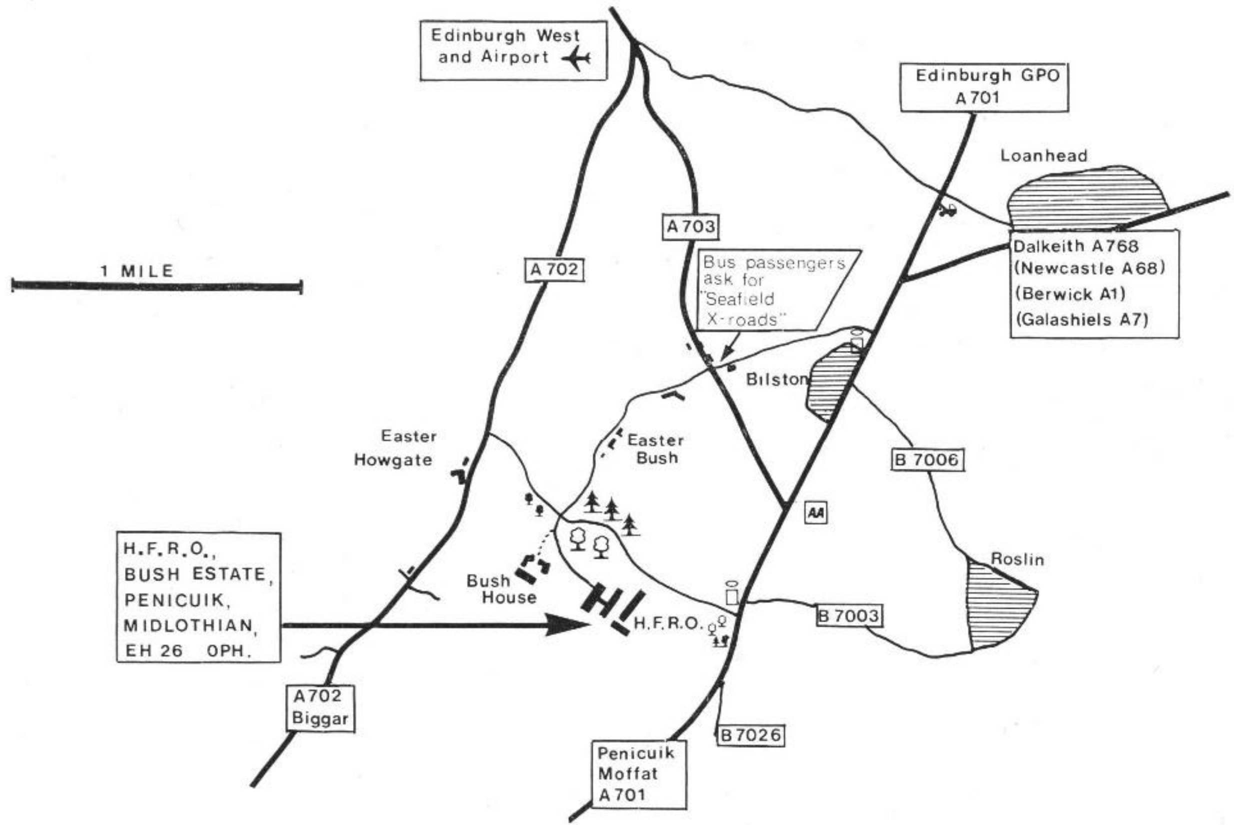
# HILL FARMING RESEARCH ORGANISATION

## SIXTH REPORT

1971-1973

Hill Farming Research Organisation, Bush Estate




SKETCH MAP TO SHOW LOCATION OF HILL FARMING RESEARCH ORGANISATION

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SIXTH REPORT

1971-1973

BUSH ESTATE, PENICUIK, MIDLOTHIAN EH26 0PH

Tel. 031 445 3401

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## PRESENT BOARD OF MANAGEMENT



## OTHER MEMBERS DURING PERIOD OF REPORT

# STAFF

(as at 31 December 1973)

*Director*

J. M. M. Cunningham, BSC(AGR), PHD, FRSE, FIBIOL

## Animal Nutrition and Production Department

*Head of Department:* J. Eadie, BSC(AGR)

R. D. M. Agnew, HNC
Richard H. Armstrong, BSC(AGR)
L. Bagley, BSC
G. R. Bolton, BSC(AGR)
Mrs J. M. Brown, MA
D. R. Campbell, SDA, NDA
Mrs. L. Common
T. G. Common
M. Cowie
J. M. Doney, BSC, PHD
A. R. Fawcett, AMILT
Miss J. Z. Foot, BSC(AGR), MAGRSC, PHD
R. G. Gunn, BSC(AGR), PHD
R. A. Hetherington, BSC
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C. S. Lamb, BSC(AGR)
Mrs C. Landale
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J. C. MacRae, BSC, PHD
T. J. Maxwell, BSC(AGR), PHD
Mrs W. McLaren
J. A. Milne, BSC(AGR), PHD
Miss P. E. Moberly, BSC
N. W. Mortimer
J. N. Peart, BSC(AGR), MSC
I. R. Pitkethly
A. J. F. Russel, BSC, MAGRSC, PHD
A. R. Sibbald, HNC
E. Skedd, HNC
A. D. M. Smith, NDA, SDA
W. F. Smith, AIST
Miss N. Tarn
I. R. White
A. Whitelaw, BSC, FRCVS
T. K. Whyte, SDA, HNC
S. Wilson, BSC(AGR), MS

*Postgraduate Students*

Miss A. Tait, BSC(AGR)
D. J. MacDonald, BSC(AGR)
Miss D. A. Vine, BSC

## Plants and Soils Department

*Head of Department:* P. Newbould, BSC, BAGR, DPHIL

G. J. Baillie
G. T. Barthram, BSC
D. Bruce
A. R. M. Chambers, BSC
G. E. Davies, BSC
C. C. Evans, HNC
M. J. S. Floate, BSC, PHD, ARIC
Miss S. A. Grant, BSC, MSC
A. Haystead, BSC, PHD
A. D. Ironside
J. King, BSC(AGR), PHD
K. Kinnaird
W. I. C. Lamb, HNC, MIBIOL
A. G. Lowe, BSC
J. Mackenzie, ONC
W. G. McDermott, BSC, MIBIOL
C. C. J. McGill, ONC
Mrs McGregor, OND

Mrs M. S. Pimplaskar, BSc, MSc, PhD
Miss C. Reid
J. A. Rogers, BSc, PhD
D. E. Suckling, HNC, MIBiol
Mrs C. Thompson
Miss L. Torvell, BSc

## Field Research Stations

### Glensaugh

*Officer in Charge:* A. L. Fairlie, BSc (Agr)
M. Begg
S. Buschman
A. J. MacDonald, NDA

*Red Deer Project*

W. J. Hamilton, BA(Open) NDA, NDD, MIBiol

### House O' Muir

*Officer in Charge:* A. J. Senior, SDA

### Sourhope

*Officer in Charge:* R. H. Armstrong, MSc, PhD, ARIC
G. H. Kay, HND
P. Watchorn, BSc(Agr)

### Lephinmore

*Officer in Charge:* D. C. Currie, NDA, NDD

*Information Officer/Librarian:* Miss A. Ramsden, BSc, MSc

## Administration

*Secretary:* D. Warne, FCIS, MBIM
*Assistant Secretary:* C. G. Williamson, ACIS, AMBIM
*Director's Secretary:* Miss J. A. Brown

Miss I. C. R. Anthony
Miss J. C. Brown
Miss E. V. Deans
Miss A. M. Johnston
Mrs E. B. H. Reid
H. Thompson
Mrs H. Tulloch
F. Ward, MInstPS
Mrs G. White

## RESEARCH STATIONS

THE three research farms continue to function under their respective officers-in-charge, Mr A. L. Fairlie (Glensaugh), Mr D. C. Currie (Lephinmore) and Dr R. H. Armstrong (Sourhope).

**Glensaugh**, Laurencekirk, Kincardineshire

Glensaugh is situated at the eastern end of the Grampians. It consists of some 2070 acres of rough hill grazings dominated by heather and ranging from 450 to 1600 feet, with 334 acres of short- and long-term leys and 27 acres of forage crops. Average rainfall is 41 inches. The breeding stock consists of 950 Blackface ewes and 140 hill cows.

**Lephinmore**, Strathlachlan, Strachur, Argyll

Lephinmore is situated on the east side of Loch Fyne in Argyll. It consists of some 2830 acres of hill grazings up to 1550 feet altitude, mostly over peat, and with a mixed herbage, including heather, *Molinia*, *Scirpus* and hill grasses. There are 77 acres of short- and long-term leys. Average rainfall is 67 inches at sea level. The breeding stock comprises 732 Blackface ewes and 52 hill cows.

**Sourhope**, Yetholm, Kelso, Roxburghshire

Sourhope lies 15 miles south of Kelso on the western slopes of the Cheviots. There are 2633 acres of hill grazings at 690 to 2000 feet, consisting largely of grasses, such as the *Agrostis* and *Festuca* spp., with substantial areas dominated by *Nardus* and *Molinia*. There are 111 acres of short- and long-term leys. Average rainfall is 37 inches. The breeding stock comprises 783 South-country Cheviot, 467 North-country Cheviot, 564 Blackface ewes, 305 North-country and South-country Cheviot crosses and 74 hill cows.

**House o' Muir**, Midlothian

In November 1970 the Organisation took over part of the farm of House o' Muir, which is located on Turnhouse Hill of the Pentlands range and lies about two miles from Bush Estate. There are 583 acres of rough grazings at 800 to 1500 feet altitude consisting largely of *Agrostis/Festuca* pastures overlying brown earth soils, with 62 acres of short- and long-term leys. Average rainfall is 33 inches. The land carries a flock of 317 Blackface ewes and hoggs. There are also buildings which will be used for work on hill beef cattle.

# LOCATION of RESEARCH STATIONS – SCOTLAND

# INTRODUCTION

SINCE our last report the administration and laboratory section of the Organisation has moved into new premises at Bush, where we now have a range of modern laboratory facilities, animal accommodation and glasshouse and associated buildings suitable for the comprehensive programme of research which has been developed.

The new laboratories were officially opened by H.R.H. Prince Philip, Duke of Edinburgh, on 10th July 1973 in the presence of distinguished guests associated with hill farming from throughout Great Britain.

This transfer has enabled the Organisation to become a member of the Edinburgh Centre of Rural Economy which is an association of teaching and research institutes using the facilities on the Bush Estate. Being at Bush has further improved opportunities for collaboration with other institutes and we are grateful for the continued support and assistance which we have received from the Edinburgh School of Agriculture, the Animal Breeding Research Organisation, the Animal Diseases Research Association, the National Institute of Agricultural Engineering (Scottish Station) and the Scottish Society for Research in Plant Breeding.

An example of such collaboration is the creation and joint management of a carcass dissection unit to service Animal Breeding Research Organisation, Edinburgh School of Agriculture and ourselves.

As a consequence of the White Paper 'Framework for Government Research and Development' important changes have occurred in the central planning of agricultural research. This has involved the introduction of a system of research classification and a costing system which was introduced in April 1972.

The Joint Consultative Organisation which has been established has received wide publicity and HFRO will contribute in close association with the Department of Agriculture to the new planning system.

The White Paper proposed the so-called customer/contractor relationship whereby the Agricultural Departments would act as customers, paying for a substantial amount of future research and that the Agricultural Research Council and the Institutes would contract to undertake the work suggested by the Joint Consultative Organisation. This demands the organisation of research into packages or areas of work the titles of which are the main headings given in the programme of work (p. 19).

The move to new Headquarters has permitted the re-organisation of the work into two Department groupings—Soils and Plants, and Animal Nutrition and Production.

Apart from the provision of laboratory accommodation for individual scientists, service laboratory facilities to meet the requirements of all staff have been provided.

The present report contains review articles which discuss findings from research. In particular, the contributions dealing with the nutrition of the pregnant ewe and on studies with reproductive performance brings up-to-date previous reports on topics of vital importance particularly in hill sheep production.

Two contributions, that on the subject of plants for hill land improvement, and also that dealing with the problems associated with wet soils are attempts to assess the present state of knowledge and to evaluate the need for further investigation. We would be grateful, therefore, to receive relevant comments from farmers, advisers and scientists.

Hitherto, very little investigation has been undertaken by HFRO on factors affecting the growth of lambs other than on milk production of the ewe. The report on lamb growth deals with a limited but none the less important aspect of this subject.

It clearly emerges that clover must have an important role to play in improved pastures on poor soil not only because of the fixation of nitrogen which takes place but also because of its contribution to the nutritional value of grazed herbage.

In our last report the basis of our programme of systems development was comprehensively outlined. The article in the current report, on the economic appraisal of investment, deals with an important aspect of development research, namely the evaluation of investment possibilities in actual projects. We believe that the econometric techniques devised may be of value as a tool in farm management advisory work where capital investment in hill farming is under consideration.

Progress reports on our development research appeared in Colloquium Proceedings No. 3 published by the Potassium Institute Ltd. We consider that the stage has now been reached when the applications of the new ideas developed by HFRO and tested at Kirkton, West of Scotland Agricultural College, Redesdale Experimental Husbandry Farm (Agricultural Development Advisory Service) and on HFRO farms now merits controlled trials on commercial farms. To this end a programme of work by the three Scottish Colleges of Agriculture and co-ordinated by the Scottish Agricultural Development Council should commence in 1974.

The ever-increasing demand for home-produced food and the improved prospects for beef and lamb have lead to an improvement in the long-term outlook for hill farming. A further argument in support of hill farming is that viewed against a background of declining and vastly more costly energy supplies, it is of significance that energy inputs relative to outputs in animal production systems on the hills are of an order of efficiency much greater than many other systems of food production or harvesting.

**Board of Management**

On the appointment of a new Board of Management several long serving members demitted office.

Mr J. Crozier retired as Chairman of the Board of Management. His guidance and advice were invaluable during a period of transition and expansion.

We wish to acknowledge the considerable interest, support, understanding, friendly and wise counsel received from Professor R. C. Garry, who has now retired, and from Professor P. E. Weatherley, Mr J. G. Jones and Mr A. G. Black.

**Staff**

The Staff of HFRO, his many friends in the agricultural research service and in the farming industry were deeply sorry to learn of the death of Arthur Wannop in September 1972 and an appreciation is included in this report.

During the triennial period Dr W. N. M. Foster left to take up a post in the University of Melbourne.

**Visits**

Dr R. H. Armstrong: Nuffield Scholarship to study sheep and cattle systems in Australia and New Zealand.

Dr J. M. M. Cunningham: to present a paper at an International Symposium on Semi-mountain and Mountain Sheep Breeding at Varna, Bulgaria; lecture tour in Nova Scotia.

Dr J. M. Doney: VII International Congress on Animal Reproduction and Artificial Insemination at Munich, Germany; British Council Scholarship to visit Czechoslovakia.

Mr J. Eadie: Sir George Stapledon Memorial Fellowship to visit laboratories in Australia and New Zealand; European Association of Animal Production Symposium on Animal Production and Farm Structure at Vienna, Austria.

Dr M. J. Floate: Fourth General Meeting European Grassland Federation at Lausanne, Switzerland.

Dr R. G. Gunn: Third World Congress on Animal Production and visit to laboratories in Australia and New Zealand.

Dr P. Newbould: visit to research institutes in the Netherlands.

Mr J. N. Peart: Symposium on Milk Recording of Sheep and Goats in Israel.

Dr A. J. F. Russel: IX International Congress of Nutrition in Mexico.

## ARTHUR ROBSON WANNOP, OBE, B ENG, BSC

ARTHUR WANNOP, the first Director of the Hill Farming Research Organisation, died at his home in Edinburgh on 11th September 1972, seven years after he had retired from the post of Director. He was appointed late in 1953 and remained with the Organisation until he retired in 1965, some twelve years later having reached his retiral age. For some years before he became Director he had been a member of the Hill Farming Committee. This committee, set up by the Department of Agriculture for Scotland, co-ordinated the investigational work in hill farming in Scotland and helped to finance it. Its membership was those drawn from the staffs of the Colleges of Agriculture and the Research Institutes that were concerned with work on the hill or marginal farm. A number of leading hill farmers were also members and it was here that Arthur Wannop was in close touch with the problems of Scottish hill farming and with those who were working on them. At that time, too, he was Technical Development Officer to the Department of Agriculture for Scotland, a post he had held since 1st January 1948. Among his duties as Technical Development Officer he had become involved in the running of a number of hill farms that were in the hands of the Department of Agriculture.

It was no surprise then to his many friends in agriculture that Arthur Wannop was invited to become the Director of the newly formed Hill Farming Research Organisation, a body that was to study the problems of hill farming in Great Britain including the hill farming areas of England, particularly the North, and also of Wales.

He was particularly fitted for this post since he came from an agricultural family, members of which are still farming in Cumberland, where his father was a leading agriculturist. He was, thus, brought in contact with the marginal farm and the hill farm with their interrelated problems at an early age.

Now the Hill Farming Research Organisation was launched, the new Director had to marshal his forces and get a programme into being. The three agricultural Colleges had built up some facilities for research and investigation and some field laboratories were available. Glensaugh in Kincardineshire, Sourhope in Roxburghshire and Lephinmore in Argyll were taken over from the Colleges as a nucleus and a Headquarters was set up in Edinburgh with limited laboratory facilities.

The early programme had perforce to contain a high proportion of investigational husbandry problems, and a scientific programme was gradually grafted on to this as the field laboratories were strengthened. It was, nevertheless, a difficult time since scientific staff could not be offered the facilities they desired and much had to be improvised.

Arthur Wannop used to say that he was not a scientist, an attitude that was unfair to the man himself. He did see the problems, could plan the husbandry experiments and knew where the scientific work fitted in, and that was what was required as the three farms were gradually developed as research farms and the necessary facilities were obtained.

By the time he retired much valuable work had been done, many problems had been defined, some solved, and a sound research programme, with a strong husbandry bias, was in being. Publications were appearing from the staff, both scientific and practical and the Director was losing no opportunity of letting the hill farmer know what was being done. His success in this last can be gauged by the fact that he received the George Hedley Award of the National Sheepbreeders' Association in 1962.

When Arthur Wannop retired in 1965 he left behind a soundly based research body poised to tackle the underlying scientific problems of the hill and the marginal farms. A central laboratory was still required but the direction in which the work would go was becoming quite clear.

After his retiral up to the time of his death Arthur Wannop retained his interest in the Organisation and often went to see the work as it was developing.

