clover can be exceptionally efficient at fixing nitrogen. For this reason, it may be possible that the amount of nitrogen fixed by white clover to be grown in soils already possessing effective strains of rhizobia might be enhanced if super-effective or elite strains of *Rhizobium* were added to the soil, and if they were able to compete with the existing organisms and form nodules.

The overall process by which an active symbiosis between rhizobia and white clover is formed falls into a number of stages: (a) rhizobia and a young clover root come together in the soil; (b) infection of clover root hairs occurs; (c) nodules develop at the site of infection; (d) the nodules become active in fixing nitrogen.

The need for 'inoculation' (Stages a and b).

Rhizobia are only abundant in soil when associated with their host legume and they are strongly affected by adverse conditions such as heat, drought and acidity. A characteristic of hill soils is that, if they contain rhizobia at all, they are either non-infective (that is do not penetrate clover root hairs) or are ineffective, producing inactive nodules (Holding and King, 1963).

Provided soil conditions are suitable both of the above types of rhizobia will grow and compete with other micro-organisms in the absence of a host plant. However, some soils, especially peats which are frequently too acid and contain bacteriocidal substances, inhibit rhizobial growth. Reduction of acidity on all soil types, by liming, will create an improved environment for rhizobia which will grow and increase the possibility of clover nodulation. Conversely, if the soil becomes waterlogged and oxygen cannot penetrate then the rhizobial population will fall and clover will fail to nodulate.

The chance introduction of even a few effective rhizobia on seeds, farm implements, workers' boots or animals' feet can have a considerable impact on clover growth if soil conditions are favourable, since it is possible that white clover has the ability to select the most effective strains of *Rhizobium* from a mixed population (Masterson, 1973).

Unfortunately, in many soils these processes do not always occur naturally; in these situations good nodulation will only take place if effective rhizobia which match the variety of white clover to be grown are deliberately added to the soil. There are several ways in which this can be done. Bacteria can be sprayed on to the soil or can be added in a solid form along with fertiliser. However, the most usual, and possibly the most efficient way, is to treat (or 'inoculate') the clover seed with a layer of bacterial cells suspended in a mixture of ground peat and glue. After the glue has dried the seeds run freely and can be mechanically sown. A coating of lime can be added to the inoculated seed to speed up drying and make the seed run even better. Table 1 gives a suitable recipe for the inoculation of white clover seed on an agricultural scale.

TABLE 1

Inoculation of clover seed with rhizobia

Requirements:

1. 2·5 kg white clover seed.
2. Rhizobial culture containing $13{\cdot}5 \times 10^8$ cells in 100 ml of growth medium.
3. 'Sticker' or glue composed of 14 g of methyl cellulose in 280 ml of cold tap water.
4. Finely ground peat*—25 g.

* The peat used should be of a special type—non-acid and low in sodium.

Procedure:

Mix the peat with the culture of rhizobia and then with the glue. Add the seed and stir until all the seeds are coated. Allow to dry for 2-3 hours in a cool dark place. Mix quickly to break up any lumps and sow as soon as possible.

Clover seed inoculated by this technique is almost invariably used in New Zealand and Australia when hill land is oversown with clover and under some circumstances (soils with a thick layer of peat) can be shown to be of considerable benefit to similar improvement schemes in the United Kingdom (see Table 2). However, the benefits of clover inoculation in British hill land are not always apparent and in many cases have been disappointing, particularly where commercially prepared inocula or seeds inoculated some time before sowing (pre-inoculated) have been used. There are a number of reasons why this may be so. The first, and perhaps the most important of these, is the poor 'quality' (i.e. low numbers of rhizobia) in commercially available inocula. Australian standards require that clover seed should be sown with no fewer than 300 viable rhizobial cells per seed at the time of sowing if good nodulation is to be ensured. In a situation where the added rhizobia are required to compete with an infective, but possibly ineffective, indigenous population, this figure can only be a minimum and a much higher viable cell count should be used whenever possible.

TABLE 2

Effect of inoculation of white clover seed with rhizobia on deep peat at Lephinmore (Sowing Date 28.6.72)

Seedling Emergence (No/m^2)	Untreated seed	Rhizobia* on seed
20.7.72	543	558
26.9.72	221	498
23.3.73	65	323
Loss of seedlings over winter (%)	71	35
Yield of dry matter (kg/ha)		
10.6.73 Clover	20	534
Perennial ryegrass	110	259

* Mixture of three strains selected and cultured by Dr A. J. Holding, Edinburgh School of Agriculture.

Secondly, current research in Australia shows that commercial pre-inoculation of legume seeds in which seeds are inoculated several weeks before sowing, is not yet sufficiently reliable if expensive pasture improvement schemes are at stake. In most batches of seed examined the number of living rhizobia was low and in many they were completely absent. The shelf life of pre-inoculated seed, whether commercially prepared or home-produced, is limited (see Fig. 1). The very rapid fall-off in the numbers of living rhizobia per seed shown in the figure occurs under near ideal seed storage conditions. Rhizobia would probably die even faster under normal conditions of transport and storage of seed for agricultural use. To be certain that inoculum quality is high, inoculation should take place no more than two days before sowing, the seed being stored in a cool dark place until required.

Thirdly, the strain of *Rhizobium* may not suit the variety of white clover in the soil conditions where it is to be sown.

The growth of nodules and the onset of nitrogen fixation (Stages c and d)

Once infection has taken place the rhizobia enter the root and form active nodules provided that (a) sufficient energy in the form of sugars transported from the leaves (see p. 52), and soil nutrients are available for the growth of nodule tissue and the synthesis of the nitrogen fixing enzyme (nitrogenase), and (b) that the root environment is favourable for nodule development to occur.

The factors which exert the greatest influence on these processes

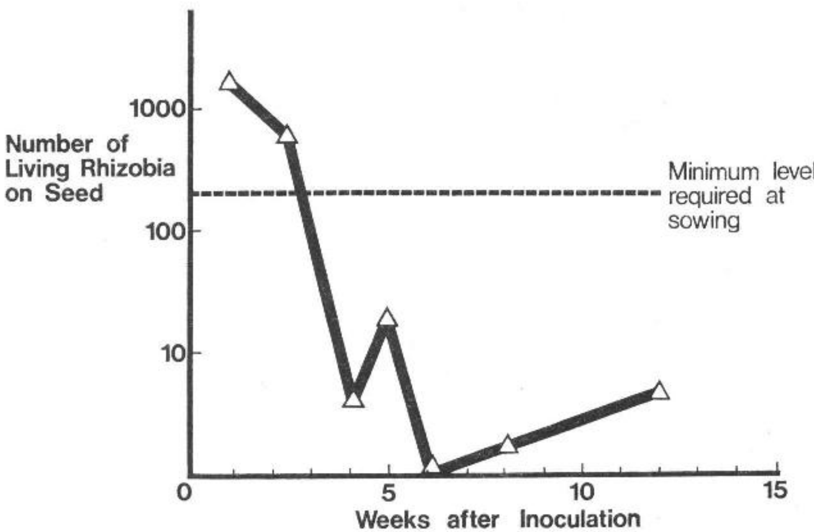

FIG. 1.—Shelf life of pre-inoculated white clover seed (Brockwell *et al*, 1975).

are temperature, the amount of nitrogen fertiliser in the soil and the availability of various micro-nutrients (e.g. cobalt, molybdenum, boron) involved in the biochemistry of the nitrogen fixing system.

Temperatures below about 7°C inhibit root infection but nodule development and the onset of nitrogen fixation can occur below this limiting temperature. In hill environments soil temperatures frequently remain below 7°C until late in the spring but fixation may occur in established clover in early spring as new nitrogen-fixing tissue can develop in existing nodules.

Fertiliser nitrogen, in either the nitrate (NO_3^-) or ammonium (NH_4^+) form, inhibits both infection and nodulation. Nodule growth is depressed if infection has taken place and the onset of nitrogen-fixing activity can be arrested or delayed.

During the establishment phase of a newly sown sward, clover seedlings growing in a nitrogen deficient soil pass through a stage of severe nitrogen deficit which may last for 5-6 weeks. This period occurs after the very limited seed reserves have been exhausted and before the nodules have become fully functional. In these circumstances it is beneficial if a small amount of fertiliser nitrogen is made available to the clover seedlings. A marked improvement and acceleration in clover seedling establishment can be obtained without too much effect on nodulation and nitrogen fixation. Moreover, some

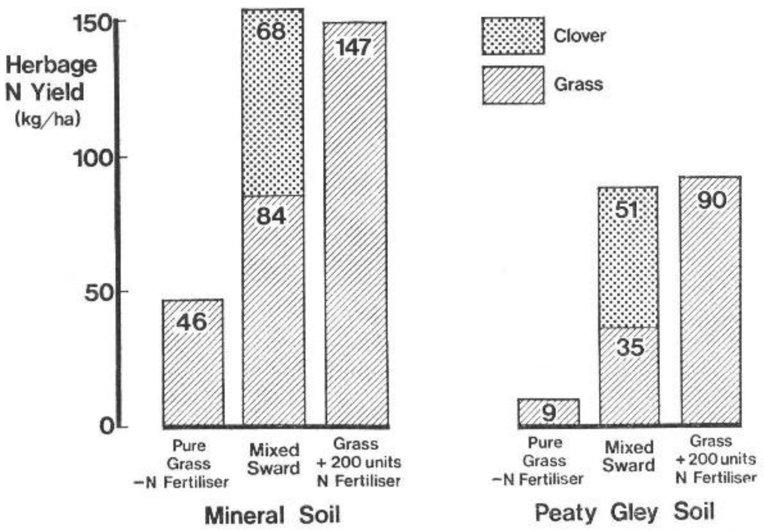

FIG. 2.—Clover contribution to the herbage N yield of mixed swards on hill soils (after Munro and Davies, 1974).

nitrogen fertiliser is needed for the grass component of the mixture until it can be provided by transfer from the clover. For these reasons it is usual practice to add from 30-80 kg N/ha to the seed bed of a mixed sward.

The amount of nitrogen fixed by white clover in agricultural systems

The contribution made by white clover to the nitrogen economy of grass/clover swards has been measured in a number of ways. The most straightforward approach is to compare rates of production in pure grass swards with those observed in grass/clover mixtures. If this is done the results obtained are most often of the type shown in Fig. 2. Clover increases total sward yield of nitrogen in two ways. Firstly, it contributes the nitrogen in its own leaves, and secondly, it stimulates the growth of the grass component. In an experiment in which plots of grass are grown with nitrogen fertiliser instead of clover, the fertiliser equivalent of clover can be calculated. Several experiments of this type have been conducted over the last ten years or so in a variety of different agricultural situations. Table 3 shows the results obtained by a number of experimenters using this method. The net contribution of clover to a sward is not necessarily a measure of the amount of nitrogen being fixed by white clover since it does not tell us how much of the fixed nitrogen is immobilised in the soil,

TABLE 3

Contribution made by white clover to the nitrogen economy of a grass/clover sward

	Nitrogen contribution (kg/N/ha/yr)			Fertiliser* equivalent (kg N/ ha/yr)
	Direct (Clover-N)	Indirect (Extra grass-N)	Total	
Herriott and Wells 1960 (ryegrass/clover)	99	85	184	373
Cowling 1961 (cocksfoot/clover)	110	67	177	215
Reid and Castle 1964 (ryegrass/ clover)	78	43	121	185
Munro and Davies 1974 (ryegrass/clover)				
Mineral soil	51	39	90	128
Peaty podzol	48	50	98	229

* Fertiliser-N required to give the same total yield in the absence of clover.

lost to the air, or washed out of the soil by rainwater. It is almost impossible to measure nitrogen fixation under grazing conditions—which, after all, is what really counts to the farmer. If a grass/clover sward is to be correctly managed then we need to know, not only how much nitrogen is fixed per growing season, but precisely the periods of maximum fixation and loss, and the effects of sward management factors on these patterns of nitrogen fixation.