Some clue to the capabilities of the first Director can be gained from his early life. After leaving school in Penrith, he went to Liverpool and took a degree in engineering, which he then proceeded to cap with a degree in agriculture at Aberdeen. This scientific training, together with his practical background, was ideal for the work he was to do. He started in the educational and advisory service in Scotland and his first post was with the Edinburgh and East of Scotland College of Agriculture. He went first to Fife and then to the Borders, to be responsible for the work in Berwickshire, Roxburghshire and Selkirkshire. During his time here (ten years from 1922 to 1932) it is interesting to note that there was a very marked increase in farm mechanisation for which Arthur Wannop must have found his academic qualifications ideal. The next three years he spent south of the Tweed in Northumberland as Chief Agricultural Organiser. From there he came back to Scotland as Director of County Work for the North of Scotland College of

ARTHUR ROBSON WANNOP, OBE, B ENG, BSC

Agriculture at Aberdeen, a post he occupied up to 1948 when he joined the Department of Agriculture for Scotland. This was a period when Arthur Wannop really got to know the problems of agriculture in the North of Scotland but he was known throughout the whole of the country since he was the most senior member of the whole advisory service north of the border.

During the war he, with other members of the advisory services, came into close contact with all problems of the agricultural industry, economic, practical and scientific. He served on many central committees and was sent to the United States of America in 1943 as a member of a delegation that went to examine the advisory system operating in that country. This work led to his appointment as an Officer of the Order of the British Empire in 1946.

In looking at the man himself, one is struck by his great and abiding interest in the young people in agriculture. Throughout his life he was a power in the Young Farmers' Club movement and gave up much of his spare time furthering its aims. He was a representative to the Scottish Association of Young Farmers' Clubs for over thirty years, and served some years as Chairman of the Association.

Arthur Wannop took an active part in the development of agricultural education and was a well-known figure at agricultural congresses. He was a member of the Agricultural Education Association, the British Grassland Society and the British Society of Animal Production. He was a founder member of this last and was also a regular attender at the meetings of the British Association for the Advancement of Science taking an important part in the work of the Agriculture Section M. He was elected a Fellow of the Royal Society of Edinburgh in 1952 and was a well-known figure at the Dining Club of the Royal Society.

He was a man of wide interests, but most of his time was devoted to agriculture which, to the deeply involved person, becomes a hard master; time consuming but always deeply rewarding. This involvement with his chosen profession Arthur Wannop never lost.

Emeritus Professor S. J. WATSON CBE.

# SUMMARY OF RESEARCH

IN 1973-74 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, and their interrelationships with a view to 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 in relation to hill land |

## CURRENT RESEARCH

### Performance of sheep in Hill and Upland Environments

The improvement of reproductive efficiency.

Repeatability of ovulation rate during the breeding season. (A. W., J. M. D., R. G. G., W. F. S.)

Nutrition, body condition and fertility in hill ewes. (J. M. D., R. G. G., W. F. S.)

Fertility and body condition in upland ewes. R. G. G., J. M. D., W. F. S.)

The improvement of lactation and lamb growth.

Factors affecting lactation and lamb growth in hill sheep. (J. N. P., W. F. S.)

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

Effect of undernourishment during mid-pregnancy on placental and faecal development. (A. J. F. R.)

The objective assessment of feed inputs to pregnant hill ewes (A. J. F. R., T. J. M.)

The objective assessment of feed inputs to pregnant upland ewes. (A. J. F. R., T. J. M.)

The performance of improved genotypes.

The effectiveness of improved genotypes in utilising better hill land resources. (J. M. D., T. J. M., J. N. P.)

Studies of factors affecting fleece casting.

The regulation of wool growth and fibre shedding in Cheviot ewes. (W. F. S., J. M. D.)

Studies on the interaction of body composition and nutrition.

A study of some biological consequences of increasing fatness of sheep, with particular reference to food requirements for maintenance and gain, and ability to catabolise body fat and protein in undernourishment. (A. J. F. R.)

Studies on the factors of animal origin affecting the voluntary intake of roughages.

Food intake in pregnant and lactating ewes. (J. Z. F.)

Factors affecting the long term intakes of roughages by sheep. (J. Z. F.)

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

The digestibility and voluntary intake of heather. (J. A. M.)

The partition of digestion in sheep given heather diets. (J. C. M., J. A. M.)

The development of methods for measuring the intake of grazing sheep on heather. (J. A. M., A. J. F. R., A. R. M. C., Dr A. K. Martin HRI)

The importance of palability in determining the voluntary intake of heather by sheep. (J. A. M., A. T.)

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.)

The utilisation of grass and heather by the grazing sheep. (J. A. M., L. B.)

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 in the nutritive value of poor quality hill roughages and their supplementation.

Development of techniques for studies in the digestive physiology of the supplementation of hill pasture diets. (J. C. M., S. W., C. C. E., C. S. L., D. R. C.)

Investigations into the effect of supplementation on the nutritive value of winter hill herbages.

(*a*) grazing experiments. (C. S. L., J. C. M., J. E.)

(*b*) Related indoor experiments on cut herbage. (C. S. L., J. C. M.)

(*c*) Digestive physiology studies on roughages and supplements. (J. C. M., S. W.)

The improvement of lamb growth rates.

Studies on clover in the diet of hill lambs. (Rchd, H. A., J. E.)

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

The nutritional and production responses to a range of improvement techniques on a range of hill soils and pastures. (J. E., R. B. H., T. G. C.)

The nutritional and production responses to range of improvement techniques on blanket peat. (J. E., G. R. B.)

**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.
   - On a grassy hill. (R. H. A., J. E., T. J. M., P. W.)
   - On blanket peat. (T. J. M., J. E., D. C. C.)
   - On heather moor. (T. J. M., J. E., A. L. F., C. D. K.)
2. Inwintering systems
   - On a grassy hill. (R. H. A., J. E., T. J. M., P. W.)
   - On blanket peat. (T. J. M., J. E., D. C. C.)
   - In association with Edinburgh School of Agriculture (Boghall). (T. J. M., J. E., with E. S. A.)

Sheep production systems studies in the uplands.

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

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

A preliminary evaluation of existing data. (T. J. M., A. R. S., A. V., J. E.)

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

Veterinary monitoring of all systems studies, including parasites, mineral deficiencies, etc. (A. W., A. R. F.)

**Beef Cattle in Hill and Upland Environments**

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

The effect of nutritional state during late pregnancy on the production of beef cows. (A. J. F. R., A. W., J. N. P., A. J. M., W. F. S.)

Lactation studies with beef cows and calf growth rate.
(J. N. P., A. W., A. J. F. R., A. J. M., W. F. S.)

The effects of nutritional state during late pregnancy and of genotype on immunoglobulin production and absorption in beef cattle.
(A. J. F. R. with R. Halliday, ABRO, A. J. M.)

## Hill and Upland Pasture Production

*Plant Nutrition*

Improved production of white clover.

1. Major nutrient requirements on blanket peat. (W. G. McD., G. R. B.)
2. Coated seeds. (P. N., W. G. McD., R. H. A.)
3. Inoculation with effective rhizobia. (P. N., W. G. McD., M. D.—ESCA)
4. Factors which affect nitrogen fixation. (A. N., A. G. L.)

Assess availability of phosphate to plants from hill soils. (M. P.)

Improvement of the growth and nutrition of herbage plants by the use of earthworms. (P. N., W. G. McD., CSIRO, Z. D.—ESCA)

*Nutrient Interactions*

Study of the interactions between lime, aluminium and phosphate in hill soils on growth of herbage plants. (M. J. S. F., M. P.)

Study of the interactions between lime, aluminium and organic matter on the lime requirements of hill soils. (M. J. S. F.)

*Nutrient Cycling*

Study of the influence of the grazing animal in 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. Mineralisation of nutrients from plant materials and sheep faeces. (M. J. S. F.)
4. Maintenance of improved pastures on peat. (M. J. S. F., J. E., G. R. B.)
5. Maintenance of improved pasture on mineral soils. (M. J. S. F.)

*Effects of Moorland Utilisation by Grazing Sheep*

1. On stability and productivity of blanket bog. (S. A. G., C. D. K., G. R. B., W. I. C. L.)
2. On carbo-hydrate reserves and regrowth of heather. (W. I. C. L.)
3. On growth form and productivity of heather moor. (S. A. G., W. I. C. L.)
4. On the production and utilisation of grass and heather in mixed swards. (S. A. G., J. A. M., T. J. M., G. T. B.)

*Growth and Regrowth in Hill Pastures*

1. Effect of defoliation, season of use and type of sward. (J. K.)
2. Measurement using determinations of net photo synthesis. (J. K., D. E. S.)

*Pasture Establishment*

Determination of the conditions for optimum germination of selected grasses and white clover in hill soils (J. A. R.)

Determination of extra herbage production when bracken cover is reduced. (G. E. D.)

Examination of the response of a range of hill soils and pastures to different improvement techniques. (M. J. S. F., J. E., R. B. H., T. G. C.)

*Systems development*

Biological monitoring

1. Soils. (M. J. S. F.)
2. Pastures. (J. K., J. A. R.)

**Husbandry of Red Deer** (with Rowett Research Institute)

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. and RRI)

# 1. ECONOMIC APPRAISAL OF INVESTMENTS IN HILL SHEEP PRODUCTION

T. J. MAXWELL, J. EADIE AND A. R. SIBBALD

## Introduction

An improvement in sheep production from hill grazings depends on increasing pasture production and improving the efficiency of its utilisation, so that the better quality feed available will increase individual animal performance (Eadie, 1970). It is known that the efficiency of hill pasture utilisation under traditional systems is poor and can be improved by increasing land improvement and sheep performance, since the potential of hill sheep is well above that currently achieved.

Better systems of hill sheep production have developed but capital investment is required and increased variable costs may be incurred. It is vital, therefore, to ensure that the changed cost structure associated with increased output leaves margins better, or at least similar, to those likely to be obtained from comparatively low output systems. Thus methods of economic analysis have been developed by the Hill Farming Research Organisation, and these permit an assessment to be made of the effects on profits and gross margins on the application of knowledge in new systems. They also assist in the choice of priorities for investment.

This paper describes some of these methods in detail and also examines some of the issues to be taken into account when considering investments in hill sheep farming.

## The Need for Appraisal of Capital Investment

Capital investment in hill farming will be concerned chiefly with land improvement. It may, in some cases, involve investment in buildings for winter housing. Both kinds of investment will provide, in many instances, an opportunity to increase stock numbers. This, too, is a form of capital investment.

Capital investment will also bring about changes in variable costs and fixed costs. Variable costs are defined as those costs which can be readily allocated to a specific enterprise and which vary according to changes in the scale of that enterprise. The main variable costs are seed, fertilisers, sprays, concentrated feeding stuffs, casual labour and contract work. Fixed costs cannot easily be allocated to specific enterprises; they include regular labour, machinery depreciation, rent, rates and general expenses: fuel and repairs are also included.

The aim of hill land improvement is, in part, the improvement of sheep performance. To fully exploit the better summer nutrition provided by improved pasture, it will often be necessary to increase supplementary feed inputs in late pregnancy, and perhaps also during the winter generally. This will cause variable costs to increase. In order to maintain production from improved pastures it will be necessary to apply lime and phosphate at appropriate intervals and this, too, will increase variable costs.

Where systems of management are changed, particularly where greater control of stock is intended, changes in regular labour costs (i.e. fixed costs) may occur. The improvement of land and an increase in stock may bring about changes in rent. An increase in the amount of fencing will, in time, lead to increased maintenance costs.

An economic assessment of improved systems of hill sheep farming is essential, and such an assessment must include capital investment appraisal, which involves establishing in economic terms, the consequences of a range of investment possibilities. Assumptions about the levels of output to which an investment may reasonably be expected to give rise must be made. The Organisation's systems development programme is concerned with evaluating these output increases.

Initially, therefore, an economic assessment of new investment in hill sheep production is not concerned with a capital investment appraisal in the conventional sense, but rather, with identifying the levels of output which are necessary to justify the capital outlay. It is necessary to obtain an estimate of the increase in output required to break even on various levels of capital investment, in terms of possible combinations of stocking rate increase, improvement in sheep performance, and variable costs. A method produced by Harkins (1968), using a breakeven budget technique, has been used as the basis for this part of the economic analysis.

Having established an output objective it is then necessary to examine the various ways in which this can be achieved without creating short-term cash flow problems.

Finally, when alternative policies for a given hill unit have been formulated (the biological implications of each having been agreed to be possible within the set economic constraints) the most economically attractive policy can be established by comparing the net present value of the capital invested in each. The net present value (NPV) is the surplus after discounting the annual profits (net annual cash flows) at a fixed rate of return (marginal investment rate) and deducting their total value from the initial investment.

**Output Objectives**

To obtain an initial guide to the increases in output necessary to break even on a given level of capital investment, the breakeven budget technique of Harkins (1968), in which capital investment is amortised, is used. The method has been developed for application in assessing both the current results of systems studies in HFRO, and in planning their future development.

The breakeven equation on which the method is based is written:

$$E_1 GM_1 = E_2 GM_2 - Y,$$

where $E_1$ is the number of stock, $GM_1$ the gross margin per ewe before investment, $E_2$ the number of stock and $GM_2$ the gross margin after capital investment. $Y$ is the amount required to service and repay the capital, i.e. the annual capital charge.

Gross margin is used because it reflects the increase or decrease in gross output from a particular enterprise net of the increase or decrease in variable costs. Thus, the technical changes in performance of the enterprise are reflected in economic terms. Changes in fixed costs are not included at this point since they may have an impact on other enterprises on the farm and because they tend to vary greatly from hill farm to hill farm. $E_1$, $GM_1$ and $E_2$ are known. The servicing and repayment charges ($Y$) must be calculated from an amortisation formula.* The breakeven equation must also be adjusted to take account of the interest charges on the capital invested in extra stock. This value must be deducted from the gross margin after capital investment ($GM_2$).

It is now possible to calculate the gross margin per ewe that would be required after capital investment for any given increase in stock numbers. It is rare, however, that the examination is confined to one particular level of stocking rate increase. It is much more likely that output increases over a range of stocking rate increases require to be examined. The calculations are many and tedious and a computer programme has therefore been written. The output of this programme can be presented in the form of a graph of which an example is given in Figure 1.

* To calculate $Y$ for a given capital investment ($c$), the rate of interest ($i$) and the period of repayment ($m$) must be stated thus:

$$Y = c\frac{i}{1-(1+i)}-m$$

Breakeven equation becomes $E_1GM_1 = E_2GM_2-(E_2-E_1)\ VI- Y$.

$I$ = annual interest rate on capital invested in stock.

$V$ = value per head of extra stock.

The series of curves describes the minimum gross margin per ewe, over a range of stocking rate increases, which would be required to reach the breakeven point for different levels of capital investment.

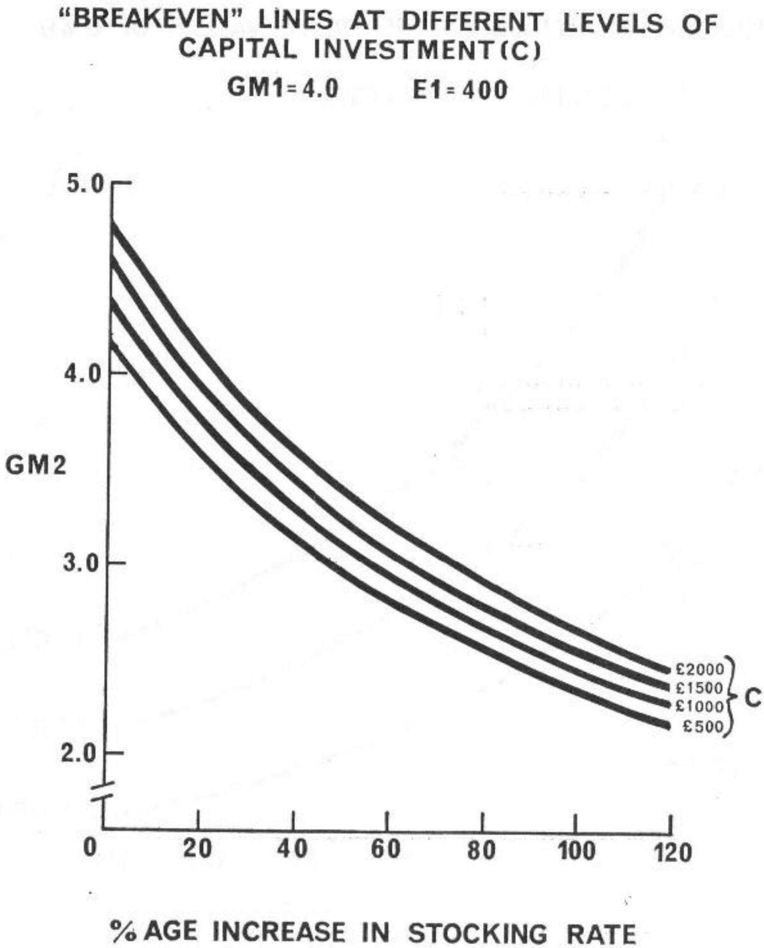


FIG. 1.

The 'breakeven' curve is obtained from a series of difference calculations, i.e. $GM_2 = \dfrac{E_1 GM_1 - Y}{E_2}$ in which $Y$ remains constant. Its position is therefore dependent in part on $E_1$ (the stock numbers before investment) and $GM_1$ (the gross margin before investment).

The relative effects of the original flock size ($E_1$) and its level of output ($GM_1$) on the breakeven value of $GM_2$ (the gross margin after investment) are illustrated in Figures 2 and 3.

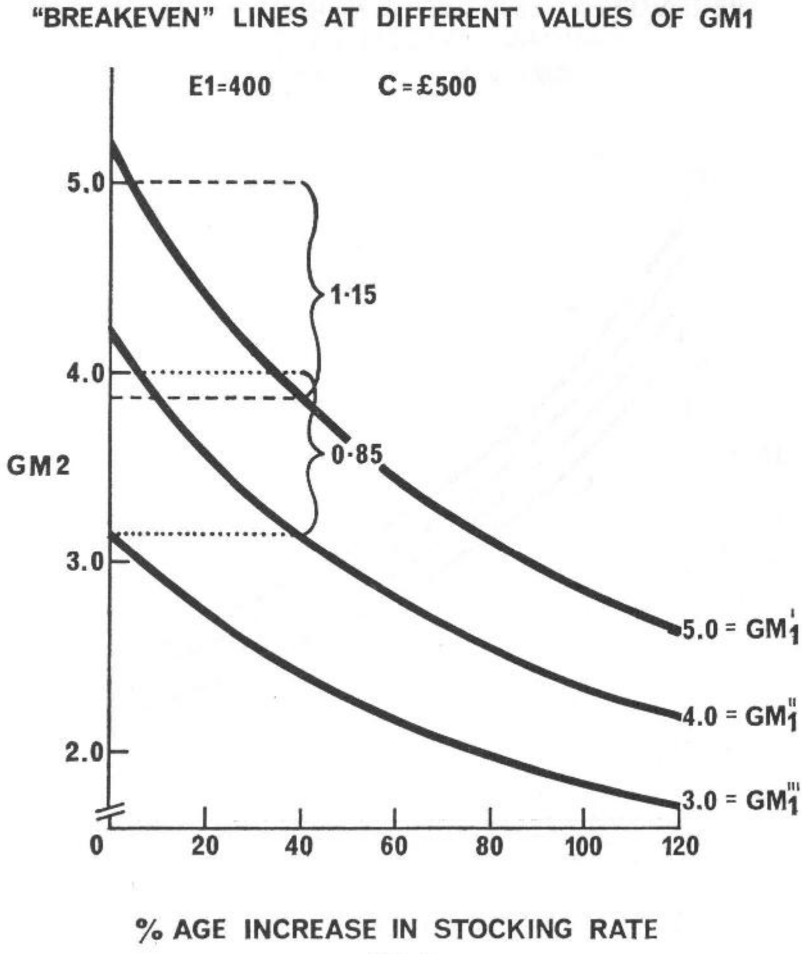


FIG. 2.

For a given level of capital investment, the extent to which *variable costs* may be increased is very much dependent upon the value of the gross margin before investment ($GM_1$). For example, Figure 2 shows that for a 40 per cent stock increase, and a $GM_1$ of £5, the minimum breakeven value of $GM_2$ is £3·85, a difference of £1·15 per ewe. For the same increase in stock but a $GM_1$ of £4 the minimum breakeven value of $GM_2$ is £3·15, a difference of £0·85. It could be argued, therefore, that for an investment of £500, a $GM_1$ of £5, and

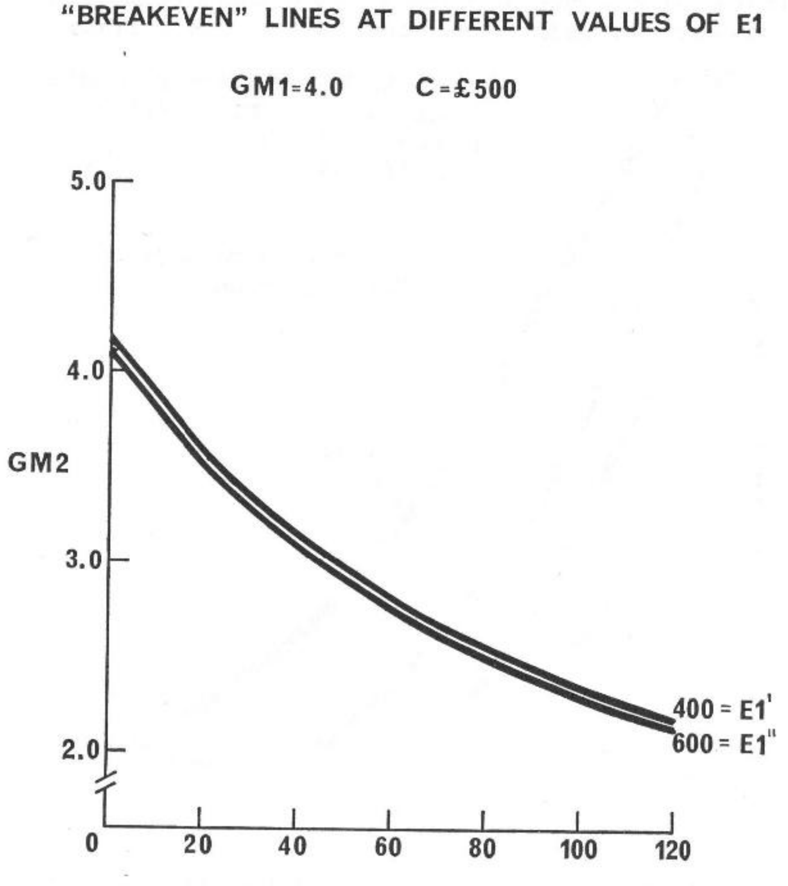


FIG. 3.

a stock number increase of 40 per cent, the variable costs in feeding could be increased to a greater extent than for a similar situation but where $GM_1 = £4$.

The initial stock number ($E_1$) has little effect on the breakeven curve. In fact, the effect of different initial flock sizes is very small in relation to the effect of the gross margin before investment.

So far output has been expressed financially, in terms of gross margins. For some purposes it may be found more useful to express output in physical terms, weaning percentage for example. Whether these physical outputs can be realised, will depend upon the amount and kinds of inputs the invested capital and the changes in variable

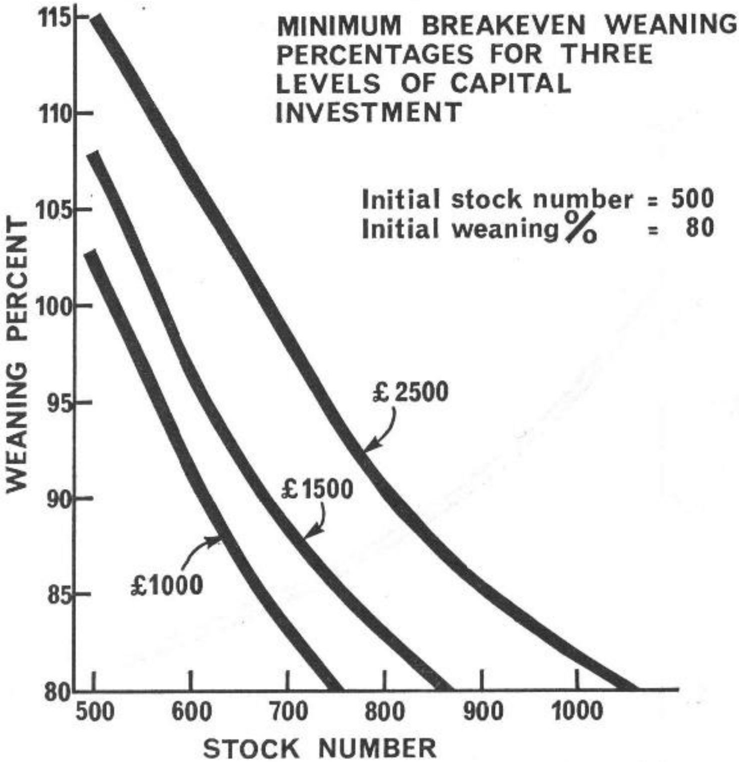


FIG. 4.

costs represent. The way in which the inputs (e.g. land improvement, increased feed) are used in a system of production will have a considerable effect on the levels of performance achieved.

Figure 4 demonstrates how weaning percentage would require to increase in order to service three levels of capital investment, viz. £1000, £1500, £2500, with increased variable costs of £0·70, £0·85, £1·00 respectively for a range of stocking rate increases. The pre-investment flock size was 500 ewes and gimmers with a gross margin per ewe of £4.

In assessing the progress of a development project, the graphical representation as presented in the example (Fig. 5) can be most useful. The point labelled $GM_2A$ is the gross margin obtained after a number of years have elapsed since £500 was invested in land improvement. The present gross margin is assumed to be maximal

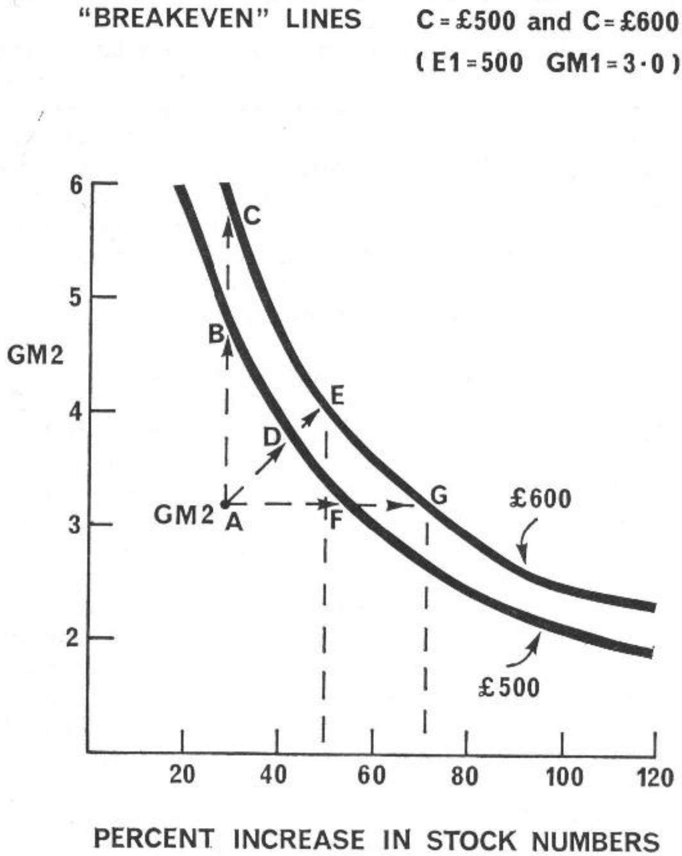


FIG. 5.

from the resources presently employed and even though it is greater than the gross margin before investment, the increase has been insufficient to adequately service the investment. Various alternative policies can now be postulated, e.g.

1. improve individual performance—i.e. move from A to B (Fig. 5);
2. reduce variable costs—i.e. move from A to B (Fig. 5) and;

3. increase stock numbers and maintain present levels of performance and variable costs—i.e. move from A to F.

To make some of these changes it is likely that further investment would be required. Such a possibility is represented by the breakeven curve for an investment of £600.

The new levels of output necessary to break even on this investment can now be assessed.

Combinations of improved animal performance, decrease in variable costs and an increase in stocking rate can also be assessed (as shown in Fig. 5) by moving from A to D and possibly E, for example. Improvements in animal performance can be expressed as increases in weaning percentage, weaning weight, or any other change that might be deemed possible. None of this obviates the need to make technical judgements. It does, however, provide a framework in which they can be realistically considered.

A procedure is therefore available whereby it is possible to identify the levels of output necessary to service and repay the capital invested in a project. If all the capital is invested in the first year, this analysis assumes that in the second year the 'target' levels of performance necessary to service that capital would have been attained. Under most circumstances this would not be possible. Responses to improved pasture, for example, and increases in stock number (particularly if they are increased from within the flock) are likely to take some time.

Up to this point it is possible to indicate the magnitude of the output increase required to service and repay invested capital; but the way in which this is achieved in practice, in terms of the proportion of the capital invested at any one time, the rate of flock expansion, and the rate of improvement in flock performance, and their effects on cash flow and liquidity require further consideration.

**Cash Flow and Liquidity**

Cash flow and liquidity are both important determinants of the success or otherwise with which new capital has been invested.

Annual cash flows are important in two respects. Firstly, because they determine the end year balance of a project (i.e. the liquidity of the project), and secondly, they are the basis of methods of capital investment appraisal. In the early stages, negative cash flows are inevitable, but it is vital that in planning investments leading to changes in production, the relation between inputs and outputs is such that negative cash flows exist for as short a time as possible.

An examination of the cash flows arising out of an investment requires a considerable number of calculations, particularly where comparisons between alternative policies are required. These calculations involve different rates of stock number increase, different rates of improvement in animal performance and different timing of capital investment. A computer programme which can deal with these alternatives has, therefore, been written. The programme has

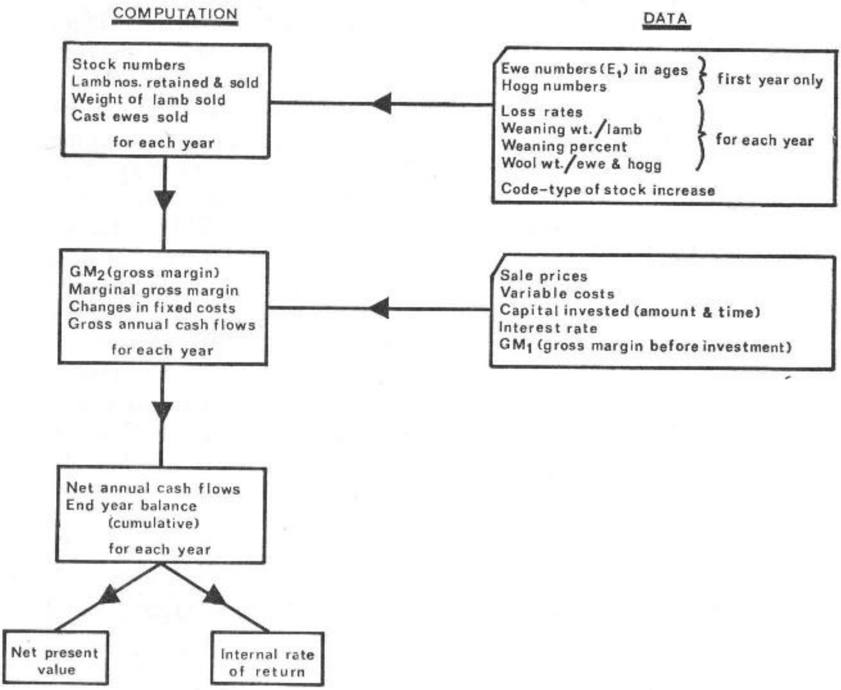


FIG. 6.

been designed for use on the multi-access system at the Edinburgh Regional Computing Centre using an ICL 4/75 computer. Access is by teletype. This allows an operator to make judgements about his results, change the input data and instantly compute a further set of results.

For convenience of description the process of calculation has been broken down into four sections. The function of each section, the input data necessary to each section and the way they are linked is shown in Figure 6.

The first section deals with physical outputs and stock number adjustments. This part of the programme is so designed that, given the initial number of stock, their age distribution, loss rates and weaning percentages in each year of the project, it will automatically calculate the numbers of ewes entering the next year. If stock numbers are to be increased, given the number that has to be attained in a particular year, the programme carries out the necessary calculations.

Stock numbers can be increased by obtaining extra ewe lambs or by buying in ewe hoggs. In the latter case stock number increases for each year must be specified. A diagram showing the various stages in the stock numbers adjustment part of the programme is given in Figure 7.

The actual rate of stock increase will depend on a number of factors, e.g. the rate of pasture improvement, current flock weaning percentages and weaning weights. Buying in extra stock may often be hazardous from the point of view of introducing disease.

Stock purchases made early in the life of a project will increase the level of capital investment and may therefore exacerbate negative cash flows, and the effect of purchases on bank overdraft must be considered; but early increases in stock numbers will also allow an early potential increase in output from the flock as a whole.

It is of interest, therefore, to determine the effect of stock number increase on cash flow. To do this an 'iterative' programme was developed as an extension of the main programme. This enables the user to state the year in the project in which a positive balance must be reached; the programme then calculates the minimum increase in stock number that will achieve this.

A similar type of programme is being developed to study the effects of rate of increase of stock numbers (at present the rate is linear, which is not always the most economically advantageous), and also to examine the effects of different rates of weaning percentage increase.

On completion of stock numbers adjustments and the calculation of flock output (lambs, wool, cast ewes, etc.), the flock gross margin for each year is calculated. Since it is the effects of marginal capital investment that are being assessed, it is the increase in gross margin as a result of the investment, that must be calculated. The gross annual cash flow is then calculated. This comprises the marginal gross margin net of changes in fixed costs. The net annual cash flow is the gross annual cash flow less capital investment.

The end year balance is calculated as follows:

End year balance = last year's balance + net annual cash flow $\pm$ interest.

Interest is either 'paid out' in the case of negative balances or 'paid in' in the case of positive balances (this assumes re-investment).

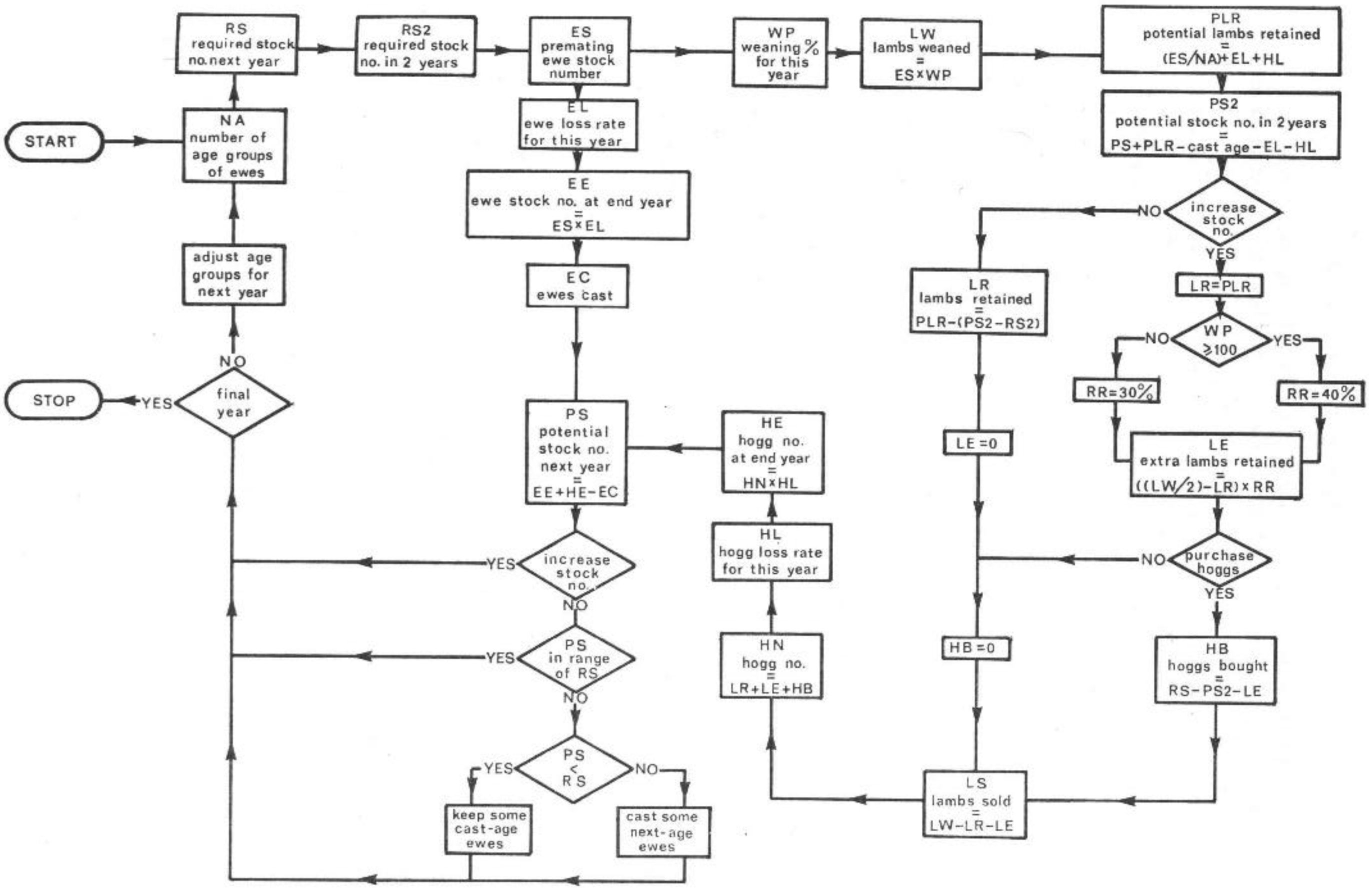
START
NA
number of
age groups
of ewes
RS
required stock
no.next year
RS2
required stock
no. in 2 years
ES
premating
ewe stock
number
EL
ewe loss rate
for this year
EE
ewe stock no. at end year
=
ES×EL
EC
ewes cast
WP
weaning %
for this
year
LW
lambs weaned
=
ES×WP
PLR
potential lambs retained
=
(ES/NA)+EL+HL
PS2
potential stock no. in 2 years
=
PS+PLR-cast age-EL-HL
increase
stock
no.
NO
YES
LR=PLR
WP
≥100
RR=30%
RR=40%
LE
extra lambs retained
=
((LW/2)-LR)×RR
purchase
hoggs
HB
hoggs bought
=
RS-PS2-LE
LR
lambs retained
=
PLR-(PS2-RS2)
LE=0
HB=0
LS
lambs sold
=
LW-LR-LE
HN
hogg no.
=
LR+LE+HB
HL
hogg loss rate
for this year
HE
hogg no.
at end year
=
HN×HL
PS
potential
stock no.
next year
=
EE+HE-EC
increase
stock
no.
PS
in range
of RS
PS
<
RS
keep some
cast-age
ewes
cast some
next-age
ewes
final
year
adjust age
groups for
next year
STOP

FIG. 7.