In the last few years new techniques have become available which enable the experimenter to measure nitrogen fixation directly. The most important of these is the acetylene reduction method which exploits the fact that all biological systems (free-living bacteria or symbioses) which fix nitrogen can also produce ethylene gas from acetylene gas. The ethylene produced is released into the air around the nitrogen fixer and is easily measured. So, by enclosing clover plants in a container with acetylene and measuring the ethylene produced, the nitrogen fixing capacity of the plants can be determined under the prevailing conditions. Using this method it is possible to determine the pattern of nitrogen fixation over a single day (see Fig. 3a). The different behaviour shown by plants growing in the same soil in pots or in the field is probably due to changes in the temperature of nodules in the pots but not in the field. It is also possible to follow the pattern of nitrogen fixation over a growing season, or perhaps most important of all, to compare the amounts

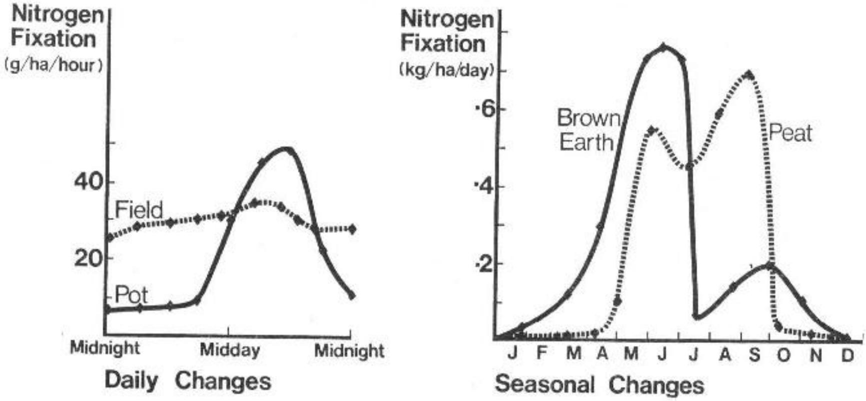

FIG. 3.—Changes in nitrogen fixation by white clover assessed by acetylene reduction.

(a) Daily—plants grown in the same soil in the field or in pots;

(b) Throughout a growing season—plants grown in two types of hill soil.

of nitrogen being fixed in swards treated differently or on different soil types (Fig. 3b).

Factors affecting clover nitrogen fixation

The rate at which effectively nodulated clover fixes nitrogen is ultimately dependent on two things: the rate at which the plant can produce sugar in its leaves and hence supply energy to its nodules, and the ability of the nodules to utilise this energy. Since the energy for symbiotic nitrogen fixation is generated photosynthetically in the leaves it is affected by climatic factors such as the availability of sunlight and the temperature of the leaves and the tissues conducting sugars to the roots and nodules. Management factors, for example cutting and grazing, which reduce the amount of foliage, similarly affect the generation and transport of sugars to the nodules and will reduce the rate at which a clover plant can fix nitrogen. The second rate-limiting factor, the capacity of the nodules to utilise energy supplied by the leaves, is a function of their number and size and of the efficiency with which they utilise sugar for the fixation of nitrogen.

From the agriculturist's point of view, the supply of energy to drive nitrogen fixation is clearly maximised by procedures which optimise photosynthesis. For example, grazing and cutting regimes should be sufficiently severe to prevent shading by the grass component of the sward whilst at the same time maintaining a good proportion of clover leaf. However, as we shall see in the next section, procedures which give the best rates of clover growth and nitrogen fixation do not necessarily give the highest rates of fixed nitrogen release to the soil and the grass component of the sward, which, from the point of view of whole sward productivity, is equally as important.

3. *Transfer of nitrogen fixed by white clover to other plants*

Nitrogen fixed by white clover growing in association with non-nitrogen fixing plants (grasses for example) is released into the soil and ultimately becomes available to the roots of both grass and legume. There are several ways in which this transfer can take place. A limited amount of nitrogen may be lost or actively secreted (exuded) from growing clover roots and may diffuse out into the soil. The extent to which this process operates varies from legume to legume, but in the case of clover probably represents a small proportion of the total amount of nitrogen released. Clover nitrogen is also lost to the soil as leaves and stolons decompose at the soil surface. This process occurs as older leaves are shaded by expanding new ones and as the result of mechanical damage to the sward. A similar sort of nitrogen release occurs when clover roots and nodules break down in response to chilling (for example with the onset of winter), shading (usually by a vigorously growing companion grass) or defoliation in cut or grazed swards. The largest movement of fixed nitrogen, however, occurs through the grazing animal and is released to the soil in the form of urine and faeces.

The relative importance of these different transfer processes varies during the season and is different for different legume/grass associations, climatic conditions and soil types. In general, however, published evidence tends to show that although 80 per cent of the fixed nitrogen returned to the soil passes through the grazing animal (of this about 75 per cent is urine-nitrogen) and immediately benefits the grass, this flux is not necessarily the most important in terms of the slow build-up of soil fertility. There are a number of reasons why this may be so:

1. The deposition of urine and dung is patchy, a fact which is of particular significance in extensive hill grazing systems although it might be less evident in the small enclosed areas of improved pasture.
2. Once deposited, urine-nitrogen can be lost to the system by leaching and as gaseous products of bacterial activity.
3. Faecal-nitrogen is incorporated into the soil quite slowly by rain and treading but thereafter most of it, like urine-nitrogen, can be mineralised and so becomes available for absorption by plants and susceptible to leaching.

It seems then that whilst the grazing animal serves to increase the rate at which nitrogen cycles within the plant/soil system the long term increase in soil organic matter and the plant available nitrogen pool probably occurs as a result of the cycle of growth and decay of the clover roots and nodules.

Factors affecting the transfer of fixed nitrogen

In swards where the proportion of clover is increasing, or is maintained at a constant level, the rate of underground transfer of fixed-nitrogen is low. Conversely, when the clover percentage is being depressed by climatic or management factors, the loss and breakdown of clover roots and nodules increases, and the rate at which nitrogen is released into the soil and taken up by companion plants is high.

Factors which depress the proportion of clover in a sward can be divided into two main types, those which increase the rate at which the grass component grows and hence increase the severity of competition for light and soil nutrients, and those which specifically inhibit clover growth. Some of these factors can be controlled, for example nitrogen fertiliser application and adjustment of grazing pressure, whereas others, such as soil desiccation and changes in soil temperature due to climate cannot. Both sets of factors interact in a complex way making it difficult to predict the state of nitrogen transfer at any point in time. Some of the general ways that particular events alter the situation are listed below:—

Fertiliser nitrogen: In general, grasses compete more strongly for soil nitrogen than does clover, and in the presence of high soil nitrogen will grow and shade out the clover component with a consequent release of fixed nitrogen into the soil. In the continued presence of fertiliser nitrogen, however, nitrogen fixation will be prevented and nodulation of new root material will not occur. The percentage of clover in the sward will fall and may not increase again even when the fertiliser nitrogen is depleted.

Cutting and grazing: Severe defoliation, i.e. frequent, and with herbage cut to less than about 3 cm in height, arrests nitrogen fixation and induces a breakdown of roots and nodules in which one-third to one-half of the root and nodule nitrogen may be released to the soil (Chu and Robertson, 1974). As shown in Fig. 4, however, nitrogen fixation is slow to restart and the productivity of the whole sward will be depressed. Moderate defoliation, i.e. infrequent, and with herbage cut to no less than 5 cm in height, on the other hand, favours the clover component by making more light available and

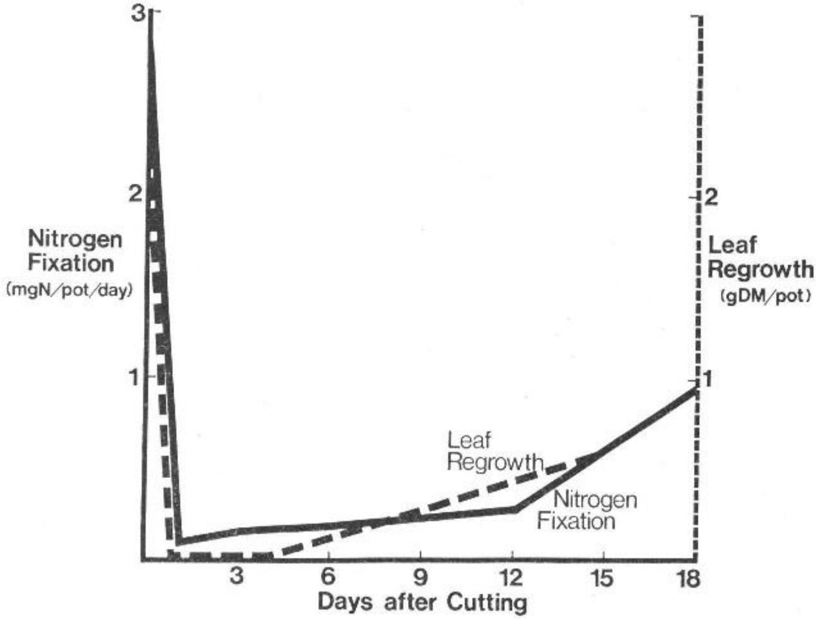

FIG. 4.—Effect of cutting on clover nitrogen fixing activity.

at the same time permits the release of a proportion of the clover fixed nitrogen to the soil (Butler *et al*, 1959). Nitrogen fixation is not completely arrested when a proportion of the foliage remains intact, thus sward productivity is maximised.

The effects of moderate and severe grazing are similar to those of cutting with the additional effects of treading and the return of animal excreta to the soil surface. Treading tends to depress the growth of clover more than that of grass since clover shoots are more easily damaged. Smaller leaved, more prostrate varieties of clover are more resistant to treading than are the larger leaved, more productive varieties. The return of nitrogen to the soil in the form of animal excreta promotes vigorous grass growth thus depressing growth of clover by shading; it also depresses nitrogen fixation and inhibits nodulation. In the hill pasture situation these effects are most marked in night camp areas which are often lightly grazed and tend to become rank with a high proportion of weed species.

Nutrient depletion: As an improved pasture ages there is a tendency for soil acidity to increase and for there to be a gradual leaching and removal of plant nutrients. Clover is more sensitive to these effects than are the usual sown grasses and its growth will be depressed as the phosphate and potassium status of the soil decreases. Removal in herbage of trace element nutrients intimately involved in the nitrogen fixation process, notably molybdenum and boron, may similarly depress the clover percentage in an ageing sward. When this process occurs fixed nitrogen in the clover is released to the soil.

Practical Considerations

The complexity of the biological processes involved in the fixation of nitrogen by white clover and in the transfer of the fixed nitrogen to other plants, particularly with regard to the presence of nitrogen fertiliser and the delicate balance between clover and grass in grazed swards, is apparent. The next section summaries how these processes might be optimised in practice on the basis of present knowledge, but because of the many factors (soil, plant, animal and climatic) which can affect the processes there is no one perfect recipe to meet all practical situations.