The programme can also take account of tax, if required.

The result of this part of the analysis will allow a judgment to be made as to whether the target levels of performance suggested by a breakeven analysis lead to an economically viable outcome in terms of cash flow and 'liquidity'.

To examine a situation for which a number of projects are possible, and where the amount of capital invested and the way in which it is to be used is different for each, a capital investment appraisal in terms of net present value is the appropriate method of assessment.

For this purpose net annual cash flows must be calculated on the following basis. By definition, net annual cash flows comprise profits less taxes when actually paid, less replacement capital expenditures when actually made, plus net changes in working capital, together with the recovery of any net residue values from assets at the end of a project's life. Miscellaneous cash receipts which fall into none of these categories are also included.

Since this appraisal is only concerned with marginal investment, 'profit' is interpreted as being the gross margin after investment less the gross margin before investment, net of changes in fixed costs.

In order to compare projects where capital is invested differently in time the appraisal technique has been modified. Comparisons are made on the basis of a 'notional' capital requirement which takes effect from the beginning of the project. This has been done by discounting back to the first year capital invested after the first year. A discounting rate is used which reflects the return on that capital during the years it was not required in the project.

The tax allowances on depreciation are made from the year the capital is actually invested even though that capital is discounted back to the first year.

To demonstrate how the methods of cash flow analysis can be used, and also to indicate the general economic implications of various improvement possibilities, a hypothetical flock of 500 ewes with a weaning percentage of 80 and a gross margin per ewe of £5·28 is considered (Table 1).

Four improvement possibilities are postulated as follows:

*Project 1.* The creation of a substantial area of improved pasture and the erection of fencing for controlled grazing. The capital invested amounts to £750 net of grant spread over four years. The consequential increase in feeding cost amounts to £0·60 per ewe. It is assumed that weaning percentage will increase to 100 by the fourth year.

*Project 2.* The same as Project 1 and stock rate increased to 750 (50 per cent increase) by the seventh year.

*Project 3.* The same level of investment in pasture improvement and fencing with similar increases in feed cost as Project 2. In the sixth year an inwintering house is erected for 1000 ewes costing

TABLE 1

*Extract of hypothetical data for* $GM_1$ = £5.28 $E_1$ = 500

| | |
|---|---|
| Lamb weaning % | = 80 |
| Lamb weaning weight (kg) | = 24·0 (25·0 kg year 3 of all projects) |
| Ewe fleece weight (kg) | = 1·8 |
| Hogg fleece weight (kg) | = 1·7 |
| Ewe mortality % | = 6·0 |
| Hogg mortality % | = 3·5 (improved to 3·0% year 2 of all projects) |
| Income prices: | |
| Lamb | 28p/kg live weight |
| Wool | 44p/kg |
| Cast ewes | £4·30 |
| Subsidy | £1·65 |
| Expenditure costs/ewe: | |
| Ewe feed | £0·40 (increased to £1·00 year 1 of all projects) |
| Ram replacement | £0·32 |
| Ram feed | £0·05 |
| Vet. cost | £0·50 |
| Haulage | £0·12 |
| Hogg wintering | £2·50 |

TABLE 2

*Economic Evaluation of Projects* 1-5
(Initial stock, 500 at £5·28 per ewe, £2642)

| Project | Total capital invested (£) Discounted to year 1 | Net present value (10%) | Internal rate of return (%) | Gross margin year 10 (£) |
|---|---|---|---|---|
| 1 | 613 | −97 | 7·8 | 2836 |
| 2 | 1415 | 1845 | 20·0 | 4628 |
| 3 | 4552 | 683 | 11·5 | 5334 |
| 4 | 3028 | 2036 | 16·1 | 5334 |
| 5 | 3614 | 725 | 11·8 | 5430 |

£4200 net of grant (100 per cent increase in stock number by tenth year) and feed costs increased to £2·50 per ewe. Weaning percentage increases to 115 by the sixth year.

*Project 4.* As Project 2 up to the sixth year. Ewes are then off-wintered in an enclosed area of the hill. Capital invested (£1500 net of grant) is used to fence the enclosure, build hay shed and provide feed boxes. Stock is increased to 1000 ewes by tenth year, weaning percentage to 115 in the sixth year.

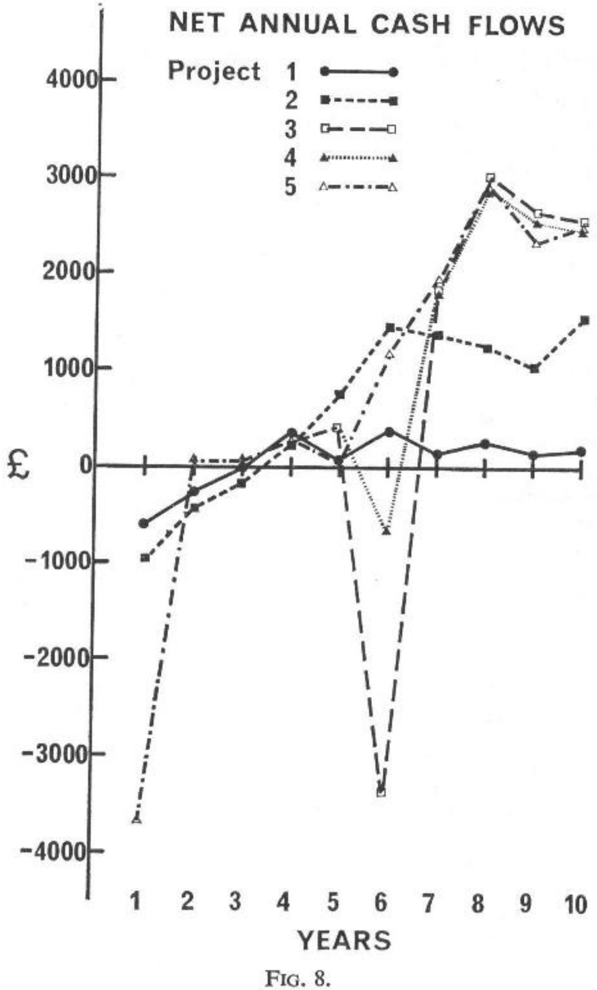


FIG. 8.

*Project* 5. Same as Project 4, with all investment in the first year.

The projects are compared over ten years. The results in terms of net annual cash flows and end year balances (cumulative) are given in Figures 8 and 9 and Table 2 shows the total capital invested in each project, the net present value, the internal rate of return and the gross margin in the tenth year.

The examples illustrate the way in which net annual cash flows are

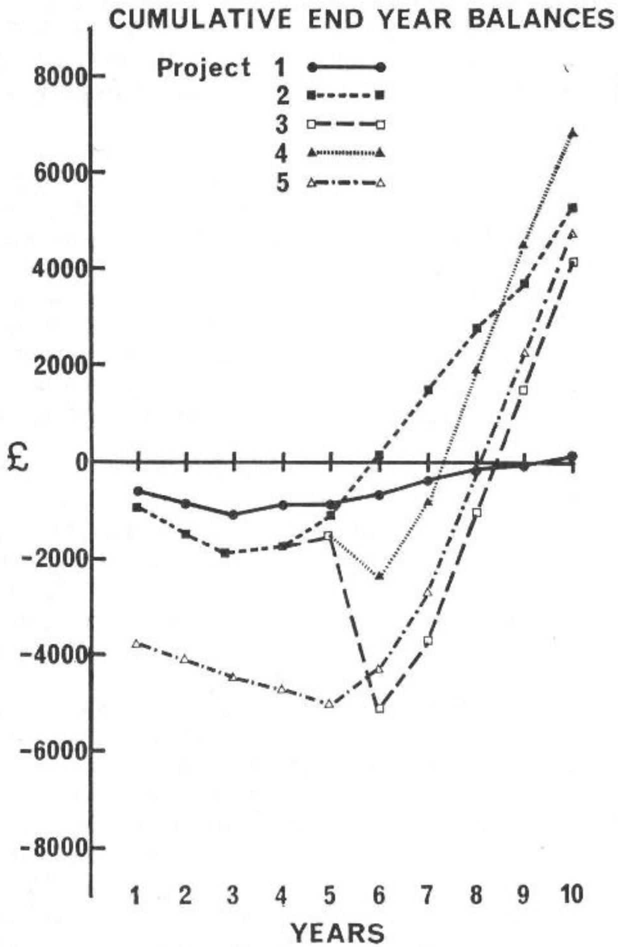


FIG. 9.

reflected in the end year balances and how both are affected by the rate of improvement in animal performance and increase in stocking rate relative to the timing of capital investment.

All the projects, apart from Project 1 (in which there is no investment in extra stock), perform in the early years in a similar way. In Project 1 there is no increase in stock, the net cash flows are small and the end year balances are negative throughout the life of the project. This is because the value of the increase in weaning percentage is almost wholly offset by the increase in feed costs.

In Project 2, stock numbers are increased by 50 per cent to 750 ewes, and the cash flows are much improved; the end year balances show an almost linear increase of £1200 per annum from the seventh year.

Projects 3 and 4 both incur investments in the sixth year and this clearly affects cash flow and end year balance in the later years appreciably. Project 4 (offwintering) recovers sufficiently by the tenth year to give a significant positive balance. The end year balance for Project 3 (inwintering) is considerably less. Where inwintering is proposed, the timing of investment in relation to the improvement in animal performance and increase in stock numbers is critical. Both inwintering and offwintering bring with them substantial increases in variable costs which, more than the capital investments in house or wintering enclosure, are responsible for cash flow difficulties.

It should be noted, however, that even though the returns on the capital invested in Projects 3 and 4 are low the flock gross margins are greater in the tenth year than they are in Project 2. This, in effect, gives greater technical and economic flexibility for the future.

A further possibility emerges from the analysis, however. Clearly Project 2 has much to commend it; it requires the least amount of capital, it gives a higher net present value and it gives the earliest positive end year balance. By the tenth year it has given rise to a balance in excess of £5000. It is, perhaps, at this point when dependence on borrowed capital can be reduced to a minimum that offwintering or inwintering might be considered.

In principle large capital investment projects which also incur substantial increases in variable costs should only be considered where animal performance can be increased significantly and when cash flow and end year balance permit such investment. The return on the capital may be low but the net farm income could reach a very high level compared to the alternative, and this approach may therefore be highly attractive in some cases.

The importance of the timing of investment relative to cash flow and end year balance is further illustrated by comparing the end year balances for Project 4 with a similar project (Project 5) in which all the capital is invested in the first year. The negative balances are more prolonged in the latter project, and the balance in the tenth year is some £2100 less than in Project 4. To obtain an early positive balance (which is dependent upon creating an even earlier positive cash flow) capital should always be invested in relation to the actual or expected increase in animal performances and expansion in flock size.

**Summary**

The breakeven budget technique provides a basis for a detailed economic analysis of any proposed improvement policy. It establishes the output objective (gross margin/stocking rate) that must be achieved to service any given capital investment.

The output objective depends upon the amount of capital invested, the gross margin before investment and, to a lesser extent, on the initial number of ewes in the flock. It is helpful in planning investments in hill sheep production to express output objectives not only in terms of gross margin but also in terms of weaning percentage, weaning weight, etc. The technical feasibility of a proposal can then be more readily assessed.

The effects of rate of improvement in animal performance and the rate of flock expansion in relation to the timing of investment are examined in terms of net annual cash flow and end year balances.

The relationship between the amount of capital invested, the year of investment and the expected rate of increase in output has a major effect on net annual cash flow.

Generally, comparatively small amounts of capital, invested in land improvement for example, are more likely to give rise to quite substantial cash flows and to involve only short periods of negative balance on bank overdraft. Large amounts of capital, on the other hand, particularly if invested all at once, can produce very difficult cash flow problems. High levels of capital investment must be spread over a number of years and made at times which are closely related to expected increases in animal performance.

The various conclusions suggest a strategy of improving net farm incomes initially by means of comparatively low levels of capital investment. The investment, after a few years, will give rise to increasing end year balances (providing 'price'/cost relationships remain the same); further investment can then be made from 'cash flow'. Even if the return on this capital is low, i.e. if the next step has to be the investment of substantial sums in inwintering or offwintering, it may nevertheless give rise to a large increase in the size of the farm business and in net farm income.

Finally, alternative policies can be compared on the basis of net present value to determine that which makes the best use of capital.

In using NPV for this purpose alternative marginal rates of return should be examined. High rates will favour projects in which most of the capital is invested early, whereas low rates will favour projects in which most of the capital is invested later. This procedure is particularly important if in one project a large amount of capital is invested in the early years as compared with another in which a large amount is invested much later. Such a procedure is doubly important if a notional total capital requirement is used in which all capital is discounted back to the first year.

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# 2. NUTRITION OF THE HILL EWE DURING LATE PREGNANCY

A. J. F. RUSSEL, T. J. MAXWELL AND JANET Z. FOOT

FOR a considerable time one of the most controversial points in any discussion on hill sheep has been the supplementary feeding of ewes during the weeks before lambing. Although this topic is as much debated now as ever, the ground for debate has, in fact, changed in recent years. Instead of discussing the merits of feeding or not feeding hill ewes before lambing, there is a more general acceptance of the need to feed in most cases, and the more frequently posed questions now concern the quantities of feed which should be supplied.

There is, of course, no single answer to the question of how much concentrate or other food to give to hill ewes in late pregnancy, or indeed to the question of whether supplementary feeding is necessary at all. Each case must be considered in relation to a number of factors including the expected lambing percentage, the amount and quality of available pasture and the body condition of the ewe. The results of recent research work in the Organisation do, however, provide guidelines which enable decisions regarding supplementary feeding during late pregnancy to be made with some degree of objectivity.

**Feed Inputs in relation to Feed Requirements**

The amount of fresh or conserved herbage which a ewe will eat is largely determined by the quality of that food. During the weeks before lambing the grazing ewe is generally eating only relatively small quantities of poor-quality herbage, and therefore requires some concentrate feed as a supplement to ensure a satisfactory level of nutrient intake. Even in inwintering systems where ewes are fed hay which is of a higher quality than the herbage available to a grazing animal at that time, the amount of roughage which can be eaten per day is usually insufficient to provide the desired level of nutrition, and again some supplementary feeding in the form of concentrates is required.

In discussing supplementary feeding the term 'late pregnancy' is generally taken as applying to the last six or eight weeks before lambing. By the beginning of this period, i.e. three months after mating, the uterus and its contents weigh between 3 and 4 kg depending on the size of the ewe and the number of foetuses. This represents about one-third to one-half of the ultimate uterine weight immediately before lambing. At this time the placenta, through which the foetus receives its supply of nutrients from the ewe, is fully developed, but the foetus itself is still relatively small. The major tissues and organs of the foetus have been formed by this stage, and all that remains is for them to increase in size and weight; approximately 70 per cent of foetal growth takes place during the final six weeks of pregnancy.

The growth and development of the highly specialised foetal tissues are expensive processes in terms of nutrients, and require considerably more food per unit of weight gain than is necessary for the same weight gain in an adult animal. This low efficiency of conversion of nutrients to foetal tissues, and the very rapid increase in foetal weight in late pregnancy, result in a considerable increase in the ewe's requirements for nutrients, and particularly for energy. In addition to the nutrients needed for foetal growth and development, and those required to support the other products of conception, nutrients are also required for the satisfactory development of mammary tissue and to meet the needs of the ewe herself.

In the last few days of pregnancy, a ewe carrying a single foetus requires approximately twice as much food as is needed to prevent loss of weight in a non-pregnant ewe; the requirement of a ewe carrying twin foetuses is about two and a half to three times that of a non-pregnant animal. It must be emphasised, however, that these very high requirements exist for only a short period of time, and refer to the amounts of food needed to prevent the ewe from drawing on her body reserves. In practice it is not necessary or economic to attempt to meet these very high requirements in full; a moderate degree of undernourishment, in which the ewe is using body tissue to a limited extent to meet the deficit between intake and requirements, is generally considered to be acceptable.