1. *Establishment*

For hill pastures which will have to depend on clover for nitrogen, it is important to have rapid establishment and the early onset of nodulation and nitrogen fixation. The usual procedure is to remove the existing plant material either by burning, cutting, grazing, use of herbicides or cultivation, add lime and slowly available phosphate and prepare a seed bed where necessary. Potassium, rapidly available phosphate, a little nitrogen and trace elements are added near to the time of sowing. Suitable seed mixtures with a freshly applied rhizobia inoculation, particularly for peat soils and for soils which have not recently grown white clover are sown. Grazing with sheep should start as soon as the clover is established and long before the grass heads.

Seed bed preparation: White clover must not be sown at depth in a soft seed bed. In wet situations surface seeding with trampling in by stock rarely fails although the difficulty here is to reduce competition from the indigenous vegetation. In dry situations rotovation to mix organic and mineral layers is needed but the resulting 'puffy' layer should certainly be heavily rolled. The use of sod seeders or tools to expose small areas of mineral soil have succeeded in some environments. However, the siting of young clover plants in long drills or on patches of loose mineral soil can cause difficulties because whole plants are uprooted when the swards are first grazed by sheep.

Seed rate: Many experiments have shown that the use of high seed rates of clover does not necessarily result in a high percentage of clover in the sward. Rates generally used are from 2-3 kg/ha of white clover with 25-30 kg/ha of grass seed.

Variety of white clover: A mixture per hectare of 1 kg small leaved (e.g. S184 or Kent Wild White) and 2 kg medium-small leaved (e.g. NZ Grasslands Huia or S100) prostrate varieties are best suited to hill conditions. The latter establish quickly and soon fix nitrogen but may not persist while the former take longer to establish but then they are very persistent.

Companion grass: Space does not permit extensive discussion of this subject. The grass should complement the clover as far as possible having a long period of growth with little or no mid-summer dip, being responsive to transferred nitrogen but not over demanding on the scarce supplies of soil phosphate. A mixture of early, intermediate and late heading varieties of perennial ryegrass with smaller amounts of either timothy or cocksfoot together with some red fescue appears the most appropriate mixture from seeds available at the present time.

Lime: Preferably magnesium limestone, at least 5 tonne/ha on mineral soils and 7·5 tonne/ha on peat soils, if not previously improved.

Nitrogen: 30-80 kg N/ha as ammonium nitrate, calcium nitrate or compounded with the phosphate and potassium.

Phosphate: 30-80 kg P/ha divided equally between slowly available (basic slag or ground rock phosphate) and rapidly available (superphosphate) forms.

Potassium: 50-100 kg K/ha usually compounded with the nitrogen and rapidly available phosphate.

Trace elements: Molybdenum, copper, cobalt, zinc, sulphur and boron are required for nitrogen fixation. Manganese may be necessary on peat soils and magnesium may also be needed if magnesium limestone is not used. Twenty kg/ha copper sulphate, 2 kg/ha cobalt sulphate and lesser amounts of the other elements are usually added.

Time of sowing: Spring sowing when moisture is still available in the soil and the major period of frosts is over, is usually recommended. If autumn sowing is unavoidable it should be carried out by mid-August at the latest so that the plants are strong enough to survive the winter.

2. *Maintenance*

Grass and white clover compete for light, moisture and nutrients. Some aspects of the complex situation with regard to the transfer of nitrogen have already been discussed. At any site there will be a tendency for an equilibrium grass/clover balance to be reached and for reasons already stated, management practices should be designed to favour the retention of white clover. It is difficult to give dogmatic guide lines for the following reasons:—

(a) Grasses start growing earlier in the season than clover and they tend to have a rest period in mid-summer when clover growth is very vigorous. Thus, within any one season the ratio of grass/clover tends to vary.
(b) The higher the proportion of clover in the sward, the higher the amount of nitrogen that is fixed and transferred. The latter favours grass growth.
(c) Grasses tend to be erect plants while clover is prostrate. Thus anything that favours grass growth tends to reduce clover growth.
(d) Clover has a higher demand for phosphate, potassium and for a more alkaline soil ($pH > 5{\cdot}5$) than grass. Thus, neglect of the need for periodic additions of lime and fertiliser P and K will favour the grass.
(e) Severe grazing favours grass because it can withstand close removal of leaves better than clover.

However, continuous grazing to a moderate height to reduce the competition for light from grass; anticipation of the need for maintenance dressings of lime and fertiliser; the prevention of clover heading which reduces nitrogen fixation, and the avoidance of over-grazing, particularly in the autumn, form the basis of a sound management practice. The strategy for using the improved paddocks of white clover and grass described in the two-pasture system and shown to enhance output from hill sheep farming systems (Armstrong *et al*, 1978) accords with this management plan by alleviating too heavy grazing and providing the sward with a mid-season rest. Five tonne of lime per hectare every 5-7 years and 50-80 kg K and P per hectare every 3-5 years are generally accepted amounts of fertiliser, the precise frequency of application being influenced primarily by rainfall and soil type. The need for periodic re-inoculation with effective strains of *Rhizobium* is still under investigation.

Future Developments

Research is in progress on the following subjects:—

1. Selection of white clovers which will grow both earlier and later in the season than existing varieties, i.e. able to grow and nodulate effectively at lower temperatures, and better able to tolerate high soil acidity and low availability of phosphate.
2. Selection of strains of *Rhizobium* which can infect root hairs, fix nitrogen and survive in the soil at lower soil temperatures and in more acid conditions than hitherto. The matching of these strains to the clovers resulting from 1 above will be necessary.
3. The more accurate quantification of the fertiliser levels, and especially that of nitrogen, needed to start and maintain hill pasture rich in clover.
4. The development of more efficient ways of inoculating white clover with rhizobia, and the design of a system of quality control for inocula sold in Britain.
5. The selection of grasses which will be 'ideal' companions for white clover (see p. 64).
6. Examination of other legumes, e.g. birdsfoot trefoil, some varieties of which might have qualities superior to those of white clover.
7. Investigation of seed bed preparation procedures, including design of appropriate machinery and the use of minimum cultivation or sod-seeding techniques, and determination of the best time to sow improved hill pastures. The ability to change a species-poor acid grassland into a species-rich sward containing white clover by the addition of lime and phosphate and the establishment of white clover plants without destroying all the existing grassy vegetation requires further examination.
8. Research is needed on the disease and past susceptibility of white clover. It appears that some cultivars (S100 and Grasslands Huia) widely used on the hills may be susceptible to clover root disease (*Sclerotium trifoliorium*). Leather jackets and the clover cyst nematode (*Heterodera trifolii*) are also reputed to attack white clover. Since these pests are more abundant in some seasons than others, their effects on white clover may also vary leading to some of the unpredictability in production noted by farmers.
9. If white clovers with a longer season of growth cannot be found, attempts to select cultivars which will tolerate nitrogen fertiliser

applied to extend the pasture growing season may be worthwhile.

10. The use of separate blocks or strips of pasture, dependent either on clover nitrogen or on fertiliser nitrogen, might optimise use of the biologically fixed nitrogen and avoid some of the complexities of management needed with mixed swards.

Summary

In the present environment of rising fertiliser nitrogen costs and world shortages of protein, legumes have an increasing part to play by contributing to increased food production and improving the efficiency of farm economics. The role of white clover in hill land improvement is clear. Despite some uncertainties about fine detail, general guidelines for the establishment and maintenance of clover-rich hill pastures are available. A positive attitude to encourage use of white clover whenever hill pastures are being improved, and to emphasise the importance of managing the pastures so that it flourishes is required. The benefits in increased animal production and in lower farm costs will soon become evident.

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THE DEVELOPMENT AND ASSESSMENT OF A MODIFIED HILL SHEEP PRODUCTION SYSTEM AT SOURHOPE, IN THE CHEVIOT HILLS (1968-1976)

R. H. ARMSTRONG, J. EADIE AND T. J. MAXWELL

It has been appreciated for many years that the future prosperity of hill farming is likely to depend on land improvement and the better use of natural hill vegetation. The way in which these are used in achieving practical and economically viable hill sheep management systems, has not, until recently, received the attention and critical assessment that is necessary to understand the biological and economic implications of achieving this objective.

Research work of the Hill Farming Research Organisation and elsewhere has led to a better understanding of the feed requirements of the hill ewe during pregnancy, lactation and the late summer/autumn recovery period. It has been concluded that lamb mortality will be reduced by increasing lamb birth-weights as a result of feeding a limited amount of a cereal/protein supplement during the last six weeks of pregnancy. Similarly, the use of better quality pasture during lactation and in the late summer and autumn will in turn improve lamb growth rates, ewe body weight recovery and conception rates.

It is also clear that better use can be made of certain more favoured hill grazings, if grazing control by fencing is introduced as a first stage in land improvement.

The application of these ideas with the objective of improving animal and flock performance substantially, requires a considerable change in the traditional management of the hill flock and cannot be achieved without capital investment. Hence the economic implications of changes in management proposed cannot be ignored.

It was therefore necessary that the Hill Farming Research Organisation test, on a sufficiently large scale, the impact of new management techniques, not only on individual animal performance in terms of lamb weaning percentage, lamb growth rate, ewe body-weight change throughout the year, on flock performance in terms of total amount of saleable lamb and wool produced, but also on the return to extra capital investment which has been made.

This paper reports the consequences of operating a modified system of hill sheep management, based on the ideas outlined above, at Sourhope in the Cheviot hills.

A characteristic of the hill grazings at the Sourhope Hill Research Station is the occurrence of significant quantities of Agrostis-festuca dominant sward, controlled grazing of which has been shown to lead to improved overall pasture utilisation and to better quality feed (Eadie and Black, 1968). Whilst controlled grazing of Agrostis-festuca pasture is only one of a range of pasture improvement measures, restriction of capital inputs was considered advisable since the hill farming industry has rarely been in the position to invest large sums of capital. Thus, at the outset, capital inputs would be restricted to fencing alone, and to the increased retention of stock ewe lambs to allow a build up of stock numbers. Further inputs of capital by way of lime, phosphate, reseeding, etc. would be delayed to the point where the additional capital required could be generated, in part at least, from within the system. This point was reached at the close of 1973.

Resources

The area chosen for study extends to 283 hectares, ranging in altitude from 250 to 490 metres, with 35-40 per cent of the area carrying an Agrostis-festuca or bracken covered Agrostis-festuca vegetation, and the remainder a Nardus and Molinia-dominant grass heath.

A minor reorganisation of previous land use and sheep stocks was necessary to establish the study, but this was not considered to affect materially the production data obtained over a previous 5-year period for the sheep stock under both traditional management and stocking rate. The sheep comprised both North-Country Cheviots and South-Country Cheviots but from the start of the programme North-Country rams have been used on both flocks. The initial 398 ewes gave a stocking rate of 1 ewe to 0·72 hectares as in previous years.

Beef cows had been carried on the area but both numbers and seasonal incidence of grazing had varied, and it was decided to graze permanently a fixed number of 25, which was thought to be that which could reasonably be supported in winter bulk food by the area of conserved grass normally found on hill farms in the area.

Practice: Within a five-year period, beginning in 1968, a total of five Agrostis-festuca dominant areas of hill vegetation, each of approximately 20 hectares, were fenced off. The first two areas were fenced in June 1968, the third in autumn 1969, and Paddocks 4 and 5 in 1972 and 1973 respectively. In deciding upon fence lines, consideration had to be given not only to size of paddock and uniformity of vegetation enclosed, but to provision of adequate water and shelter. A map of the Project area showing the fence lines is given in Figure 1.