The aim of a practical feeding system during late pregnancy is to achieve a compromise between meeting the ewe's high requirements in full and preventing severe undernourishment with excessive depletion of the ewe's body reserves. The former is unnecessary and unjustifiable on economic grounds, and the latter will lead to reduced lamb birth weights, with high levels of mortality, and possibly to a delayed onset of lactation and a poorly developed maternal instinct in the ewe.

### Measurement of Nutritional State

The problem in practice, then, is to find some means of measuring the degree of undernourishment or nutrient deficit so that it can be held within the limits set by economic considerations on the one hand, and an excessive production penalty on the other. In experimental work the degree of undernourishment can be measured by analysing blood samples to determine the rate at which the ewe is drawing on body fat. The concentration of non-esterified fatty acids (NEFA) (also referred to as free fatty acids or FFA) and ketone bodies in the blood plasma are related to the rate of fat breakdown, and are the most commonly used indices of nutritional state, i.e. the extent to which the ewe's energy requirements are being met by its energy intake.

Plasma NEFA concentrations are a very sensitive index of moderate degrees of undernourishment, but are less useful in situations of prolonged severe undernutrition; plasma ketone concentrations, which show only relatively small increases in moderate undernourishment, are markedly elevated in severe undernourishment, and are most responsive at levels where NEFA concentrations become less useful. In experimental work carried out under carefully controlled conditions both parameters can be used to monitor with precision the whole spectrum of undernourishment. Plasma NEFA concentrations are, however, very susceptible to certain hormonal changes which follow any upset or disturbance of the animal, and are consequently of less use in the field situation with ewes which are unaccustomed to frequent handling or to the procedures associated with blood sampling. Plasma ketone concentrations are less readily affected by such factors and are generally a more reliable index of nutritional state in any work with large numbers of animals under practical conditions.

Although the biochemical determination of plasma ketone concentrations in blood samples from pregnant hill ewes is unlikely to have any widespread application in farming practice, it is a very useful tool in research work carried out under practical conditions, and the use of this technique in such work will enable the establishment of other more readily applied criteria for the assessment of the adequacy of nutrition during pregnancy.

The technique has now been used for a number of years in the Organisation's development programme in which improved systems of management based on the results of earlier research work are being examined and tested. These systems of management are discussed in detail in the Organisation's Fifth Report, in the section on Hill Sheep Production Systems Development by John Eadie (p. 70). The technique is used primarily as a means of objectively determining the inputs of supplementary feeding required to maintain an acceptable level of undernourishment during late pregnancy. It also serves as a measure of the degree of consistency in nutritional state of animals in any project from one year to the next, and also between the flocks in different projects.

**Determination of Feed Inputs**

In each flock in which this technique of controlling the level of feeding has been used, a group, generally of 40 ewes which are representative of the age structure and previous level of performance of the flock, are blood sampled once a week from about six weeks before the beginning of lambing until one week before lambing. In those flocks which have been sampled over a number of years, and where we have some knowledge and experience of nutritional states during late pregnancy, the frequency of sampling has been reduced. The use of ram harnesses and crayons at mating time allows the ewes to be separated into early and late lambing groups, and blood samples are collected from only the early lambing ewes. The levels of feeding of these early lambing ewes are reviewed in the light of the results of the blood analysis, and adjustments are made which will maintain mean plasma ketone concentrations around 3mg/100 ml. The pattern of feeding of the later lambing ewes is similar to, but generally some two weeks behind, that of the early lambing group.

This technique has now been used for four years in a year-round grazing system at Sourhope (with North Country Cheviots on Hairney Law and North Country × South Country Cheviots on Auchope), for three years in the inwintering systems at Sourhope (South Country Cheviots), and Lephinmore (Scottish Blackfaces) and for one year in an inwintering system run jointly by the Organisation and the Edinburgh School of Agriculture at Boghall (Scottish Blackfaces). At Sourhope and Lephinmore only the inwintering with land improvement projects are considered here. Mean plasma ketone concentrations and mean quantities of the standard commercial concentrate fed in response to these ketone concentrations over the years are illustrated in Figure 1. In the Sourhope year-round grazing system the concentrate was fed as a supplement to grazing; in the inwintering systems it was given in addition to a daily allowance of 900 g hay per head.

In general the nutritional states of ewes in these flocks were maintained at a relatively constant and moderate degree of undernourishment during late pregnancy. Although plasma ketone concentrations somewhat higher than those shown in Figure 1 can be tolerated without risk of incurring an undue production penalty, it must be remembered that these are mean values which refer to groups of ewes with differing nutritional requirements and food intakes. In flocks containing a significant proportion of twin-bearing

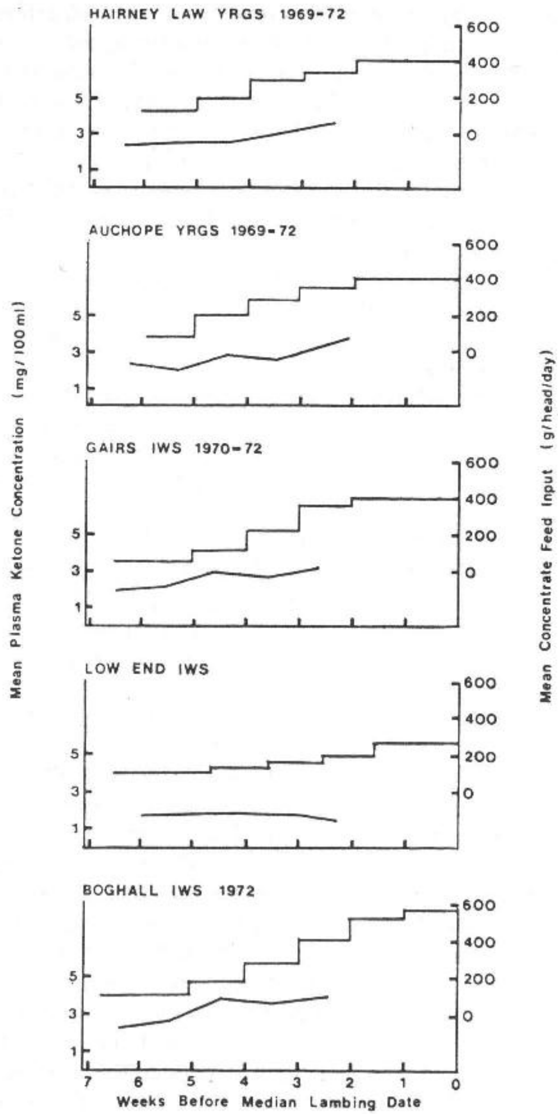


FIG. 1.—Plasma ketone concentrations and levels of concentrate feeding to sheep in five flocks. In the year-round grazing systems (YRGS) the concentrate was fed as a supplement to grazing, and in the inwintering systems (IWS) the concentrate was given in addition to an allowance of 900 g hay per head. The levels illustrated are mean values over the years indicated, with the exception of the Auchope YRGS flock which was blood sampled in only 1969 and 1970.

ewes, average ketone concentrations of around 3mg/100 ml inevitably mean a number of individual values of between 4 and 5 mg/100 ml or higher, and it is the need to prevent these increasing further which very often determines the timing and magnitude of the next increase in feeding, particularly when such values are found in more than 15 to 20 per cent of the ewes. The extent of the variations in nutritional requirements and food intakes in group-fed sheep, and the effect of these factors on plasma ketone concentrations are discussed later in this section.

The pattern in which feed increases were given (Fig. 1) in response to plasma ketone concentrations is remarkably similar in all flocks, and as would be expected in a situation in which nutritional state remains relatively constant, matches the pattern of foetal growth. This characteristic pattern of feeding, which parallels the ewe's increasing energy requirements, is likely to result in the more efficient use of a given quantity of feed than the equal distribution of that same quantity over a similar or greater period of time.

**Performance in relation to Feeding**

The success of this technique of determining feed inputs during late pregnancy must be judged in practice by the lambing performance achieved. Information on this is given in Table 1. These data, like those in Figure 1 are, in most cases, averages over several years, and consequently do not show the improvement in performance with time, which has been a feature of these flocks under improved systems of management. (This more extensive information is outwith the scope of this contribution and will be published separately.) The lambing data are considered to be very satisfactory for hill flocks. The lambing percentages (calculated as the number of lambs born alive per hundred ewes put to the ram) in the flocks at Sourhope and Lephinmore range from about 95 to 120, and was 130 at Boghall. Mean lamb birth weights are all high, and the levels of lamb mortality are less than in traditionally managed flocks. It should be noted that the mortality figures include lambs which are born dead. Excluding lambs dead at birth would reduce the percentage mortalities by between 4 and 6 per cent. These levels of performance cannot, of course, be wholly attributed to the inputs of feed during late pregnancy, but are the consequence of improvements in year-round nutrition resulting from the overall management systems. On the other hand these figures are unlikely to be achieved without a satisfactory nutritional regime during late pregnancy.

The levels of feeding illustrated in Figure 1 show relatively little difference between flocks, but this does not mean that these levels of input should therefore be adopted in all hill flocks. As indicated above, supplementary feed inputs must be related to requirements and the intakes obtained from either grazing or conserved feed. Requirements and intakes will vary considerably from one flock to the next, and as information on plasma ketone concentrations is unlikely to be available to assess nutritional state in commercial practice, some other more readily measured criterion of the adequacy of nutrition must be sought. In practice live-weight change can be used as a guide to the adequacy of nutrition during various stages of pregnancy, and particularly over the critical final weeks. Live-weight change has the disadvantage that it must be measured over a period of at least a few weeks to be meaningful, and cannot supply information as to the nutritional state at any one point in time, as is the case with blood parameters. None the less, the regular recording of weights to follow the course of changes thoughout pregnancy and to allow comparisons between years is an invaluable aid to good nutritional management.

Results from experimental work on a wide variety of breeds of sheep suggests that live weight increases over the final eight weeks of pregnancy of 10 per cent in ewes carrying single lambs and of 18 per cent in ewes with twins are indicative of a satisfactory level of pre-lambing nutrition. These results were obtained in situations where ewes could be weighed regularly to within a few days of lambing. In practice, lambing is spread over a period of some weeks, and even when a flock is divided into groups of early and late lambing ewes it is impracticable to obtain weights during the two weeks prior to the mean lambing date of the early lambing ewes.

These general recommendations must therefore be adjusted to refer to the period from eight to two weeks before lambing. Data from experiments with pregnant hill ewes, supported by weight changes measured in the development studies referred to above, suggest that the level of feeding at this time should be such as to give gains of about 6 to 7 per cent in ewes carrying single lambs and of 10 to 12 per cent in ewes with twins over this six-week period. Because there is no technique which can be used on a large scale at a reasonable cost to distinguish between single and twin-bearing ewes during late pregnancy, the desired average weight increase in any particular flock during late pregnancy must be calculated on the basis of an expected lambing percentage.

## Nutrition of the Pregnant Gimmer

The question of the feeding during pregnancy of the hill ewe lambing for the first time at two years of age (i.e. the pregnant gimmer) deserves special consideration. Production from this age group is usually lower than that from mature ewes; the lambing percentage is invariably lower than average, lamb birth weights are also below average and the level of mortality of lambs from this age group is generally disproportionately high (see Table 1). It is

TABLE 1

*Lamb birth weights and percentage lamb mortality in some development study flocks*

| | Sourhope | | | | |
|---|---|---|---|---|---|
| | Hairney Law YRGS* 1969-1972 | Auchope YRGS* 1969-1972 | Gairs IWS* 1970-1972 | Lephinmore Low End IWS* 1970-1972 | Boghall IWS* 1972 |
| Lamb birth weight (kg): | | | | | |
| Singles | 4·2 | 4·0 | 4·2 | 4·3 | 4·3 |
| Twins | 3·4 | 3·2 | 3·2 | 3·1 | 3·2 |
| Lamb mortality (%):† | | | | | |
| Singles | 14·9 | 10·4 | 19·1 | 11·4 | 13·2 |
| Twins | 18·5 | 9·7 | 14·8 | 14·8 | 19·5 |
| Ewes' lambs | 14·1 | 8·8 | 14·7 | 11·3 | 18·7 |
| Gimmers' lambs | 24·8 | 15·9 | 31·9 | 18·3 | 12·6 |

* YRGS = year-round grazing system; IWS = inwintering system.
† Calculated as number of lamb deaths from birth to weaning, including those dead at birth.

reasonable to suppose that part of this production difference is due to these younger ewes not being fully grown at the time of their first pregnancy, but it has also been assumed that part of the difference is attributable to poor nutrition during late pregancy. In the traditional system of hill sheep management, where poorer lambing performance from gimmers is common, there is seldom opportunity to separate these animals from the main flock where they are likely to be at a disadvantage in competing with older ewes for limited amounts of supplementary feed.

The Organisation's development programme, and particularly the inwintering systems already mentioned, provided an opportunity to separate gimmers from mature ewes during late pregnancy and to ensure, by the use of blood parameters as described above, that these animals were adequately fed during the weeks before lambing.

In the first year of one of the inwintering studies the feed inputs to the gimmer age group were such as to maintain mean plasma ketone concentrations below 2 mg/100 ml. This level would suggest that the animals were not drawing on body reserves to any measurable extent, and was on average about 1 mg/100 ml less than the level measured in the mature ewes of that flock. The lambing performance of the gimmers was, however, poorer than expected; lamb birth weights averaged 3·35 kg as compared to a figure for single lambs from mature ewes of 4·15 kg. (This difference was reduced but not eliminated by expressing birth weights per unit of maternal weight.) The higher rate of mortality of gimmers' lambs (18·3 per cent) as compared to that of ewes' lambs (10·2 per cent) was undoubtedly associated with the difference in birth weights.

This, then, presented a situation in which the nutritional state of gimmers during late pregnancy appeared to be eminently satisfactory, and indeed better than that of mature ewes, but in which the lambing performance of the gimmers was substantially poorer than that of ewes. Two possible explanations of this apparent anomaly are, first, that because of a difference in the partition of nutrients, the criteria of adequacy of nutrition of ewes do not apply to gimmers, or secondly, that nutrition during the earlier stages of pregnancy is more critical in the gimmer than the ewe, and is more important than is commonly supposed. In the former case lamb birth weights should theoretically be improved by higher levels of feeding in late pregnancy, while in the latter an increase in feeding during the earlier stages of pregnancy would be required to effect a birth-weight response.

An experiment was subsequently conducted to obtain information regarding the relative importance of nutrition during the first 14 and last 7 weeks of pregnancy. Gimmers on a nutritional regime which resulted in an apparent live-weight loss of about 4·5 kg between mating and 7 weeks' prepartum, but provided adequate nutrition during the final 7 weeks of pregnancy, produced single lambs weighing 4·06 kg. A higher level of nutrition during the final 7 weeks of pregnancy failed to increase single lamb birth weight (4·09 kg). Gimmers on a superior nutritional regime from mating to 7 weeks' prepartum, giving an apparent live-weight increase of 1·5 kg during this time, and which were adequately nourished during the final 7 weeks of pregnancy, produced single lambs weighing 4·25 kg. The birth weight of lambs from gimmers treated similarly in early pregnancy, but receiving the higher level of nutrition in the final 7 weeks, was 4·30 kg.

None of the differences in mean lamb birth weights between treatments was statistically significant, but the results nevertheless suggest that the difference in level of nutrition during the earlier stages of pregnancy had a greater effect than had hitherto been supposed. The birth weights of gimmers' lambs in this experiment were higher than in the situations where the problem was identified initially and were, in fact, quite satisfactory and comparable with those of lambs from mature ewes. Two factors are considered to have contributed to this; first, the animals used in this experiment were larger and heavier than average for their age, and secondly, the weight changes induced by the nutritional treatments between mating and 7 weeks' prepartum were not as extreme as had been planned, and in particular the lower level of feeding was probably better than that generally pertaining in the field. The apparent live-weight loss in practice is frequently greater than 6 kg, whereas in the experiment it averaged about 4·5 kg.

The results of this experiment do not prove conclusively that birth weights of gimmers' lambs are depressed by the level of nutrition generally experienced during the earlier stages of pregnancy, but they do indicate clearly that higher levels of feeding than those required to maintain a satisfactory nutritional state, as measured by plasma ketone concentrations, in gimmers during late pregnancy are not reflected in increased lamb birth weights.

It is possible that the levels of undernourishment experienced by many hill gimmers during the earlier stages of pregnancy may affect the development of the placenta, leading to placental insufficiency during late pregnancy. It is also possible that this effect may be exacerbated by a different partition of nutrients between maternal and uterine tissues in gimmers which are still growing, compared with that in adult ewes. The examination of information collected in the course of the development studies indicates that live-weight loss during the first 3 months of pregnancy is largely independent of mating weight. One of the results of the new systems of management tested in these studies is that the gimmers are now heavier and in better condition at mating, and it is apparent that some of the problems associated with the pregnant gimmers are becoming less serious as the weight of successive gimmer age-groups increases. These facts suggest that the effects of nutrition during the earlier stages of pregnancy on gimmer lambing performance may be related to the live weight, size, or some other measure of degree of maturity attained at first mating. This hypothesis is being tested in a current experiment.

**Implications of Group-feeding**

The feeding of pregnant ewes, whether it is as a supplement to grazing, or the entire diet to housed animals, involves certain important differences from the normal grazing situation. The feed given is different in form and quality from that obtained by the grazing animal, and it is also generally restricted in quantity, so that individuals are competing against each other for available food.

The variation in food intake by individual sheep penned and fed in groups has been measured in recent studies. The results of this work indicate that the variability in the intake of concentrates is usually considerably greater than that in the intake of roughages such as hay or dried grass. In one group of only 11 non-pregnant ewes which were fed a daily maintenance ration averaging about 740 g hay plus 120 g of a grain-based pelleted concentrate per head, daily hay intakes ranged from 72 to 127 per cent of the group mean (coefficient of variation (CV) = 12·9 per cent) and those of the concentrates from 12 to 131 per cent of the mean (CV = 35·8 per cent).

The effect of competition between individual animals for restricted quantities of food has also been investigated. In an experiment in which the complete diet was pelleted, analyses of blood samples from animals which were penned and fed in groups, and from others which were penned in groups but fed individually, showed that those which were competing for the available food had significantly higher plasma NEFA concentrations. It was calculated from changes in the relationship between live weight and food intake that the effect of competition was to increase the animal's feed requirements by 22 per cent.

In inwintered ewes variation in food intake between animals is likely to be least where a large proportion of the diet is given in the form of a roughage. An all roughage diet is, however, generally impracticable as ewes will not eat a sufficient quantity to ensure the desired level of nutrient intake, and in practice it is necessary to use a mixed diet of hay and concentrates. Best results will be achieved by ensuring that the roughage portion of the diet is of a high quality, thus enabling the concentrate to be kept at levels similar to those illustrated in Figure 1.