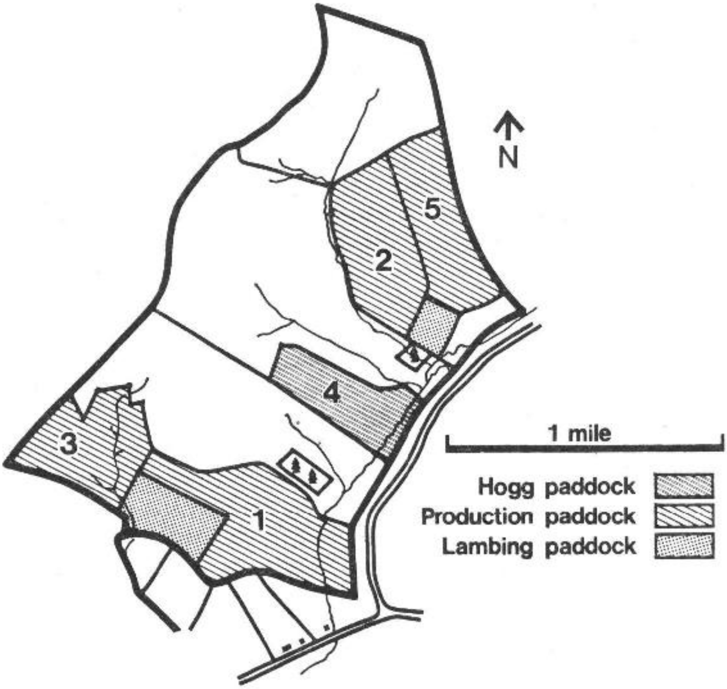

FIG. 1.—Project Area.

As each paddock (hereinafter referred to as production paddocks) was enclosed it was first subject to sustained grazing pressure to eat off as much as possible of the ungrazed herbage. Thereafter the regrowths within these areas have been used by the production stock at the two key periods of post-lambing, i.e. early and mid lactation, and again during the pre-mating and mating period. At the end of a grazing period the dry sheep and the cattle, of which the latter are used throughout only as "tools" of grazing management, are put into the production paddocks to remove ungrazed residual herbage, before the paddocks are rested to allow regrowth to occur.

Thus, management requires that as single-bearing ewes lamb, they are transferred to the enclosures, ewes with twins being kept until weaning on the inbye area of the farm as in the past. Depending on the season it is usually necessary to rest the production paddocks at the end of May or early June for 2-3 weeks, the ewes and lambs being transferred to a previously rested hill area. The ewes and lambs get first choice of the regrowths and then the early summer grazing period is completed by the dry sheep, followed by the nursing cows and calves. The object is to leave the enclosures to make their mid-to-late summer regrowth for autumn use, having used the available feed as effectively and efficiently as possible by mid-August.

Lambs are weaned in mid-August, the ewes being then grazed along with the hoggs and cattle on the hill. Depending on the amount of regrowth, the ewes are returned to the production paddocks around mid-October so that good quality grazing lasts until the first cycle of mating is completed, when it is usually necessary to distribute the ewes more generally over the resources. The cattle are then used to "clean off" remaining rough herbage within the paddocks, before being removed from the unit at the end of December.

The winter management of the ewe stock is based on the division of pregnancy into two periods. From mating to 5 to 6 weeks prior to lambing the aim is to depend on grazed pasture to the maximum extent with 'storm' feeding being given as necessary. In recent years sugar-beet cubes have largely replaced hay for this purpose. In the late pregnancy period from mid-March to April, the aim is to feed ewes to the point of ensuring adequate birth weights and vigorous viable lambs. Concentrate feeding continues through lambing at levels dependent on the availability of pasture, and may, in a late spring, continue for a short period after lambing. Lambing takes place in two small fields which were initially outwith the Project area, but adjacent to the enclosures. With ewes raddled at mating, early and late lambing ewes are separated at lambing, late lambing ewes being left on the hill for a further 7 to 10 days.

As stock numbers have been built up it has become standard practice to feed the gimmers independently of the ewes in late pregnancy. A departure from traditional practice has been the regular use of Paddock 4 each year, as a hogg-wintering paddock to reduce the vulnerability of this class of sheep to winter storm, and ensure better nutrition of the hoggs in their first winter. Thus this paddock is only available to the nursing ewes in the summer months.

It will be recalled that at the outset the sheep stock comprised both Hill North-Country Cheviots and South-Country Cheviots. The policy of using North-Country Cheviot rams throughout on the ewe stock was continued until mating in November 1974 when home-bred cross Cheviot tups were introduced. It is intended to use alternately the two types of cross-bred tup, i.e. the progeny of N.C.C.♂ × S.C.C.♀ and S.C.C.♂ × N.C.C.♀

At the outset the sheep stock within the project ran as two sub flocks, each in regular ages and hefted to its own ground. This situation was left unchanged over the early years to ease both management and recording, and to take advantage of benefits attributable to the possession of 'hefting instinct' by each sub-flock. However all stock ewe hoggs were combined from both units for wintering, and only re-united with their respective sub-flocks as gimmers with the approach of tupping. Thus a measure of de-hefting was introduced with each ensuing age-group. In the autumn of 1975, the entire ewe stock was merged and divided into two manageable units by age group alone. Thus ewes of the oldest age groups are now run as one unit, with gimmers, 1-crop and some 2-crop ewes comprising the second.

In the winter of 1974-75 proprietary self-feed blocks were introduced for the ewe stock, to replace some hand feeding with sugar beet pulp cubes and concentrates, and this practice is continuing.

Further capital inputs: The point was reached in 1974 when further inputs of capital directed towards land improvement were considered necessary, greatly increased stock numbers having resulted in the approach to optimum utilisation of both the unenclosed hill and the improved grazings within the paddocks.

Priority was given to the provision of a reseeded area capable of providing adequate grazing for twin-nursing ewes which up to this time had been grazed on resources outwith the project area (at an annual cost to the project). Such an area would be available for nursing gimmers and other production stock in spring and summer, the requirements for the twin nursing ewes having first been met; it would also be available for all production stock in autumn and early winter. The provision of this reseeded area was made in 1974 by incorporating the two lambing paddocks fully into the Project area at full reseeding costs per acre.

At the same time a further stage of land improvement within production Paddocks 1 and 2 was carried out, with those areas within the two paddocks accessible to a wheeled tractor being spread with 6·63 tonnes/hectare of ground magnesium limestone (2·64 tons/acre), and 665 kg/hectare of ground mineral phosphate (5·3 cwt/acre). A total of 33·2 hectares (82 acres) was so treated.

In August 1974, 9·7 hectares (24 acres) within Paddock 2 were sprayed to eradicate bracken, and in early June of 1975 this area was rotovated and oversown with a grass and clover seed mixture, the reseed being top dressed with 206 kg/hectare (1·8 cwt/acre) of a

TABLE 1

Flock Production Data

	Base Data 5-year Average	1969	1970	1971	1972	1973	1974	1975	1976
Stock numbers (Ewes and Gimmers)	387	398	451	518	528	573	600	601	620
Weaning %	90·6	84·7	86·7	102·5	104·7	99·5	91·5	102·7	108·5
Total weight wool produced (kg)	869	850	1017	1253	1369	1561	1454	1535	1543
Total weight lamb weaned (kg)	7924	7786	9188	14177	14046	14193	14329	16042	17902
Average weaning weight (kg) — Singles	23·6	—	23·6	27·7	25·9	24·4	26·3	25·5	27·2
Average weaning weight (kg) — Twins	20·9	—	22·3	25·4	24·7	26·4	24·7	27·1	25·7
Average weaning weight (kg) — Overall mean	22·6	23·1	23·5	26·7	25·4	24·9	26·1	26·0	26·6
Weight of lamb weaned/ ewe mated (kg)	20·5	19·6	20·4	27·4	26·6	24·8	23·9	26·7	28·9
% twin-bearing ewes (of ewes of tup)	20·5	16·5	19·7	22·9	27·4	23·4	15·5	25·0	28·9
% barren ewes	7·1	11·3	10·8	7·1	9·0	8·2	10·0	8·2	7·9

compound fertiliser (20: 10: 10) in the following spring. In August 1976, 11·3 hectares (28 acres) within Paddock 1 were sprayed to eradicate bracken.

Full details of all capital inputs to the project from 1968 to the end of 1976 are given in Table 10.

Results

Production data: Flock production data over the eight years of the project, together with the 5-year average of production prior to the start of the project, are shown in Table 1.

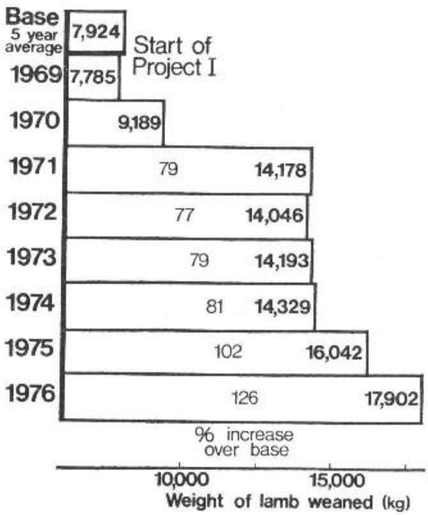

FIG. 2.—Total weight of lamb weaned (kg).

The total output of weaned lamb from the project area showed a really marked increase in 1971, an increase which was maintained fairly constantly each year thereafter (see figure 2) until the flock year of 1975 when a further major increase occurred. Total weight of lamb weaned in 1976 showed a 126 per cent increase over the average weight of lamb weaned from the same area in the five years prior to the start of the project.

Total wool production likewise has increased significantly (see figure 3) to the point that production in 1976 showed an increase of 78 per cent over average wool production in the five years preceding the project.

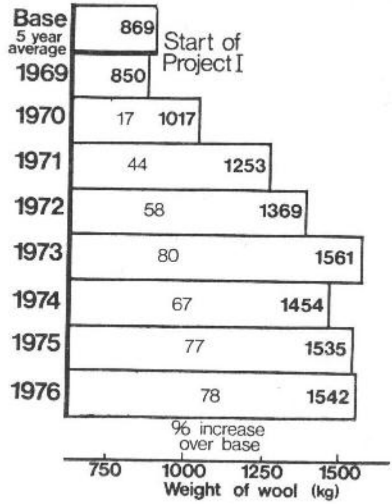

FIG. 3.—Total weight of wool produced (kg).

These increases in both lamb and wool production are in large measure the result of the significant increases in stocking-rate (see figure 4) with ewe numbers being built up from 398 in autumn of

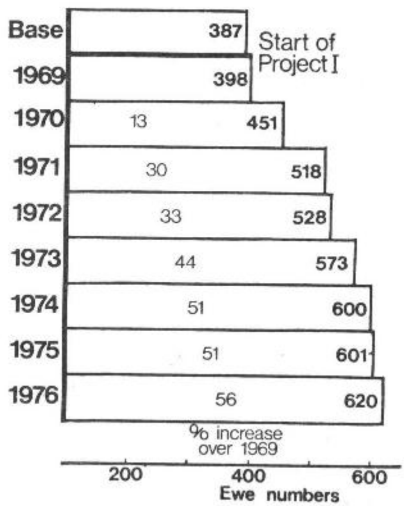

FIG. 4.—Numbers of breeding ewes.

1968 to 620 in the autumn of 1975. However examination of individual ewe performance as measured by 'weight of lamb weaned per ewe mated' (Table 1) shows that stocking-rate increase was not the sole factor leading to increase in overall lamb production. The data shows that there was a significant improvement in individual animal performance by the third year, when stocking-rate had already increased by 30 per cent, mainly as the result of improved lambing performance, lower lamb death rates and an increase in lamb weaning

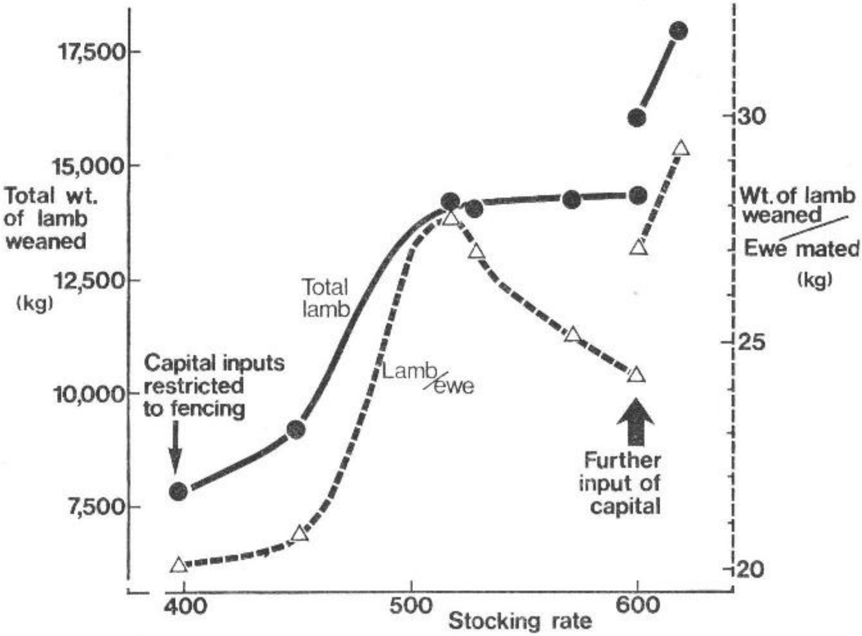

FIG. 5.—Relationships between stocking rate, total weight of lamb weaned and weight of lamb weaned per ewe mated.

weight. As the stocking-rate further increased to 573 ewes in the autumn of 1973, individual animal performance began to decline until the further capital inputs, beginning in 1974, allowed land improvement to be carried a stage further, with its impact on individual ewe performance.

The relationships between stocking-rate, individual ewe performance and total output for the project are shown in Figure 5. The overall picture is that at the outset, with inputs of capital restricted to fencing alone, and with progressive increase in stocking-rate, total production has shown a sustained increase, an increase which in

TABLE 2

Pre-mating Bodyweights of Breeding Flock, and Bodyweight Gain (+) or Loss (−) over 7 periods in year (kg)

Production Year	Pre-mating Bodyweight	Pre-mating to Post-mating *16/11-5/1	Midwinter 5/1-12/3	Pre-lamb Feeding 12/3-10/4	Pre-lamb to Marking 10/4-24/5	Marking to Weaning 24/5-8/8	Weaning to early October 8/8-2/10	October to Pre-mating 2/10-16/11
1969	50·9	−3·5	−3·2	+3·3	−3·2	+4·9	+4·6	−0·4
1970	53·2	−3·5	−1·8	+3·1	−5·0	+4·8	+3·3	+2·1
1971	56·0	−1·6	−1·1	+2·7	−3·6	+2·1	+3·1	−0·1
1972	57·7	−1·6	−1·1	+1·1	−3·0	+2·4	+4·0	−0·2
1973	59·3	−7·2	+2·8	+4·0	−8·7	+3·6	+3·4	−3·5
1974	53·7	−3·2	−0·7	+2·3	−2·8	+5·7	+1·8	−1·0
1975	55·7	−2·4	−0·9	+3·0	−5·6	+5·1	+2·6	−0·4
1976	58·0	−1·8	−2·5	+2·5	−3·9	+4·0	−1·0	−1·7
1977	53·6							

* All dates shown are average dates over 7-year period, when each specific weighing carried out.

the early stages of the project resulted from both increases in ewe numbers and ewe performance. As individual ewe performance declined with further increases in stocking-rate, it is the latter alone which allowed the increase in total overall production to be maintained. Only with the further land improvement measures beginning in 1974, has individual ewe performance begun to improve again.

Ewe Bodyweight data: The pre-mating ewe bodyweights together with subsequent bodyweight change in seven well-defined periods in each year from 1969 to 1976, are shown in Table 2.

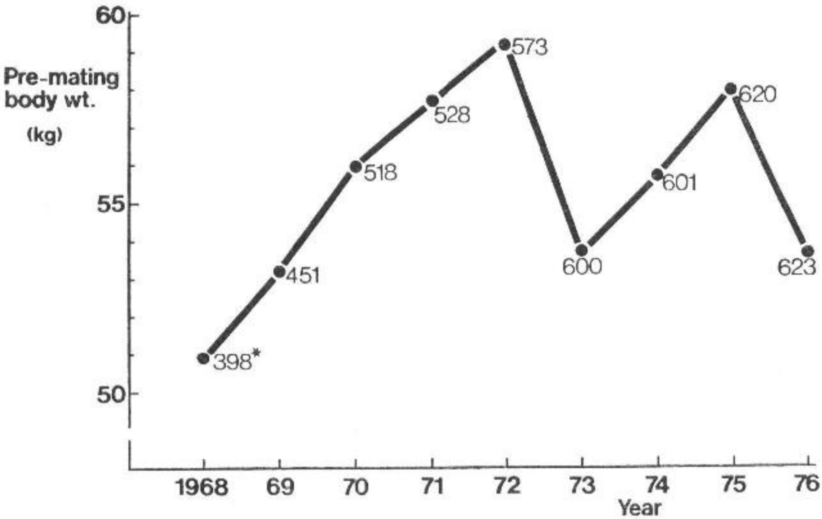

FIG. 6.—Pre-mating ewe body weights. (* Ewe numbers at mating (November)).

Pre-mating ewe bodyweight is seen to have progressively increased (4 per cent) each year as stock numbers increased from 398 at the outset, to 573 in November 1972 (Figure 6). With a further increase in stock numbers, pre-mating ewe bodyweight had fallen considerably by autumn 1973. Thereafter there has been a progressive recovery in ewe bodyweight to date. To understand more clearly the events which led to the significant fall in ewe bodyweight which had occurred by late autumn 1973, it is necessary to examine the sequence of bodyweight change throughout each successive year.

Examination of the data in Table 2 shows that in the 1973 flock production year the pattern of ewe bodyweight change altered significantly. Not only was overall bodyweight loss from November to May greater than in any previous, or subsequent, year but for the first and only time until the autumn of 1976, this loss was not recouped in the ensuing six months. It should be noted that the average bodyweight of incoming gimmers in autumn 1972 (Table 3) was higher than for any year before or since, and that in the following autumn incoming gimmers were at their lightest.

TABLE 3

Bodyweight Change of Youngest Age of Sheep from 12 months to 18 months of age

	Average Bodyweight (kg)		Gain in Bodyweight (kg)
	April (as hogg)	November (as gimmer)	April-Nov.
1969	29·0	48·3	19·3
1970	30·4	50·1	19·7
1971	33·5	50·3	16·8
1972	32·0	54·0	22·0
1973	31·1	46·7	15·6
1974	29·4	48·1	18·7
1975	31·2	50·8	19·6
1976	34·3	46·7	12·4

Between pre-mating in autumn of 1972 and post-mating, all age groups of sheep showed a remarkably uniform and dramatic fall in average weight, so that in early January 1973, the overall average bodyweight loss of all ewes and gimmers was 7·2 kg. This rapid loss in body condition of the ewe stock was attributed to nutritional stress, although simultaneous checks were made on parasite burden, and on blood cobalt levels with negative results. Sugar-beet pulp cubes were immediately fed to the sheep stock, and overall average bodyweight had improved by 2·8 kg by early March.

That nutrition again became limiting in the following autumn is apparent from the failure of the breeding stock to recuperate further in bodyweight after weaning. The hogg age of that year also failed to make satisfactory growth through the summer, the gain in average bodyweight between April and November being less than for any other year of the project (Table 3) with the exception of 1976.

It was in the summer of 1976 that severe drought conditions prevailed at Sourhope, and indeed throughout much of the country, as a consequence of which not only was there little or no herbage growth, but early autumn store lamb sales were severely depressed. It was decided that, whilst ewes and lambs would be weighed at the normal weaning date, actual weaning would be delayed for three weeks. From the data of Table 2 it will be seen that in the period from August to early October 1976, when it is normal to expect bodyweight recovery in all hill ewe stocks, the average bodyweight of all ewes in the project fell by 1·0 kg compared with a gain in each of the preceding seven years, which averaged 3·3 kg. The continued absence of pasture growth in the late summer period, with its severe effect upon ewe nutrition, obviously imposed severe stress on the ewes, a stress which can only have been exacerbated by the delay in weaning.

Ewe bodyweight loss continued through to pre-tupping in 1976. Likewise from Table 3 it will be seen that bodyweight gain in the gimmer age was substantially lower than in any previous year.

Lamb bodyweight data: Lamb bodyweights classified by birth-type, are shown both for birth and weaning in Table 4. Whilst birth-

TABLE 4

Mean Lamb Bodyweights of all Ewes and Gimmers

	Birth Weight (kg)			Weaning Weight (kg)		
	Single Lambs	Twin Lambs	All Lambs	Single Lambs	Twin Lambs	All Lambs
1969	3·8	3·0	3·6	23·1	23·2	23·1
1970	3·9	3·2	3·8	23·6	22·4	23·4
1971	4·3	3·3	3·9	27·4	25·4	26·6
1972	4·3	3·5	3·9	25·9	24·7	25·4
1973	4·3	3·6	4·0	24·3	26·0	24·9
1974	4·2	3·4	3·9	26·5	24·9	26·1
1975	4·1	3·4	3·8	25·6	26·7	26·0
1976	4·1	3·5	3·8	27·2	25·7	26·6

weights have tended to increase over the first five years followed by a slight fall, this reduction in birthweight has not been reflected in any falling off in weaning weight as stock numbers have further increased. The well established relationship between pre-mating ewe bodyweight and lambs born and ultimately reared is borne out in this project with pre-mating ewe bodyweight being significantly correlated with lamb weaning percentage (Figure 7). Thus it is not surprising that as stocking rate increases reached the point where pre-mating ewe bodyweights declined, birth and weaning percentages also declined, only to recover as autumn ewe bodyweight responded to a further stage in land improvement.

Ewe and lamb mortality: Data for both ewe and lamb mortality are given in Table 5.

Over the eight years of the project ewe mortality averaged 3·2 per cent, and remained virtually unchanged whilst stock numbers in-

Table 5

Ewe and Lamb Mortality

Year	Percentage Death-rate Ewes and Gimmers	Lambs Born Dead		Nos. of Lambs born alive	Lamb Losses			% Loss of Lambs born alive
		Nos.	Percentage		Birth to Marking	Marking to Weaning	Total Deaths	
1969	3·5	14	3·3	406	57	13	70	17·2
1970	1·6	6	1·4	437	30	15	45	10·3
1971	2·9	21	3·5	582	37	4	41	7·1
1972	3·8	20	3·2	608	32	26	58	9·6
1973	3·8	20	3·0	638	43	21	64	10·0
1974	4·0	30	4·8	607	47	3	50	8·2
1975	2·0	40	5·7	658	28	12	40	6·1
1976	3·9	32	4·3	714	25	16	41	5·7

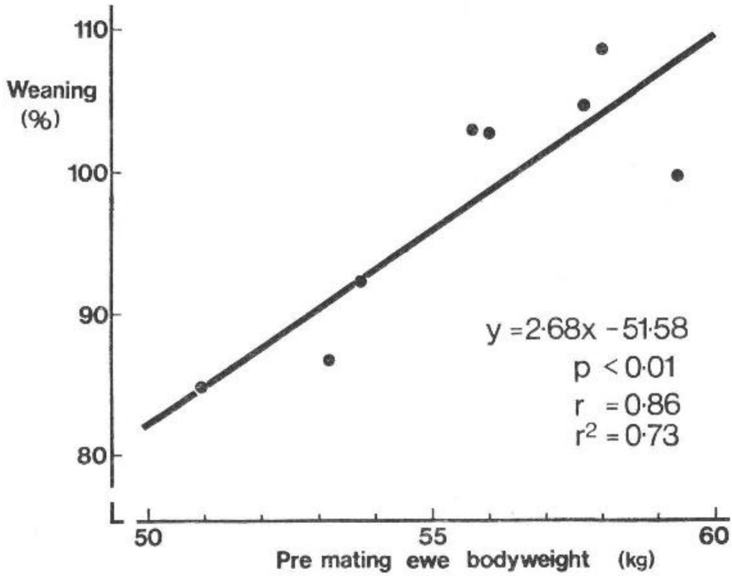

FIG. 7.—Relationship between premating ewe body weight and lamb weaning percentage.

creased by 56 per cent. It is unlikely that this relatively low death rate can be significantly reduced.