In pregnant ewes variations in nutritional state arise from differences in requirements as well as from differences in intake, and there is no evidence from the results of the group-feeding studies that the ewes with highest requirements (i.e. generally those carrying twins) have the highest intakes. In a recent experiment with three groups, each of 16 pregnant ewes or gimmers from the inwintered Boghall flock, and which were fed as illustrated in Figure 1, individual intakes of hay and concentrates were measured at intervals during late pregnancy. Estimates of energy requirements were subsequently calculated from ewe weights and lamb birth weights, and compared with energy intakes to give measure of energy deficits and surpluses. These are illustrated in Figure 2, and show that, in general, twin-bearing ewes were undernourished (only 2 of 26 twin-bearing ewes ate more than their calculated requirements), whereas approximately half of the single-bearing ewes and the two barren ewes ate more than they required. This is typical of the situation which occurs in practice and illustrates the difficulty of achieving an optimum level of feeding in group-fed ewes.

It is considered that in this particular experiment the level of feeding was satisfactory; the majority of the ewes were in fact undernourished, but in less than 15 per cent of the animals was this considered to be sufficiently severe as to affect lambing performance adversely. Although the performance of these more severely undernourished individuals would in all probability have been improved by a higher feed allowance to the group, this would have resulted in a higher proportion of ewes receiving more food than they required, and would have been unjustified on economic grounds.

The plasma ketone concentrations shown in Figure 2 are clearly related closely to the nutritional state of the ewes as calculated in terms of energy deficit or surplus, and illustrate the usefulness of this technique in determining feed inputs even in situations where there are considerable variations in both requirements and food intakes.

## The Efficient Use of Feed

Concentrate feeding stuffs are expensive and, if they are to be used efficiently, it is important to ensure that they supply those nutrients which are most needed and that they are given at the time when they will be used effectively by those animals which have the greatest need for them.

In the majority of hill sheep flocks in this country energy is the major limiting nutrient. This does not mean that protein, minerals and vitamins should not be included in the supplement, but in our experience a concentrate with about 14 per cent crude protein has proved adequate.

Ewes which are in good body condition at mating are more likely to conceive twins and therefore have higher nutrient requirements during late pregnancy, but the level of body condition associated with high rates of twinning also means that the ewe has adequate body reserves on which to draw during at least the first 3 months of pregnancy. Ewes which achieve a satisfactory body condition in the autumn will generally not require any feeding, other than in time

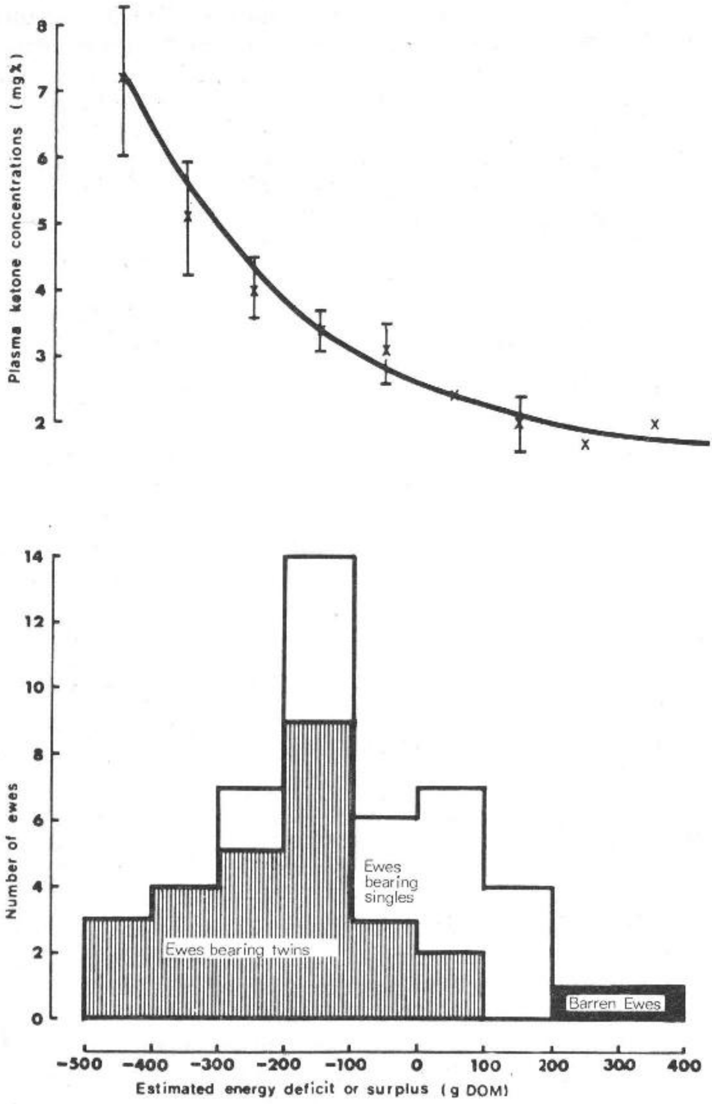


FIG. 2.—Energy deficits and surpluses derived from measurement of food intake and calculated requirements, and the relationship between these nutritional states and plasma ketone concentrations in group-fed ewes during late pregnancy.

of storm, until some 5 or 6 weeks before the beginning of lambing. Present evidence suggests that supplementary feeding during these last weeks will be used most efficiently if given in the pattern described above and illustrated in Figure 1, i.e. in amounts which are increased progressively to match the pattern of foetal growth.

Improvements in the efficiency of use of supplementary feeding can also be achieved by dividing the flock into groups of ewes which are likely to have similar nutritional requirements. The use of ram harnesses and crayons at mating to distinguish between early and late lambing ewes has already been mentioned. At about 6 weeks before the beginning of lambing those expected to lamb during, say, the first 2 weeks should be separated from the later lambing ewes and given preferential feeding. Where lambing coincides with the initiation of herbage growth later lambing ewes may obtain a higher proportion of the desired level of intake from grazing, and so require lesser amounts of suplementary feeding.

Gimmers have higher requirements in relation to body size than mature ewes, and, although in the group-feeding studies referred to above they were not at a nutritional disadvantage when penned and fed with older ewes, it is recommended that, where possible, this age-group be separated from the main flock for special attention. This is particularly important if they have not been fed as hoggs or where only small quantities of feed are being given. During the period from 8 to 2 weeks before the mean date of lambing, when the live-weight increase of single- and twin-bearing ewes should be of the order of 6 to 7 and 10 to 12 per cent respectively, gimmers expected to give birth to single lambs should be fed to gain about 9 per cent of their weight three months after mating.

At the time when the flock is being separated into groups for differential feeding during late pregnancy it is also worth while taking out any ewes in poor body condition and giving these preferential treatment.

The information contained in Figure 2 shows that the most important single factor determining requirements in late pregnancy is the number of foetuses. In practice it is not possible to identify single- and twin-bearing ewes for separate feeding in late pregnancy; although various techniques are being investigated, none is yet available at a cost which will allow it to be widely used on commercial farms. In the absence of such a technique the efficient use of feeding stuffs can be best achieved by separating the flock into groups of animals with similar food requirements, and by giving supplementary feeding in progressively increasing amounts to match the pattern of foetal growth.

# 3. SOME ASPECTS OF THE GROWTH OF HILL LAMBS

RICHARD H. ARMSTRONG AND J. EADIE

## Growth Rates of Lambs in Three Hill Environments

The Hill Farming Research Organisation has three farms in different parts of Scotland. These are broadly representative of their regions, and embrace a wide range of hill farming environments. They are Sourhope in Roxburghshire, Lephinmore in Argyllshire and Glensaugh in Kincardineshire. Their situation, climate and vegetation cover are described at the beginning of this report. Each of the farms has several self-replenishing flocks of Scottish Blackface sheep; in addition there are North and South Country Cheviot flocks at Sourhope.

For the purpose of establishing the rates and patterns of hill lamb growth, data on flock performance have been examined. These data relate to a flock of Blackfaces on each farm and a South Country Cheviot flock at Sourhope. They refer to the five-year period 1960-64 during which the management of these flocks was typical of that of the areas in which they occur. The available information includes ewe body weights and condition, and birth, 'marking' and weaning weights of lambs. Marking takes place between 4 and 7 weeks of age, and weaning between 15 and 17 weeks of age. Some 3000 ewe/year records contributed to this analysis.

The principal conclusions are based on data from lambs reared as singles, unless otherwise stated. This is for two reasons. Firstly, such lambs account for some 80 per cent of all lambs weaned. Secondly, twin lambs are usually reared on 'inbye' pasture and their performance may therefore reflect within-farm management practices to a much greater extent than does the performance of singles. In order to minimise the effect of between-farm and between-year differences in dates of birth, marking and weaning, the data are discussed in terms of rates of gain between these dates.

A comparison of the performance of different breeds of sheep running on entirely separate areas of hill ground is not justifiable. Differences in land resources, even differences in the distribution of the major pasture types, may result in significant nutritional differences between contiguous grazings. It is, however, of interest to note that the patterns and rates of lamb growth in the Blackface and South Country Cheviot flocks at Sourhope are very similar, although the Blackface flock is run on what is thought to be the poorer ground (Table 1).

Overall rates of growth are, perhaps surprisingly, similar on all three farms, at about 184 g/head/day (0·41 lb) from birth to weaning (Table 1).

TABLE 1

*Ewe live weight (kg) and condition prepartum and live-weight gain of single-reared lambs from birth to weaning (g/head/day)*

| | | 1960 | 1961 | 1962 | 1963 | 1964 |
|---|---|---|---|---|---|---|
| Sourhope | Live weight | 42·3 | 46·1 | 45·9 | 44·4 | 44·2 |
| (SCC) | Condition | 3·0 | 2·0 | 1·8 | 2·6 | 3·0 |
| | Live-weight gain | 196 | 189 | 194 | 162 | 195 |
| Sourhope | Live weight | 42·3 | 46·2 | 49·6 | 43·0 | 46·4 |
| (BF) | Condition | 2·8 | 2·0 | 1·4 | 2·6 | 3·0 |
| | Live-weight gain | 185 | 187 | 177 | 164 | 208 |
| Lephinmore | Live weight | 43·7 | 40·2 | 43·0 | 40·5 | 46·5 |
| (BF) | Condition | 2·0 | 2·4 | 2·2 | 2·4 | 2·2 |
| | Live-weight gain | 181 | 192 | 188 | 185 | 186 |
| Glensaugh | Live weight | 45·3 | 46·9 | 45·6 | 41·3 | 44·2 |
| (BF) | Condition | — | — | — | 2·2 | 2·4 |
| | Live-weight gain | 177 | 179 | 185 | 176 | 205 |

SCC = South Country Cheviot. BF = Blackface.
Condition was assessed as a score from 1 to 4 where 1 was good and 4 very poor.

Differences between hill environments are reflected much more in terms of stocking rates. The relative stocking rates in acres per ewe were approximately Sourhope 1·9, Glensaugh 4·0 and Lephinmore 4·2. It is probable that stocking rates generally decline from the better to the poorer environments at a rate which exceeds that of the decline in pasture production. It may therefore be argued that, as a consequence, diet selection opportunity is greater in poorer environments and that by this means these environments provide levels of nutrition in summer consonant with reasonable lamb growth rates.

However, differences in lamb growth rates between farms do occur (Table 2). Sourhope lambs gain weight rather more slowly prior to marking (218 g/head/day) than those at Glensaugh (231 g) and at Lephinmore (255 g). The Lephinmore results may, since lambing dates are comparable, reflect an earlier onset of pasture growth in the west. The marking to weaning rates of gain, however, are best at Sourhope (172 g) and poorest at Glensaugh (148g). This is probably due to the better quality diet obtained by the lambs from *Agrostis-Festuca* pasture when they become more dependent on herbage in later lactation. The reason for the relatively good gains during this period at Lephinmore (166 g) is not known. It may reflect greater diet selection opportunity.

There are differences between years in rates of gain from birth to weaning in all situations (Table 1).

There is an occasional interaction between farms and years; the notable example is that of the severe winter of 1962-63 which had an especially marked detrimental effect on growth rates at Sourhope.

TABLE 2

*Lamb live-weight gains 1960-64 (g/head/day)*

| | Birth-marking | | Marking-weaning | |
|---|---|---|---|---|
| | S | T | S | T |
| Sourhope (SCC) | 223 | 197 | 172 | 157 |
| Sourhope (BF) | 218 | 168 | 172 | 150 |
| Lephinmore (BF) | 255 | 193 | 166 | 161 |
| Glensaugh (BF) | 230 | 197 | 147 | 139 |
| Mean | 232 | 189 | 164 | 152 |

S = single-reared. T = twin-reared.

Within farms and years there are effects on growth rate due to ewe age (Table 3), ewe weight and body condition (Table 1) and also to lamb birth and rearing type (Table 2).

Gimmers' lambs always have poorer growth rates, while peak performance is usually attained in ewes of four or five years of age.

There is a tendency for better ewe body condition and live weight prepartum to be positively related to lamb growth rate. But ewe body weight is confounded both with body condition and age. Furthermore, body condition is subjectively assessed as a condition score. From this data it is not possible to indicate the relative magnitude of these factors affecting lamb growth rate. Among other questions it would be interesting to know, for example, what part of the age of dam effect is due to live weight and condition.

Lamb rearing type has a major effect on lamb growth rates, especially before marking. From birth to marking, single lambs grew faster than twins by 43 g/head/day. The growth rate difference declined to 13 g/head/day from marking to weaning. This difference would probably be greater but for the fact that twins are usually reared on better pasture for at least some part of the suckling period.

TABLE 3

*Live-weight gains of single-reared lambs (birth-weaning) 1960-64 (g/head/day)*

| | Age of ewe (years) | | | | |
|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 |
| Sourhope (SCC) | 169 | 186 | 193 | 195 | 192 |
| Sourhope (BF) | 169 | 186 | 189 | 190 | 190 |
| Lephinmore (BF) | 175 | 183 | 189 | 192 | 191* |
| Glensaugh (BF) | 172 | 191 | 195 | 188 | 183 |

* Data for four years.

The effect of sex of the lamb is small; males grow up to about 10 g per day faster than females.

**Lactation, Herbage Quality and Lamb Growth**

A major feature of the preceding analysis of lamb growth rates in three hill environments is that these rates are well below the genetic potential for hill lambs (Peart, 1967). A second feature is the marked decline in growth rates after marking.

The importance of milk to lamb growth is widely appreciated. Peart (1970) has reviewed his experiments on lactation performance and associated lamb growth. His results indicate, that apart from lamb-rearing type, nutrition of the ewe during lactation is the most important factor determining the milk production of hill ewes. Severe undernourishment in late pregnancy had only a marginal effect on ewes which were well fed during lactation. Ewes in lean body condition, but well nourished during lactation, milked as well as ewes in good body condition, but when feed was restricted into the third and fourth weeks of lactation, fat ewes suckling twins were able to maintain greater levels of milk production than thin ewes with twins.

Lamb growth is clearly restricted by the levels of milk production achieved by ewes on the hills, and this is primarily a consequence of their level of nutrition during lactation.

Peart (1970) has also investigated the relative importance of milk and concentrate intake on lamb growth and has shown that solid food intake can compensate to a considerable extent for an inadequate milk supply. He has also shown (Peart, 1967) that the quality of that food is important, and has suggested that the quality of the pasture ingested by the lamb is probably a more important restriction on lamb growth on the hills than is the level of ewe nutrition.

Hill lambs obtain their solid food intake entirely from hill pasture vegetation. The nutrient intake of animals at pasture is a function of the quality of the material they ingest and of the amount they consume. Consequently the improvement of nutrient intakes can only be effected by improving the quality of the ingested herbage or by increasing the amount of herbage eaten per day.

An adequate criterion of herbage quality for present purposes is apparent digestibility. As herbage ages its digestibility declines. First-growths are more digestible than regrowths.

The amount of herbage eaten—the voluntary intake—depends on a number of factors. Some are intrinsic to the herbage eaten, some are of animal origin, and some are a function of the grazing situation.

Digestibility and voluntary intake tend to be related, especially within herbage species. More digestible material tends to be eaten in greater amounts. The provision of better quality herbage therefore is not only important in terms of improving the nutritive value of that which is eaten; it also enhances nutrient intake since more of it is eaten.

The voluntary intake of herbage by lambs increases with age and weight (Joyce and Rattray, 1970). From about 8 weeks of age forage can be as efficiently digested by lambs as by adult sheep (Wardrop and Coombe, 1961). Herbage intake may be reduced in adult sheep in very good body condition (Osbourn, 1969), but this factor is unlikely to inhibit the appetite drive of young animals of high growth potential.

The factors of the grazing situation influencing voluntary intake at pasture have been little studied. The voluntary intakes of grazing sheep are known to be affected by the amounts of pasture feed available and by sward structure (Arnold, 1964). Hodge and Doyle (1967) suggested that there is little difference between the diet selected by lambs and older sheep from lowland swards. However, hill pastures are generally more heterogenous in terms of species and sward morphology. The opportunity for diet selection may, therefore, be greater, and younger and less experienced animals may be at a greater disadvantage in this respect on hill pastures than on lowland pastures.

Voluntary intake and herbage digestibility determine the digested energy intakes of lambs at pasture, but the efficiency with which digested energy is used by lambs for live-weight gain varies among herbage species. Ryegrass has been shown to be superior in this regard to Cocksfoot (Milford and Minson, 1965). There is some evidence that the superiority of white clover as a feed is in some measure due to the higher efficiency with which the digested energy is utilised for gain (Joyce and Newth, 1967). Such differences are of less importance than differences in digestibility and voluntary intake (Raymond, 1969).

Food is used by the animal for body maintainance as well as for live-weight gain. The significance of a given digested energy intake will vary with differences in body maintenance requirements. The metabolism of young ruminants is considerably higher than that of adult animals (Blaxter, 1962). The 'fasting metabolism' of lambs at two months of age is nearly twice that at six months of age (ARC, 1965). The maintenance requirement of grazing animals is greater than that of pen-fed animals indoors. The magnitude of this difference is not known with any precision though recent estimates (Young and Corbett, 1968) suggest that it may be much smaller than was hitherto thought (Lambourne and Reardon, 1963).

**Experimental Work**

The best of the lamb growth rates discussed earlier took place in a grassy hill environment in the eastern Cheviots. The annual cycle of ingested pasture quality in this environment has been studied by Eadie (1967), who showed that the organic matter digestibility of the herbage ingested by adult wethers fell from about 75 per cent in May to around 67 per cent by mid-August. Lambs are unlikely to be more selective grazers than adult sheep. The quality of the herbage they ingest is very likely to decline in the same way. That is as the lamb's dependence on herbage increases, the quality of herbage it ingests declines.

Although measurements of the nutrient intake of grazing sheep have not been made in other hill environments, it is reasonable to conclude from the available information on lamb growth rates and ewe body weight changes that levels of nutrition invariable decline as the summer advances.

Some, or all of the factors so far discussed may contribute in some measure to the relatively low lamb growth rates obtained on hill pastures. Nevertheless it seems clear that the major means of influencing hill lamb growth rates in the second half of their growth period on the hill is through the quality of pasture they ingest. There is, therefore, an obvious need to quantify the responses in growth rate to the provision of herbage of differing quality and to understand something of the processes underlying such responses.

At first sight the scope of this work, since hill vegetation is extremely diverse, would seem to be very wide. Arguments developed from experimentation on hill sheep nutrition and performance with regard to improving the latter have been presented elsewhere (Eadie, 1971; Russel, 1971). Central to these arguments is the need for an improved pasture component in hill pasture systems, and a critical question is the optimal use of such areas in whole systems. Current strategies concerning the use of improved pasture depend in part on the reasonable assumption that the provision of better quality pasture between lambing and weaning will improve lamb growth rates. But more information is needed on the value of improved pastures which are possible, and on their management for lamb growth. The pasture herbage of interest in this context is, therefore, that which is likely to feature prominently in the improved pasture component of hill farming systems. Many improved hill pastures are likely to be based on ryegrass and white clover. The only indigenous pasture which merits study is *Agrostis-Festuca*, both in its own right as a pasture, and because the indigenous vegetation which may invade sown pastures will be mainly of *Agrostis* and *Festuca* species. White clover is clearly important in both ryegrass and *Agrostis-Festuca* pastures.

A programme of work was set up to examine some of the issues outlined in the preceding discussion. Interest was focussed on the problems of lamb growth on herbage diets. Attention was directed to hill lamb growth from about two to four months of age.

## Indoor Herbage Diet Experiments

The studies were, in the main, made with weaned lambs individually penned and fed indoors, though some work has been done with grazing lambs.

This work is currently being written up for publication elsewhere; only some major points are made here.

In the indoor experiments herbage was fed *ad libitum* to 20 per cent excess (Blaxter, Wainman and Wilson, 1961). The herbages were forage-harvested then cold stored. They included first-growths and regrowths of S.23 perennial ryegrass and indigenous *Agrostis-Festuca* herbage, with and without white clover. The clover usually contained about 30-40 per cent grass (mostly perennial ryegrass) as impurity. Individual experiments ran for periods of six to ten weeks and included from 20 to 48 South Country Cheviot wether lambs, weaned in late June at about nine weeks of age.

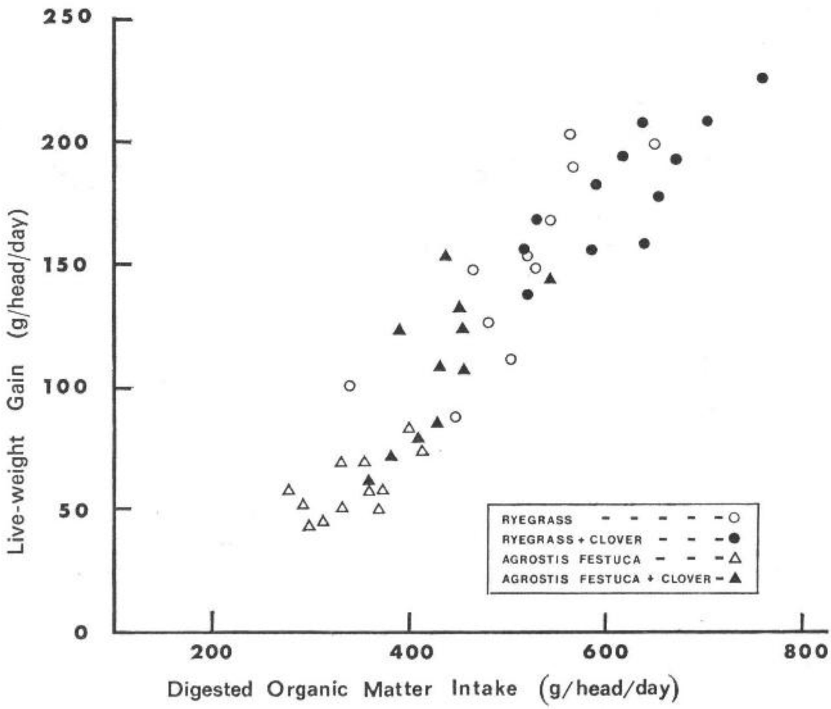


FIG. 1.—The relationship between live-weight gain and digested organic matter intake.

$$LWG = 71{\cdot}6 + 0{\cdot}41 \text{ DOM1 } (+21)$$

The rates of lamb growth largely reflected the levels of digested organic matter intake (DOMI). The relationship between live weight gain (LWG) and DOMI in one experiment is given in Figure 1.

A general summary of the results indicates that perennial rye-grass first-growths promoted live-weight gains of about 160 g/head/day, *Agrostis-Festuca* first-growths about 100 g/head/day. Perennial ryegrass regrowths gave rise to gains of about 150 g/head/day and *Agrostis-Festuca* regrowths about 60 g/head/day.

Digested energy intakes are a function of the digestibility (OMD) of the herbage and the extent to which it is voluntarily consumed.

OMD values ranged from 63·5 to 81·8. The perennial ryegrass was generally some 4-6 units higher in digestibility than the *Agrostis-Festuca* feeds.

Organic matter intake (OMI) tended to increase with lamb age and live weight on all herbages. There was a wide range of OMI (from 354 to 780 g/hd/day) between herbages.

There was a tendency for *Agrostis-Festuca* herbages to be eaten in lesser amounts than perennial ryegrass at similar levels of digestibility, and there was a tendency for regrowths to be eaten in greater amounts than first-growths of the same digestibility.

There was little advantage in terms of lamb growth rate when clover was mixed with first-growth ryegrass of high digestibility, but clover together with regrowth *Agrostis-Festuca* resulted in an increase of 70 g/head/day.

The digestibilities of mixtures of clover and grass were in accord with the digestibilities of the separate components. The effect of clover was to enhance the digestibility of mixtures with grasses, except in the case of first-growth ryegrass. This is to be expected because of the inherently high digestibility of such ryegrass and because digestibility declines much more slowly with age in clover than in grasses (Harkess, 1963).

In general, the inclusion of clover resulted in an increase in intake of a greater magnitude than would have been expected from the increase of overall diet digestibility which usually occurred. This effect has been widely reported, and has been discussed previously (Thomson and Raymond, 1970).

Various authors have attributed the higher live weight gains on clover-containing diets to a higher utilisation of the digested nutrients of white clover. The indoor experiments do not lend support to this view but, while there are dangers in making comparisons amongst lambs of different ages, weights and growth rates (Graham and Searle, 1970), it may be important to note that the herbages used were frozen. MacRae and Ulyatt (1974) have suggested that freezing affects the sites of digestion of dietary constituents, which has implications with respect to the utilisation of nutrients.

At the age at which lambs were weaned for these experiments, hill-reared lambs are still ingesting significant quantities of milk, in the region of 600 g/head/day (Eadie, unpublished). A question which arises, therefore, is the significance of moderate quantities of milk to lamb growth rate from this age; consequently two of the experiments included the feeding of measured quantities of milk substitute.

The amount fed was 160 g dry matter (containing 150 g O.M.) per head per day, which is in excess of that which hill lambs would receive in practice.

The live-weight gains of milk-fed lambs were superior to those of their herbage-only fed contemporaries (from 24 to 85 g/head/day). Milk feeding depressed herbage organic matter intake to a variable extent. The depression ranged from 78 to 123 g/O.M./head/day. Calculations suggest that when account is taken of this depression the response in live-weight gain to feeding 160 g milk substitute was about 100 g/head/day.

**Grazing Experiments**

A further question concerns the extent to which the various relationships obtained in the indoor studies hold good with lambs at pasture.

The major experimental difficulty is in determining, with adequate accuracy, the quality of herbage ingested by grazing lambs. Nevertheless it is possible to extend the results of more controlled indoor experiments, and to make some assessment of the validity of the findings in the grazing context by means of grazing experiments.

The growth rates of lambs of similar age, size and breeding to those used in the indoor experiments were first measured on perennial ryegrass and *Agrostis-Festuca* pastures.

The live weight gains of these lambs were poor (approximately 100 and 50 g/head/day for ryegrass and *Agrostis-Festuca* respectively) relative to those of suckling lambs grazing the hill, and to those obtained in the indoor studies.

Consequently, a second experiment was carried out in which milk substitute was fed to half of the lambs in each of two groups of lambs grazing *Agrostis-Festuca* at high or low grazing pressures. The gains of the non milk-fed lambs were 33 and 57 g/head/day respectively, and the gains of the milk-fed lambs at high and low grazing pressures were 140 and 145 g/head/day respectively.

The indoor experiments gave a clear indication of the advantages of clover, and suggested that a good response to milk could be obtained even with high-quality herbages. In a third grazing experiment, three groups of lambs grazed a clover-dominant sward. One group received a daily allowance of milk substitute of 160 g/head/day and one group 80 g/head/day. The unsupplemented lambs gained 230 g/head/day, and the low and high milk groups 263 and 308 g/head/day respectively.

Digested energy intakes were predicted on the basis of faeces nitrogen concentration-digestibility relationships. These were derived indoors using lambs of the same age and breeding and herbage cut from the same or similar pastures.

The rates of gain of the non-milk fed lambs grazing grass in relation to calculated digested energy intakes are in reasonably close agreement with those of the indoor experiments. The unsupplemented lambs grazing clover, however, grew at rates rather higher than would have been predicted on the basis of the relationship given in Figure 1. It seems possible, despite the evidence of the indoor experiments, that part of the explanation lies in a more efficient utilisation of digested organic matter in excess of maintenance for gain on the clover pasture.

## Summary

In relation to their potential for growth, the growth rates of hill lambs on hill grazings are poor. Lamb growth rates fall as milk yields decline and solid food becomes of increasing importance in the lamb's diet.

Growth rates in the second half of the growth period to weaning depend increasingly on the quality of the solid food the lamb ingests. Despite the fact that lamb growth rates on concentrate feeds can be substantially greater than on herbage, the relative values of concentrates and lambs are likely to ensure that better hill lamb growth rates will depend on better quality herbage feed.

The work described has clearly indicated the limitations of grass species for lamb growth. Both the indoor experiments and the grazing experiments show that, although there will be a response to the provision of better quality native *Agrostis-Festuca* herbage, the increase in lamb growth rates obtained will be comparatively small. On the evidence of the results with ryegrass, sown grass will produce better gains, but even these will be modest. The limitations of grass species are the more apparent when it is recognised that at the time of year coincident with maximum dependence on pasture feed, the available herbage will be more akin to the regrowth herbages used in these experiments than to the first growths.

The results obtained with the clover-containing herbages in the indoor experiments, and with grazing lambs on the clover sward demonstrate the potential value of this plant in improved hill pastures. Furthermore, the benefits of clover-rich improved pasture may go beyond the provision of better quality herbage to the lamb; the effect of clover-rich feed on ewe lactation performance is likely to be significant. The response in lamb growth rate to moderate

quantities of milk substitute is considerable. However, the net result of the provision of high-quality food to both ewe and lamb requires further elucidation in terms of the relationship between the quality of pasture ingested by the lamb, the amount of herbage it ingests and its consumption of milk.

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# 4. PROGRESS IN STUDIES ON THE REPRODUCTIVE PERFORMANCE OF HILL SHEEP

J. M. DONEY AND R. G. GUNN

THE effect of various environmental factors on reproductive performance of hill sheep and the implications for practical management systems were discussed in an earlier report of this series (Gunn and Doney, 1971). The conclusion drawn was that lambing percentage in the Scottish Blackface breed could be influenced by factors associated with body condition at mating and by certain features of the non-nutritional environment. Except when associated with very poor body condition, levels of intake in the period immediately before and after mating appeared to have little effect. It was found that variation could occur in both ovulation rate and early embryonic mortality, the key components of lambing percentage, and that these were to some extent independent.

A subsequent series of experiments has provided further information which must be taken into account when assessing the probable consequences of practical management situations or, conversely, when attempting to define management requirements in relation to given levels of reproductive performance.

## 1. The Effect of Pattern of Recovery in Body Condition on Reproductive Performance

Within the Blackface breed, it has been confirmed (Gunn and Doney, 1973) that the relationship between body condition at mating and reproductive performance is independent of the pathway by which the body condition is achieved. Two patterns of recovery to a uniform high condition were imposed between weaning and mating on groups of ewes in similar low condition. The two patterns were early recovery from immediately after weaning, followed by a maintenance period, and late recovery just prior to mating, preceded by a maintenance period. There was no difference between the groups in the subsequent lambing percentage. The total food consumption in the late group, however, was 23 per cent less than in the early group. This was almost entirely related to the difference in maintenance requirements between fat and thin ewes. Before this information can be applied, account must be taken of the relative cost of feed and its availability throughout the grazing cycle. Thus it may be more convenient to achieve the desired recovery in full during the summer period before the quantity and quality of pasture declines, rather than to rely on provision of additional feed from outside the grazing resource in late autumn.

**2. Influence of Early Growth on Reproductive Performance of Blackface Ewes as Adults**

It has been confirmed that the pattern of growth during the first year of life has a very significant effect on the potential range of reproductive performance in adult Blackface ewes (Gunn and Doney, unpublished). Ewes, which were well grown during early life, had ovulation rates as mature adults ranging from 220 per cent down to 120 per cent, depending on actual body condition at mating. Ewes with smaller adult size and weight, however, had ovulation rates ranging from 160 per cent to less than 100 per cent in the same extremes of body condition (grades 3 and $1\frac{1}{2}$ as described by Russel, Doney and Gunn, 1969). Some of these data were derived from earlier studies on the effects of nutrition during the first and second six months of life (Gunn, unpublished). The significant mean differences between groups in adult size and weight were dependent wholly on the management treatments imposed during these two early growth periods. One implication of this is that the potential increase in reproductive performance, associated with improved management of adult ewes, will not necessarily be expressed fully in those adult ewes which were reared in less favourable conditions. The effect of change might be cumulative and depends on the extent to which improved management affects the early growth of replacement ewes.

**3. Breed Differences in Reproductive Response**

In the previous report it was suggested that, although most of the results referred to the Scottish Blackface (BF) breed, the general principles might apply to other breeds, although differences in degree of response might be expected. Some preliminary experiments on both the North and South Country Cheviot (NCC and SCC) have been carried out, together with a pilot trial on a totally different genotype represented by the Finnish Landrace/Blackface cross. So far only the relationships between actual body condition at mating and ovulation rate or early embryo mortality have been studied. The relative importance of current nutritional levels (or of changes in weight and condition) either before or after mating is still unknown.

The response to variation in body condition has been found to differ quantitatively from that previously described in the Scottish Blackface. The range in ovulation rate at two key levels of body condition is illustrated in Figure 1. Grade 2 (approximately 20 per cent fat in the body) represents the normal average condition which can be expected from traditional systems, whereas grade 3 requires considerably raised nutritional standards during the recovery period. The difference is approximately equivalent to an increase of 9 kg (20 lb) in live weight at mating for ewes of the same body size. From the limited information shown in Figure 1 it can be seen that

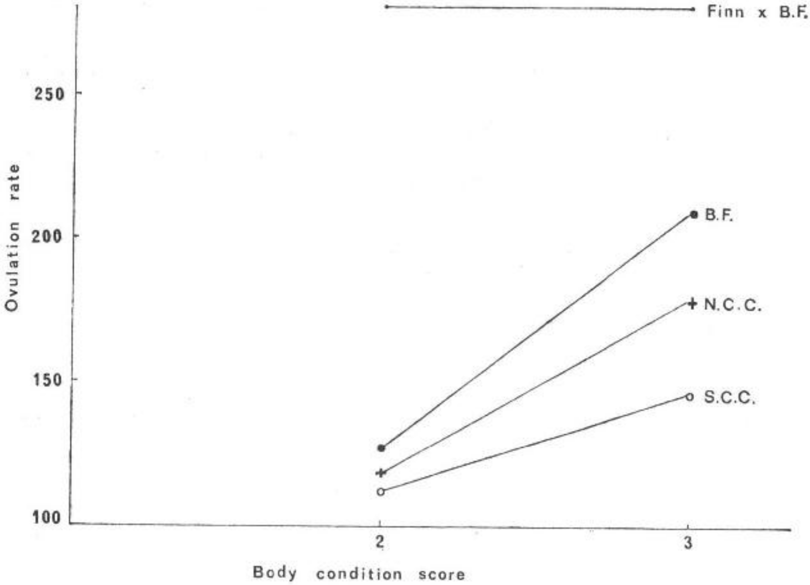


FIG. 1.—The relationship between ovulation rate and body condition in different breeds of sheep.

Key: Finn. Finnish Landrace
B.F. Blackface
N.C.C. North Country Cheviot
S.C.C. South Country Cheviot

there are likely to be considerable differences between breeds. For instance, both the South Country Cheviot and the Finn × Blackface ewes in these trials appear to be relatively unresponsive in ovulation rate (at low and high levels respectively) to change in body condition over the observed range. Since there is as yet no adequate hypothesis to account for the apparent links between body condition and reproductive performance, extrapolation of expectations to other breeds would require experimental confirmation for each.

It must be emphasised that, although change in body weight before mating in response to increased feeding (flushing) has been shown to be relatively unimportant in the Blackface breed as compared with the actual level of body condition achieved, it cannot be assumed without evidence that this will also apply to the other breeds. It is possible that the upper limit of reproductive rate is restricted for each individual and breed by genetic factors and that the level of body condition at which this limit is approached is also determined by the genotype. At lower levels of body condition and/or nutritional state than have been considered here the reproductive capacity of any genotype may be seriously impaired. It is, therefore, probable that sheep breeds differ, not only in their maximum reproductive efficiency but also in the flexibility of their response within a realistic range of situations. Knowledge of this flexibility and of the biological principles involved would be useful in making decisions concerning choice of breed for a given management system or, alternatively, choice of management objectives for a given breed and level of performance.