With respect to lamb losses, the percentage loss to weaning of those lambs which were born alive showed a decrease as the project continued, with an overall average loss of 9·3 per cent over the eight-year period. Thus over the entire life of the project to date, total lamb losses to weaning, including those born dead, have averaged 12·6 per cent.

Feed data: Total feed input data per ewe, including feed used in the lambing field, and that fed to twin-nursing ewes thereafter until late May, are shown in Table 6. From 1970-71 sugar-beet pulp cubes largely replaced hay feeding and whilst feed inputs from that date tended to show some increase to 1974-75 when 'self-feed blocks' were introduced, this increase was only in small part the cause of the significant increase in feed costs per ewe, which occurred between 1972-73 and 1973-74. This latter was the result almost entirely of the increase in cost of feedstuffs in this period.

Obviously feed patterns vary each year, with level of feeding being adjusted according to need, but since 1971 feeding has commenced

TABLE 6

Feed Input Data for Breeding Sheep—weight of each component of feed fed per ewe and total cost per ewe

	Hay (kg)	Dried Grass Cubes (kg)	Sugar-beet Pulp Cubes (kg)	Protein Concentrate (ewe cobs) (kg)	Self-feed Blocks (kg)	Cost/head at Prevailing Prices £
1968-69	18·4	—	—	21·2	—	1·03
1969-70	39·2	4·9	—	18·7	—	1·42
1970-71	—	—	15·2	11·3	—	0·87
1971-72	2·0	—	16·0	16·2	—	1·16
1972-73	4·6	—	17·5	14·0	—	1·28
1973-74	2·6	—	20·3	16·1	—	2·19
1974-75	2·4	—	9·4	11·6	5·7	2·10
1975-76	3·9	—	6·8	14·2	7·7	2·92

about mid-January. A typical pattern of feeding would be sugar-beet pulp cubes offered at 150-225 gms per head daily ($\frac{1}{3}$ to $\frac{1}{2}$ lb) at the outset, rising to between 340 and 450 gms daily ($\frac{3}{4}$ to 1 lb) by the middle of March, according to year. A proprietary ewe cob (13 per cent Protein) then replaces the beet-pulp cubes at 340 gms per head per day, and this is increased to 450 gms per day, if needed, immediately prior to lambing. Where self-feed blocks have been introduced from mid-January, then sugar-beet pulp cube feeding is delayed into February.

The ewe hoggs are wintered in a separate hill paddock (P4) so that they can be fed independently of the ewe stock. Feed data, together with relevant bodyweight data are shown in Table 7. There was a nett bodyweight loss in each of the eight years between November, when feeding is started, and early April when the hoggs are turned away to the open hill at the close of feeding. This nett loss has varied from 0·4 kg in 1970-71 to as high as 4·9 kg in 1972-73, with an overall average loss of 3·0 kg per year.

Barren ewes: The percentages of barren sheep, both ewes and gimmers, are shown in Table 8. The data for individual years show the percentage of barren sheep to have fallen over the first three years, to what must be considered an acceptable level of around 5 per cent, but that subsequently they rose to between 8 and 10 per cent, with a welcome reduction in 1976. Whilst gimmer matings over the whole eight years comprise 25·0 per cent of all matings, barren gimmers account for 40·5 per cent of all barren sheep. There is obviously a need to seek means to increase the proportion of gimmers holding to the tup, though perhaps it is not without significance in this context to note that when Sourhope was commercially farmed no gimmers were tupped.

Over the project as a whole, the proportion of barren sheep which has been reported as truly barren as distinct from those which subsequently aborted, is almost identical for both ewes and gimmers at 85·3 per cent and 87·7 per cent, respectively.

Veterinary data: Veterinary monitoring of the sheep flock showed no evidence of an increase in problems associated with internal parasites since the modified sheep management practices were adopted. There has been no significant departure from the routine anthelmintic procedures practised before 1968, with the possible exception of the ewe hoggs. These, wintered within a hill paddock at 3 to 4 hoggs/acre, are given additional worm drenchings as required over the winter months.

TABLE 7

Ewe Hoggs—Feed data per hogg together with bodyweight change over the feeding period

	Hay (kg)	Dried Grass Cubes (kg)	Sugar-beet Pulp Cubes (kg)	Protein Concentrate (ewe cobs) (kg)	Cost/head at Prevailing Prices £	Average Bodyweight Change Nov.-April (kg)
1968-69	10·0	20·4	—	—	0·72	−2·9
1969-70	20·1	27·4	2·9	—	1·28	−3·5
1970-71	1·8	10·7	8·9	—	0·62	−0·4
1971-72	4·2	10·4	8·6	—	0·75	−3·4
1972-73	2·1	14·2	14·2	—	0·94	−4·9
1973-74	—	9·7	12·4	—	1·23	−4·1
1974-75	9·2	11·3	12·3	5·1	2·30	−3·7
1975-76	16·6	11·9	11·9	6·9	3·15	−1·1

TABLE 8

Numbers of Sheep failing to breed, expressed as percentage of sheep to tup

	Ewes and Gimmers		Ewes only		Gimmers only	
	Nos. to Tup	% Barren	Nos. to Tup	% Barren	Nos. to Tup	% Barren
1968-69	398	9·8	276	8·0	122	13·9
1969-70	451	9·1	332	7·8	119	12·6
1970-71	518	4·1	402	3·7	112	5·4
1971-72	528	6·6	417	6·2	111	8·1
1972-73	573	8·2	417	4·3	156	18·6
1973-74	600	10·0	434	8·1	166	15·1
1974-75	601	8·3	454	6·2	147	15·0
1975-76	620	6·9	482	6·2	138	9·4

Cattle stocks: The herd of 25 spring calving suckler cows which has been run on the unit from May to December each year, has been managed primarily with respect to their use as 'tools' of grazing management, and with little regard to the fact that the cows were nursing. On the grass-covered hills of which Sourhope is typical, cattle have a particular role to play in grazing off the surplus ungrazed herbage within the production paddocks, as the grass runs to seed-head. Examination of the daily live-weight gains made by the calves from birth to weaning given in Table 9, shows these to be at least satisfactory, and provides evidence that the nutrition of the suckler cows has not suffered unduly in using them essentially to manage and improve the grazings for sheep.

TABLE 9

*Average Daily Liveweight Gain of Suckled Calves**

	Bullock Calves		Heifer Calves	
	kgs/day	lbs/day	kgs/day	lbs/day
1970	1·22	2·7	1·04	2·3
1971	0·95	2·1	0·82	1·8
1972	1·09	2·4	0·95	2·1
1973	0·95	2·1	0·86	1·9
1974	0·95	2·1	0·82	1·8
1975	0·86	1·9	0·82	1·8
1976	0·95	2·1	0·86	1·9

* Each year calf creep feed is offered over the last six weeks to weaning.

It is of interest to note that although very heavy cattle grazing pressure has been applied to the hill paddocks, each of which has a fairly large bracken component, in the course of this work no case of bracken poisoning has been recorded to date.

Economic assessment: The data so far presented clearly demonstrates the potential for increasing productivity from the hill area involved in this study. Thus over an eight-year period, stocking-rate has increased by 56 per cent, wool output by 78 per cent and output of weaned lamb by 126 per cent. In terms of lamb numbers, whereas in each of the five years prior to the start of the project in 1968 an average of 351 lambs of average bodyweight 22·6 kg were produced, in 1976 a total of 673 lambs of average bodyweight 26·6 kg were weaned from the unit.

This increase in physical output has been achieved as a consequence of investing capital in the unit, and it is now necessary to examine the implications of such an investment. Appropriate methods have been developed in the Organisation (Maxwell, Eadie and Sibbald, 1973).

A difficulty with studies of this kind is that they take place against a background of changing costs and prices, and yet they can only be fully evaluated if one assumes the same cost and price levels per unit of input and output across all the years. This is not to say that an assessment using costs and prices which actually prevailed at the

TABLE 10

Capital Inputs to Project 1968-76

		Prevailing Costs £	Prevailing Costs £	At 1975-76 Prices £
Phase I				
1968/69	Fencing of paddocks P1 and P2, and internal hill divisions, 4332 metres	947.60		2341·40
1969/70	Fencing P3 and P4, 1646 metres	360·00		890·10
			1307·60	
1972/73	Fencing P5, 210 metres	69·00		113·70
			1376·60	
Phase II				
1973/74	Incorporation of two lambing paddocks fully into resource	1800·00		2160·00
1973/74	Lime for P1 and P2	586·45		928·36
	Ground Mineral Phosphate for P1 and P2	909·61		1156·32
1973/74	Bracken spraying P2	288·00		321·60
			4960·66	
1974/75	Overseeding of P2	673·00		740·30
			5633·66	
1975/76	Bracken spraying P1	375·78		375·78
	Fertiliser for P2 reseed	159·70		159·70
			6169·14	

time is not of value, since the decision to invest further capital at each stage was to some extent influenced by ruling costs and returns. Hence in the work reported here an economic appraisal of the project is made, both at prevailing costs and prices and at the fixed costs and prices ruling in 1975-76.

The details of capital investment in the project are shown in Table 10. It should be noted that costs are quoted as total costs before grant.

TABLE 11

Gross Margins 1969-76 at Prevailing Costs and Prices

	1969	1970	1971	1972	1973	1974	1975	1976
Ewe Numbers	398	451	518	528	573	600	601	620
Income (£)								
Lambs	1235·4	1329·6	2196·7	3070·6	4286·9	3576·1	4494·8	7667·9
Wool	420·8	469·9	670·4	720·1	852·3	801·2	1011·6	1223·2
Cast Ewes	228·8	176·4	533·0	391·3	1170·0	744·2	963·0	1660·8
Gimmers								585·8*
Subsidy	489·5	554·7	828·8	871·2	945·5	1800·0	2163·6	2232·0
Total	2374·5	2530·6	4228·9	5053·2	7254·7	6921·5	8633·0	13369·7
Expenditure (£)								
Feed	498·5	787·2	490·0	722·2	893·3	1492·1	1477·6	2296·6
Grazing	32·5	32·5	91·8	121·0	118·7			
Fertiliser						21·9	49·5	47·9
Other costs	398·0	460·0	507·6	491·0	636·0	798·0	967·6	1178·0
Total	929·0	1279·7	1089·4	1334·2	1648·0	2312·0	2494·7	3522·5
Flock Gross Margin (£)	1445·5	1250·9	3139·5	3719·0	5606·7	4609·5	6138·3	9847·2
Gross Margin per Ewe (£)	3·63	2·77	6·06	7·04	9·78	7·68	10·21	15·88

* Ewe hoggs retained in 1975 but subsequently found to be surplus to requirements and sold as gimmers in 1976.

Gross Margin analysis: The Gross Margins for each year of the project, both at prevailing (actual) costs and prices, and at the fixed costs and prices of 1975-76, are shown in Tables 11 and 12 respectively. The detailed data of physical outputs and prices, and of physical inputs and costs, upon which the Gross Margins are based, are given in Appendices I and II respectively.

At prevailing prices the fall in Gross Margin per ewe in 1970 reflects the high feed costs of that year, but thereafter the individual ewe Gross Margin shows a steady increase to the year 1974, at which point the full impact of marked increases in feed prices linked to a depressed trade for both store lambs and draft ewes, and to a fall in individual animal performance, resulted in a fall in Gross Margin per ewe.

The Gross Margin per ewe at fixed costs and prices (Table 12) is seen to have reached a peak in 1971 and with further increases in stocking-rate thereafter, has undergone a slight fall to 1974. With the impact of further measures of land improvement leading to an increase in individual animal performance subsequently thereafter, the individual ewe Gross Margin reached a new peak in 1976.

It is, however, with Total Flock Gross Margins that one is mainly concerned and both at prevailing costs and prices (Table 11) and at fixed costs and prices (Table 12) the data show that by 1971 Flock Gross Margins had increased significantly from the levels of 1969, increases which by the end of 1976 amounted to 681 per cent and 268 per cent respectively over the Flock Gross Margin at the close of the first year. The relationship at fixed costs and prices of both Gross Margin per ewe, and Flock Gross Margin, to stocking-rate is shown in Figure 8.

The substantial increase in Flock Gross Margin which has occurred is largely the result of the increases in total output. Over the duration of the project to date, fixed costs and particularly those of labour have been constantly rising and it is obvious that one is much better placed to meet the burden of these increases in fixed costs, in a situation of greatly enhanced Flock Gross Margin such as has been obtained in this study.

Cash Flow-analysis: Since one is concerned here to make an assessment of the return on 'marginal' or extra capital investment only, it is necessary to measure the change in the Flock Gross Margin from the base gross margin, this change representing the difference in income resulting from the changes in the output from the project area, and hence the response obtained to the extra capital invested.

Thus before a cash flow analysis is possible it is first necessary to calculate a base gross margin for each year at the costs and prices

TABLE 12

Gross Margins at the Fixed Costs and Prices of 1975-76

	1969	1970	1971	1972	1973	1974	1975	1976
Ewe Numbers	398	451	518	528	573	600	601	620
Income (£)								
Lamb 54·7p/kg	2792·4	3547·8	5461·8	5349·1	5761·6	5839·2	6556·3	7667·9
Wool 79·3p/kg	674·1	806·5	993·6	1085·6	1237·9	1153·0	1217·3	1223·2
Cast Ewes £17.30	899·6	726·6	1418·6	1574·3	2024·1	2110·6	1851·1	1660·8
Gimmers £17.75								585·8
Subsidy £3.60	1432·8	1623·6	1864·8	1900·8	2062·8	2160·0	2163·6	2232·0
Total	5798·9	6704·5	9738·8	9909·8	11086·4	11262·8	11788·3	13369·7
Expenditure (£)								
Feed	1312·0	2098·1	1198·9	1625·9	1863·6	1990·8	1764·9	2296·6
Grazing £1.80/twin	52·2	52·2	147·6	194·4	190·8			
Fertiliser						47·9	47·9	47·9
Other costs	756·2	856·9	984·2	1003·2	1088·7	1140·0	1141·9	1178·0
Total	2120·4	3007·2	2330·7	2823·5	3143·1	3178·7	2954·7	3522·5
Flock Gross Margin (£)	3678·5	3697·3	7408·1	7086·3	7943·3	8084·1	8833·6	9847·2
Gross Margin per Ewe (£)	9·24	8·20	14·30	13·42	13·86	13·47	14·70	15·88

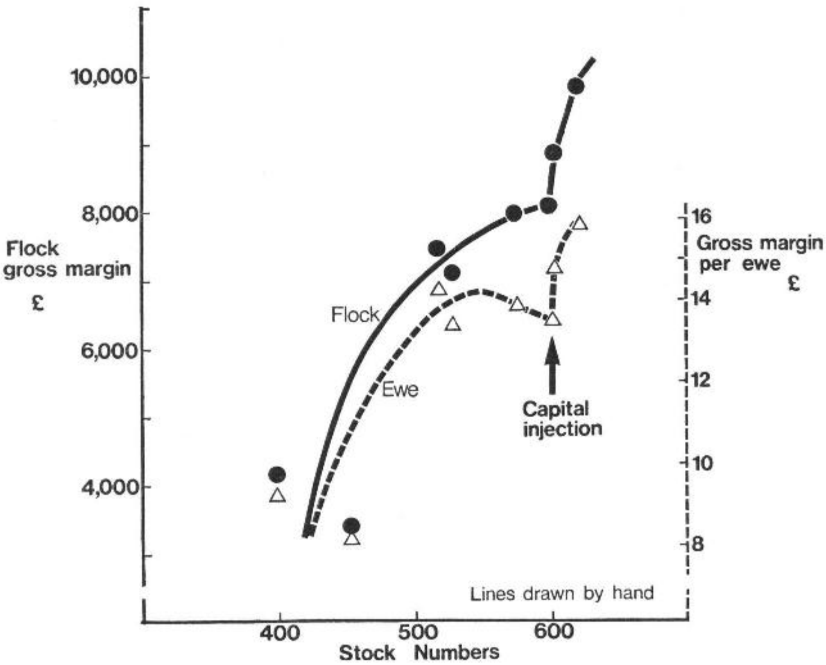

FIG. 8.—Relationships between stocking-rate and gross margin per ewe, and flock gross margin, at fixed costs and prices (1975-76).

prevailing for that year, for the average flock performance as it was recorded in the five years prior to the start of the project. This base gross margin as calculated from the costs and prices data shown in Appendices I and II is given in Appendix III.

The Cash Flow Analysis at prevailing costs and prices is shown in Table 13, and that for the fixed costs and prices of 1975/76 in Table 14. In the latter case the base gross margin data are constant for each year. A note of the procedures adopted in making the cash flow analysis is given in Appendix IV.

The cash flow at prevailing costs and prices (Table 13) must be considered satisfactory with a positive Cumulative Balance of +£7,980 at the close of 1976. The timing of the capital inputs would appear to have been soundly based, with initial low-cost inputs allowing capital to be generated from within the system so that a positive cumulative balance was reached in the fifth year. Despite very high capital inputs in the sixth year, there was no need to return to 'overdraft' financing with its attendant problem of interest repay-

TABLE 13

Cash Flow Analysis 1969-76 *at Prevailing Costs and Prices* (£)

Year	1969	1970	1971	1972	1973	1974	1975	1976
Base Gross Margin	2123	1859	2299	2690	3595	3169	3746	5424
Gross Margin	1446	1251	3140	3719	5607	4610	6138	9847
Change in G.M.	−677	−608	841	1029	2012	1441	2392	4423
Capital Investment								
Fencing	474	180			35			
Land Improvement						1792	337	268
Total	474	180			35	1792	337	268
Tax Allowances								
Depreciation	47	65	65	65	69	69	69	69
Trading Expenses						1792	337	268
Interest:								
Current Capital	36	14			3	134	25	20
Overdraft		178	321	229	89			
Total	83	257	386	294	161	1995	431	357
Net Annual Cash Flow								
Change in G.M.	−677	−608	841	1029	2012	1441	2392	4423
Less Capital	474	180			35	1792	337	268
Interest Paid	36	192	321	229	92	134	25	20
Change in Tax		29	90	135	103	56	698	151
Total	−1187	−951	610	935	1988	−429	2728	4286
Cumulative Balance	−1187	−2138	−1528	−593	+1395	+966	+3694	+7980
Valuation Extra Stock								+5346

G*

Table 14

Cash Flow Analysis at the Fixed Costs and Prices of 1975-76 (£)

Year	1969	1970	1971	1972	1973	1974	1975	1976
Base Gross Margin	5424	5424	5424	5424	5424	5424	5424	5424
Gross Margin	3679	3679	7408	7086	7943	8084	8834	9847
Change in G.M.	−1745	−1727	1984	1662	2519	2660	3410	4423
Capital Investment								
Fencing	1170	445			57			
Land Improvement						2283	370	268
Total	1170	445			57	2283	370	268
Tax Allowances								
Depreciation	117	162	162	162	168	168	168	168
Trading Expenses						2283	370	268
Interest:								
Current Capital	88	33			4	171	28	20
Overdraft		450	838	632	425	78	28	
Total	205	645	1000	794	597	2700	594	456
Net Annual Cash Flow								
Change in G.M.	−1745	−1727	1984	1662	2519	2660	3410	4423
Less Capital	1170	445			57	2283	370	268
Interest Paid	88	483	838	632	429	249	56	20
Change in Tax		72	226	350	278	209	945	208
Total	−3003	−2583	1372	1380	2311	337	3929	4343
Cumulative Balance	−3003	−5586	−4214	−2834	−523	−186	+3743	+8086
Valuation Extra Stock								+5346

ment, the further capital required being generated from within the project.

At the close of 1976 the valuation of extra stock on the project area amounted to £5,346 for 233 ewes (£20/ewe) and 49 ewe hoggs (£14/hogg). Thus to the cumulative balance of + £7,980 at November 1976 may be added the extra stock valuation of £5,346 to give the total 'cash worth' of the flocks performance which has resulted from the capital investment and management changes reported.

The cash flow analysis at the fixed costs and prices of 1975/76 (Table 14) shows the cumulative balance at November 1976 to be + £8,086, a value very similar to that for the cumulative balance at prevailing costs and prices. It lends further support to the conclusion, already reached, that the timing of capital inputs to the project would appear to have been soundly based.

Examination of the data in Tables 13 and 14 shows that there was an important difference in the two cash flows. At the fixed costs and prices of 1975/76 the negative cash flow is seen to have persisted over the first six years of the project, compared with only four years at prevailing costs and prices, with the inevitable consequence that much higher interest charges had to be met. However, prices in 1976 were relatively high in relation to costs so that in producing a cash flow using this somewhat favourable cost/price relationship, a positive cumulative balance once reached, increased very rapidly.

On the basis of the costs used, it is of interest to note that the base gross margin is providing £6·06 of income for each £1 of expenditure in the form of variable costs as against a mean value of £3·44 for each £1 of similar expenditure for the project from 1969 to 1976. This difference is due in part to the difference in feed expenditure, which comprises 48 per cent of all expenditure for the base data, as opposed to a mean of 61 per cent of all expenditure for the eight years of the project.

It is therefore recognised that the modified system appears to be more vulnerable to any less favourable change in cost/price relationships but this has to be seen against the background of substantially increased flock gross margins, accruing to the modified system. Attention has already been drawn to the advantage of increased flock gross margins in the context of increases in fixed costs, including those of labour.

The implication of all the cash flow data presented here to November 1976, is that the rates of capital investment and stocking rate increase have been soundly based, with considerable benefits in long-term economic viability, especially when viewed against ever-increasing fixed costs. The project is continuing.

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Appendix I

Physical Output and Price Data (actual prices)

	1968/69	1969/70	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76
Physical Output								
Ewes mated	398	451	518	528	573	600	601	620
Lambs weaned	337	391	531	553	570	549	617	673
Lambs sold	221	276	374	385	423	409	461	527
Lambs retained	116	115	157	168	147	140	156	146
Mean weaning weight (kg)	23·1	23·5	26·7	25·4	24·9	26·1	26·0	26·6
Total lamb weaned (kg)	7785	9189	14178	14046	14193	14329	16042	17902
Total lamb sold (kg)	5105	6486	9985	9779	10533	10675	11986	14018
Cast ewe numbers	52	42	82	91	117	122	107	96
Wool sold (kg): Ewes	636	815	1053	1063	1208	1162	1244	1216
Hoggs	214	202	200	306	353	292	291	326
Total	850	1017	1253	1369	1561	1454	1535	1542
Special gimmer sale								33
Prices								
Lamb p./kg LW	24·2	20·5	22·0	31·4	40·7	33·5	37·5	54·7
Wool p./kg	49·5	46·2	53·5	52·6	54·6	55·1	65·9	79·3
Cast ewes (£)	4·40	4·20	6·50	4·30	10·00	6·10	9·00	17·30
Subsidy (£)	1·23	1·23	1·60	1·65	1·65	3·00	3·60	3·60
Gimmers/head (£)								17·75

Appendix II

Physical Input and Cost Data (actual prices)

		1968/69	1969/70	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76
Ewe numbers		398	451	518	528	573	600	601	620
Physical Inputs									
Ewe Feed (tons)	Concentrate	8·30	8·30	5·58	8·35	7·90	9·50	6·85	8·65
	Sugar beet pulp			7·53	8·25	9·87	12·00	3·90	4·15
	Grass nuts		2·18						
	Feed blocks							3·35	4·70
	Hay	7·20	17·40		1·00	2·60	1·55	1·34	2·36
	Total ewe cost (£)	411·00	638·10	419·25	605·96	735·45	1311·50	1155·38	1811·50
Hogg numbers		122	116	115	157	168	147	140	154
Hogg Feed (tons)	Concentrate							0·70	1·05
	Sugar beet pulp		0·33	1·07	1·35	2·34	1·80	1·70	1·80
	Grass nuts	2·45	3·13	1·25	1·60	2·34	1·40	1·55	1·80
	Ewe & lamb feed		0·37		0·15		0·10	0·05	0·10
	Hay	1·20	2·30	0·20	0·72	0·35		1·25	2·52
	Total hogg cost (£)	87·50	149·05	70·70	116·28	157·89	180·60	322·25	485·06
TOTAL FEED COST (Ewes and Hoggs) (£)		498·50	787·20	490·00	722·20	893·30	1492·10	1477·60	2296·56
Fertilisers (cwts)							12	12	12
Grazing (Nos. Twins)		29	29	82	108	106			
Costs (£/ton)	Ewe & lamb feed		42·00		51·00		80·00	95·00	93·50
	Concentrate	36·00	36·00	41·00	42·00	50·00	70·00	80·00	89·80
	Sugar beet pulp		27·00	28·00	29·00	30·00	50·00	64·00	68·90
	Grass nuts	28·00	28·00	30·00	37·00	35·00	59·00	66·00	77·00
	Feed blocks							91·00	137·45
	Hay	16·00	16·00	17·00	16·00	17·00	30·00	40·00	45·00
Other Costs	(a) Vet (£ per ewe)	0·57	0·57	0·52	0·47	0·55	0·54	0·63	1·02
	(b) Haulage (£ per ewe)	0·07	0·09	0·09	0·09	0·10	0·11	0·13	0·20
	(c) Ram feed (£ per ewe)	0·04	0·04	0·05	0·05	0·06	0·13	0·15	0·18
	(d) Ram replacement	0·32	0·32	0·32	0·32	0·40	0·55	0·70	0·50
	Total cost/ewe (a+b+c+d)	1·00	1·02	0·98	0·93	1·11	1·33	1·61	1·90
Fertilisers/ton							36·45	82·50	79·85
Grazing: £1.12/Twin ewe		32·50	32·50	91·80	121·00	118·70			

Appendix III

Base Data—Physical

Stock ewe numbers 387
Lambs weaned 351
Lambs retained 97
Cast ewe numbers 74
Death rate ewes & hoggs 4·5%

Base Gross Margin at Prevailing Prices (£)

		1969	1970	1971	1972	1973	1974	1975	1976
Income									
Lamb	5732 kg	1387	1175	1261	1800	2333	1920	2150	3135
Wool	869 kg	430	401	465	457	474	479	573	689
Cast ewes	74	326	311	482	318	740	451	666	1280
Subsidy	387	476	476	619	639	639	1161	1393	1393
Total		2619	2363	2827	3214	4186	4011	4782	6497
Expenditure									
Conc.	2·59 T	93	93	106	109	130	181	207	233
Hay	6·39 T	102	102	109	102	109	192	256	287
Vet costs		135	135	135	135	135	163	194	213
Other costs		166	174	178	178	217	306	379	340
Total		496	504	528	524	591	842	1036	1073
Gross margin		2123	1859	2299	2690	3595	3169	3746	5424

Appendix IV

Cash Flow Analysis: Rate of investment is given in the second section of the analysis, and all capital sums are nett of subsidy and grant.

In claiming Tax Relief, fencing is claimed in terms of 'depreciation' at the rate of 10 per cent of total capital involved, over a period of ten years, whilst capital invested in land improvement is treated as a trading expense and relief claimed fully in the year it is carried out.

Relief on interest payments is made up of relief on the current year's capital expenditure, interest being the current rate for the capital invested that year for a period of six months, and also on the interest paid to cover the overdraft balance of the previous year. The total tax allowances are multiplied by the tax rate and the resultant tax relief claimed the following year (i.e. "Change in Tax" in section of analysis headed Net Annual Cash Flow).

The Net Annual Cash Flow is calculated by summing the change in gross margin and change in tax, and deducting both the interest paid and capital invested in that year.

The Cumulative balance is the sum of the net annual cash flows for each year.

Interest has been charged at 15 per cent throughout, and the Tax Rate assumed to be 35 per cent.

It should be noted that stock increases have been made, and the capital cost of these absorbed as a 'reduction' in the gross margin; interest on this nominal capital investment has only been paid if the 'investment' contributed to overdraft.

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* Author not on HFRO staff.

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The Agricultural Research Council co-ordinates the research programmes of all institutes, concerned with agriculture, financed from public funds. All the institutes publish periodical reports, and details can be obtained from the Secretaries of the institutes concerned.

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King's Buildings, West Mains Road, Edinburgh EH9 3JQ. (Tel: 031-667 6901.)

Animal Research Station
307 Huntingdon Road, Cambridge CB3 0JQ. (Tel: Cambridge (0223) 77222.)

Food Research Institute
Colney Lane, Norwich NR4 7UA. (Tel: Norwich (0603) 56122.)

Institute of Animal Physiology
Babraham, Cambridge CB2 4AT. (Tel: Cambridge (0223) 832 312.)

Institute for Research on Animal Diseases
Compton, Nr. Newbury, Berks. RG16 0NN. (Tel: Compton (063 522) 411.)

Letcombe Laboratory
Wantage, Oxfordshire OX12 9JT. (Tel: Wantage (02357) 3327.)

Meat Research Institute
Langford, Bristol BS18 7DY. (Tel: Churchill (0934) 852661.)

Poultry Research Centre
King's Buildings, West Mains Road, Edinburgh EH9 3JS. (Tel: 031-667 4461.)

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East Malling Research Station
East Malling, Maidstone, Kent ME19 6BJ. (Tel: West Malling (0732) 843833.)

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Worthing Road, Rustington, Littlehampton, Sussex BN16 3PU. (Tel: Littlehampton (09064) 6123.)

Grassland Research Institute
Hurley, Maidenhead, Berks. SL6 5LR. (Tel: Littlewick Green (062 882) 3631.)

Hannah Research Institute
Ayr KA6 5HL. (Tel: Prestwick (0292) 76013.)

Hill Farming Research Organisation
Bush Estate, Penicuik, Midlothian EH26 0PY. (Tel: 031-445 3401.)

Houghton Poultry Research Station
Houghton, Huntingdon, Cambs. PE17 2DA. (Tel: St. Ives (Hunts) (0480) 64101.)

John Innes Institute
Colney Lane, Norwich NR4 7UH. (Tel: Norwich (0603) 52571.)

Long Ashton Research Station
Long Ashton, Bristol BS18 9AF. (Tel: Long Ashton (027580) 2181.)

Macaulay Institute for Soil Research
Craigiebuckler, Aberdeen AB9 2QJ. (Tel: Aberdeen (0224) 38611.)

National Institute of Agricultural Engineering
Wrest Park, Silsoe, Bedford MK45 4HS. (Tel: Silsoe (0525) 60000.)

National Institute for Research in Dairying
Shinfield, Reading RG2 9AT. (Tel: Reading (0734) 883103.)

National Vegetable Research Station
Wellesbourne, Warwick CV35 9EF. (Tel: Stratford-upon-Avon (0789) 840382.)

Plant Breeding Institute
Maris Lane, Trumpington, Cambridge CB2 2LQ. (Tel: Trumpington (022 021) 2411.)

Rothamstead Experimental Station (and Soil Survey of England and Wales).
Harpenden, Herts AL5 2JQ. (Tel: Harpenden (05827) 63133.)

Rowett Research Institute
Greenburn Road, Bucksburn, Aberdeen AB2 9SB. (Tel: Bucksburn (022 471) 2751.)

Scottish Horticultural Research Institute
Invergowrie, Dundee DD2 5DA. (Tel: Invergowrie (08267) 731.)

Scottish Institute of Agricultural Engineering
Bush Estate, Penicuik, Midlothian EH26 0PY. (Tel: 031-445 2147.)

Scottish Plant Breeding Station
Pentlandfield, Roslin, Midlothian EH25 9RF. (Tel: 031-445 2171.)

Welsh Plant Breeding Station
Plas Gogerddan, Aberystwyth, Dyfed SY23 3EB. (Tel: Bow Street (0970 87) 255.)

Wye College Department of Hop Research
Wye College, University of London, Ashford, Kent TN25 5AH. (Tel: Wye (0233) 812401.)

LIST OF COMMON NAMES OF PLANTS AND THEIR CORRESPONDING SCIENTIFIC NAMES

Bell Heather (Heath)	*Erica cinerea*
Bent grasses	*Agrostis* spp.
Birdsfoot trefoil (Bacon and Eggs)	*Lotus corniculatus*
Blaeberry (Bilberry, Whortleberry, Huckleberry)	*Vaccinium myrtillus*
Bracken	*Pteridium aquilinum*
Cocksfoot	*Dactylis glomerata*
Cotton sedge (Cotton grass, Draw Moss, Hare's tail, Mossine)	*Eriophorum* spp.
Deer sedge (Deer grass)	*Trichophorum cespitosum*
Fescue grasses	*Festuca* spp.
Red fescue (Creeping fescue)	*Festuca rubra*
Sheep's fescue	*Festuca ovina*
Flying bent (Purple moor grass, Blow grass, White grass (also used for *Nardus stricta*))	*Molinia caerulea*
Heather (Ling)	*Calluna vulgaris*
Mat-grass (White bent, White grass (also used for *Molinia caerulea*))	*Nardus stricta*
Spret (Jointed rush)	*Juncus articulatus*
(Sharp-flowered rush)	*Juncus acutiflorus*
Stool bent (Heath rush)	*Juncus squarrosus*
Timothy	*Phleum pratense*
White clover (Dutch clover)	*Trifolium repens*