### 4. Breed Differences in Early Embryo Mortality

The consequences of these apparent breed differences may be further confounded by additional factors which affect early embryonic mortality (Doney, Gunn and Smith, 1973). The experimental evidence to date suggests that embryonic mortality in South Country Cheviot ewes in high body condition is significantly greater than in the other two hill breeds, whereas in low body condition, it may be less. Thus the effective lambing percentage (to first service only) of all three breeds may be fairly similar (80-90 per cent) when all ewes are in a condition at mating comparable with grade 2 but a considerable spread in performance may be expected at the upper level of body condition (around 160, 140 and 110 per cent in BF, NCC and SCC respectively from our controlled experimental flocks).

### 5. Effect of Environmental Stress

Further experiments on depression of reproductive performance by non-nutritional environmental factors at normal mating time ('stress') have supported previous evidence that various types of stress situations may have similar effects (Doney and Gunn, 1973). It is apparent that the response to a given environmental stress will depend to some extent on the genotype and on the degree of habituation of the individual exposed to that particular situation.

In conclusion it can be stated that current progress supports the practical implications, discussed in the last report, to the extent that reproductive performance can be manipulated by management procedures. The need to consider reproductive efficiency as a consequence of whole-life as well as year-round management is emphasised and it has been shown that breed differences, even amongst traditional hill sheep, are of even greater consequence than was first suggested.

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# 5. PLANTS TO IMPROVE HILL PASTURES

PETER NEWBOULD

IT is widely accepted that hill land improvement is the key to achieving greater productivity from hill sheep farms. Pasture improvement can be initiated by a range of treatments of varying cost selected to suit the underlying soil, the character of the indigenous sward and the type of utilisation system. The factors involved were considered in detail by a workshop discussion at a recent Colloquium in Edinburgh (Potassium Institute, 1973). At the cheaper end of the range, with *Agrostis-Festuca* swards, the provision of a fence which allows greater control of grazing is the minimum requirement, while at the more expensive end, on blanket bog, destruction of the existing vegetation, the application of lime, phosphate and potassium fertilisers and the sowing of seeds of better quality plants are needed in addition to the fence. In almost all the treatments between these extremes, except for a very few on *Agrostis-Festuca* swards, it is necessary to introduce better quality plants than those normally present by the use of seeds. This article discusses the characteristics of the plants ideally required for the improved pastures of efficient hill farming systems, examines how far present varieties meet this ideal and concludes by suggesting which plants the breeders might attempt to improve in the future. However, before doing this it is necessary to describe briefly the resources and the utilisation system envisaged for the improved pasture, since they determine many of the characteristics required of the plants to be introduced.

## The Resources

Hill soils have been described in a previous report (Floate, 1967); their main limitations to successful plant growth are acidity and low contents of available nutrients, in particular phosphate and nitrogen. The latter element is the key deficiency, for while lime and slag may be effective for several years after application, dressings of nitrogen are soon lost from the soil and there is a need for continuing applications, which the low output hill farming traditional system cannot support financially. It is also contended that even the more efficient systems of hill sheep farming described later will be unable to support the cost of using nitrogen fertilisers annually. This emphasises the need for plants that can provide their own nitrogen (e.g. legumes), or which can make efficient use of the very low levels which exist in most hill soils.

### The Environment

The climate on hills in the United Kingdom is more extreme than on the lowlands with the result that the growing season is very short due mainly to low temperatures. Soil physical conditions are also extreme and plant species may have to tolerate either very wet or very dry conditions, with the chief emphasis on tolerance of waterlogging.

### System of Utilisation

The most widely applicable system which seems best able to overcome the defects of the traditional, free range, set stocked system is the two-pasture system outlined by Eadie (1971) and since successfully tested on a whole farm scale in two very contrasted environments (Eadie, Armstrong and Maxwell, 1973; Eadie, Maxwell, Kerr and Currie, 1973). The essence of this system is to integrate the use of a small proportion of improved with the larger amount of unimproved hill land so that the former has the biggest impact on animal performance at key times in the annual nutrition cycle without adversely affecting its own regrowth. Thus, as stated by Cooper (1970) the effective utilisation of the herbage produced from improved pasture depends on the development of management systems in which the optimum frequency and intensity of grazing for production of the crop are balanced against the seasonal requirements of the sheep. The key stages in the sheep's annual cycle of nutrition have been identified (Eadie, 1967; Russel and Eadie, 1968) as the periods, prior to parturition, during lactation and lamb growth, and prior to mating. The highest possible quality of diet from improved hill pasture or from supplements is required at these times. Figure 1 illustrates diagrammatically the interplay of use between improved pasture to cover these stages, coupled with a typical and an ideal improved pasture growth curve and a stylised sheep live weight curve. To best show the ideal desirable shape of growth curve for an improved hill pasture the annual herbage dry matter (DM) production of the typical and ideal pasture has been taken as the same, i.e. 4500 kg/ha. More usually, as discussed in the next section, the annual DM production of the ideal pasture improved by the use of clover and lowland grasses would be greater than this. The additional attributes required from the improved pasture to best suit the 'two-pasture' system are seen to be, early spring growth (1), the continued production of high quality herbage in late spring and early summer (2), the ability to respond to the mid-summer rest period by producing autumn regrowth (3), and the need for the herbage to remain winter green for as long as possible into the winter (4).

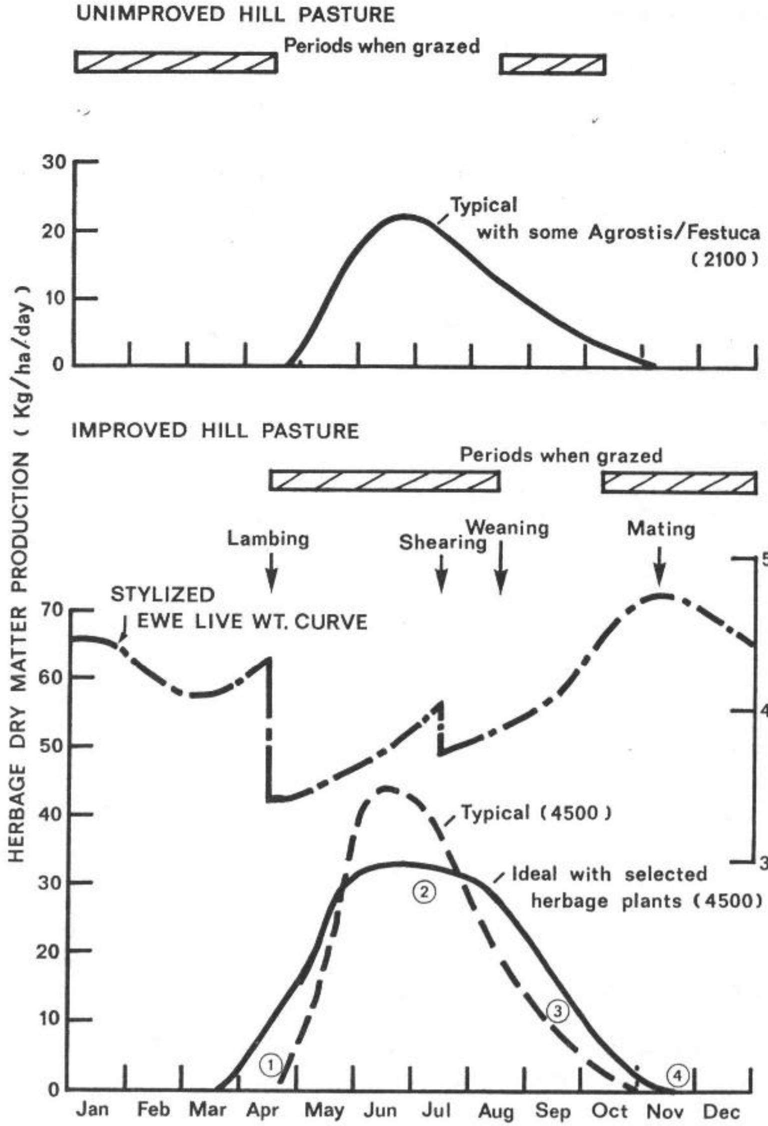


FIG. 1.—Typical and ideal herbage dry matter production curves from unimproved and improved hill pastures and the periods when they would be grazed in a 'two-pasture' system. A stylised ewe live-weight curve is given to indicate a typical annual cycle of nutrient requirements. Annual herbage DM production (kg/ha) shown in brackets. See text for explanation of circled numbers.

**Nutrient Requirements of Hill Sheep—Targets for Pasture Production**

It is not yet possible for the animal nutritionist to describe exactly how much protein, carbohydrate and minerals are required by hill sheep throughout the annual cycle of nutrition. All that can be said is that the average hill ewe requires to consume about 450 kg of herbage DM of adequate digestibility (>60 per cent) per year. Thus, to carry a ewe per 0·4 ha (one ewe per acre) which sets a stocking rate to aim at, and assuming that 50 per cent of the herbage produced is utilised, the target for pasture production over the whole farm is 2240 kg herbage DM per ha per year of moderately high quality (60-65 per cent digestibility). To meet the animal requirements within the grazing system described previously (Fig. 1) the improved pasture will have to produce about twice as much herbage DM as the average, i.e. 4480 kg per ha per year of high quality (70 per cent digestibility).

To place this target for improved pasture production into context it is noteworthy that unimproved hill pastures with little *Agrostis-Festuca* yield 1700-2200 kg DM per ha/per year at 45-60 per cent digestibility. This would suffice to maintain dry ewes etc. Unimproved pastures with a high proportion of *Agrostis-Festuca* yield from 2800 to 3900 kg herbage DM per ha per year according to type. However, levels of utilisation of such pastures in traditional systems are only about 15-20 per cent. Thus, even the latter type of pasture requires a modest increase in yield, an increase in quality and a large increase in utilisation to bring it near the target. The necessary improvement can be brought about by introducing clover with no other change of species and accompanied by grazing control to bring about increased utilisation; the treatment would need to be applied to about 20-25 per cent of the whole hill farm.

A greater degree of pasture improvement of the latter type of hill pasture can be achieved by replacing the indigenous grasses with varieties that produce more herbage DM of higher quality. Thus, yields of 6700 kg DM/per ha/per year with 70 per cent digestibility are attainable. This better quality herbage could be used to further increase animal production by increased stocking rate or individual performance or it could be used to reduce the area of hill land which needs to be improved e.g. from 20-25 per cent to 15-20 per cent.

**Plants ideally required in Improved Pastures for use in 'Two-pasture' Hill Sheep Production Systems**

To suit the characteristics of the environment and the resources on hills and to meet the requirements of sheep grazing in 'two-pasture' systems it is possible to specify a set of ideal characteristics which the plants sown in improved pastures should possess. These characteristics which are summarised below can be divided into two main groups, those concerning agronomic features and those concerning nutritional value.

*Agronomic Characteristics*

The seed must be cheap and available.

The plants must have rapid and easy germination and establishment.

The plants must be free from disease and tolerant of low temperatures and high wind.

The plants must be tolerant of low soil fertility and tolerant of either wet or dry soil physical conditions.

The plants must have early growth in spring, evenness of production through the season and for several seasons, they must have a high proportion of leaf to flowering head, they must be winter green and winter hardy, they must be persistent under grazing conditions, not over competitive to clover, but able to suppress the ingress of dicotyledonous weeds and other weed grasses.

*Nutritional Characteristics*

The herbage should have high feeding value and good palatability throughout the year, e.g. the plants should have no rough or hairy leaf edges.

The herbage should be of high digestibility and the animals should be able to eat herbage to completely fill their appetite, i.e. voluntary intake should not be impeded.

The ingested herbage should have a high efficiency of conversion.

There should be no excess of toxic or other specific components, and no deficiency of vital trace elements.

**Existing Plants—Brief descriptions of how they measure up to the ideal criteria**

**Indigenous Short Grass Communities** (for a detailed description see King *et al.* 1967).

*Agrostis tenuis*—common bent, *Festuca ovina*—sheeps fescue. Tolerant of low soil fertility, late in spring growth. Better on drier than wetter areas of hill. Palatable to sheep and of moderate digestibility throughout the growing season. Seed not available in large quantities and is very expensive.

*Festuca rubra*—red fescue. Will not tolerate the lowest fertility levels. Requires a $pH > 5{\cdot}3$ and moderate levels of N. Therefore, it matches the requirements of clover. Tolerant of waterlogging. Palatable, earlier than *Agrostis* and *Festuca ovina*. Seed available but expensive. Seedling establishment not difficult, but yields are generally low.

*Poa pratensis*—smooth-stalked meadow grass. This species tolerates low soil pH levels but performs best at pH > 5·3 and high N levels. It spreads by rhizomes and given adequate N is able to dominate a sward. It has good early spring growth, poor summer production and some genotypes appear to be winter green. Seed is costly and establishment is difficult. It is reputed to be little eaten by sheep, but there is little direct evidence of this.

*Poa trivialis*—rough-stalked meadow grass. This species has similar soil fertility requirements to Poa pratensis, but is tolerant of damp soils. It is not very competitive, although it grows well with clover. It is reported to be palatable and digestible to sheep, but few stockmen have a high opinion of it.

*Holcus lanatus*—Yorkshire fog. It is tolerant of low soil fertility and competitive with better grasses. It has low winter hardiness, is unpalatable and of low nutritional value to stock.

**Lowland Herbage Species** (for a recent detailed review of the characteristics of the main herbage species see Spedding and Diekmahns, 1972).

*Lolium perenne*—perennial ryegrass. Despite high yield and digestibility, early spring growth, and rapid and reliable establishment, the species needs high levels of soil fertility and is susceptible to winter kill. The new Dutch varieties overcome the latter deficiency, but they have been bred for even higher levels of soil fertility so may be unsuitable for hill land. Sufficient trials have not yet been carried out to be certain of the latter point.

*Phleum pratense*—timothy. This species has high digestibility and palatability, is very winter hardy, late in spring and makes poor recovery growth in autumn. It is relatively tolerant of wet soil conditions (Rogers *et al*, 1974) and is easy to establish. If varieties of this plant with greater resistance to grazing and with early spring growth could be selected it is potentially of great interest to the hill sheep farmer.

*Dactylis glomerata*—cocksfoot. The advantages of this variety in persistence and tolerance of low soil fertility and drought conditions is outweighed by its tufted growth form, its low digestibility and its high unpalatability to sheep. It is intolerant of waterlogging.

*Festuca arundinacea*—tall fescue. This species has very early spring growth, is very tolerant of waterlogged soils (Rogers *et al*, 1974), is winter hardy and persistent, but is relatively unpalatable to sheep. In addition it is very difficult to establish. A lax grazing management is needed to suit the crop and under these conditions it may be able to compete with weed species, but will then be over competitive to clover.

*Trifolium repens*—white clover. This plant would be the ideal legume for the hills if it would grow and fix nitrogen both earlier and later in the season, if its herbage was more cold hardy, and if it were more tolerant of low soil pH and levels of calcium and phosphate. These factors coupled with the lack of a British inoculum of effective rhizobia lead to unreliability of establishment on extreme soils such as blanket peat which has caused some farmers not to sow it. However, once established and used in a well managed grazing situation clover provides nitrogen for companion grasses and yields very digestible herbage of high protein and mineral content. Moreover, not only is voluntary intake and efficiency of utilisation within the animal increased but there appear to be other beneficial effects on animal performance which are not fully understood as yet (Rae *et al.*, 1964).

**Plants available to Improver at Present Time**

The hill sheep farmer who wishes to improve part of his land has no alternative at the present time other than to sow the seeds of varieties bred primarily for lowland conditions and hope that they will succeed in the harsher environment of the hill. A great deal of advice on the best seeds to use is available to the farmer from the seed merchants and from the advisory service. In England and Wales the Ministry of Agriculture Food and Fisheries (ADAS) and the National Institute of Agriculture Botany publish recommended lists of suitable varieties or mixtures of varieties, which are suitable for different animal production systems. Little attention is given to specific advice for hill sheep farmers.

In Scotland, in addition to advice from seed merchants, each Agricultural College produces a recommended list of herbage varieties and one of the Colleges (North of Scotland College, 1972) has recently published a leaflet on hill land improvement which describes suitable seed mixtures for hill land. Thus, the hill sheep farmer has a multiplicity of advice on individual seeds and mixtures of seeds which are presented in different styles by the different Institutes, but in general all are based on using the most likely lowland varieties to tolerate the environment and soils of the hills. Despite the recommendations contained in these lists the seed actually used by the farmer depends in many cases on the seed that is available at the seed merchant and the latter may persuade the farmer to buy what is available and not what he really requires for his given situation. However, some seed firms have a very high reputation for providing suitable mixtures for hill farmers, which take account of local variations in soil chemical and physical conditions and other factors. This is often achieved by the 'pepper pot' principal, which provides small amounts of several varieties of seed in the mixture in the hope that at least one variety will suit the conditions and flourish.

Taking all the foregoing considerations into account the plant which most nearly approaches the ideal is white clover. Apart from its poor early and late growth, its inability to withstand very high grazing pressures and its content of oestrogens in some cases, a pure stand of this crop possesses most of the ideal agronomic and nutritional characteristics (see p. 80). It is, however, very difficult to maintain a pure sward of white clover, even if the above defects could be eliminated. Moreover, the use of white clover without a companion plant which can benefit from the nitrogen which is fixed and added to the system is biologically unsound.

A grass/clover mixture is therefore essential and the grass species should complement the clover as far as possible making good the deficiencies of the clover plants. To meet these criteria the ideal grass should have herbage, that is frost hardy and winter green, be capable of growth at low temperature and be competitive to other grasses. Tolerance of sub-optimal nutrient levels and at least a degree of water-logging are other desirable features preferably coupled with ease of establishment and low seed costs.

A pasture type of perennial ryegrass is the only practical choice at present and if the lack of winter hardiness could be overcome it would always be the first choice for pastures where a moderately high nutrient level could be maintained. At slightly lower nutrient levels smooth-stalked meadow grass and red fescue are reasonably attractive alternatives. However, the former species is not a practical proposition until seedling establishment can be made more certain and adequate supplies of suitable genotypes are available. Red fescue is a practical alternative at the present time provided a suitable high yielding cultivar can be obtained. Both these species can creep and this may make the latter at least more useful than ryegrass for sod-seeding.

The ability to tolerate anaerobic conditions makes Timothy and tall fescue worthy of consideration despite their limitations of poor resistance to grazing and unpalatability.

The maintenance of any of these grasses in suitable mixtures with white clover calls for considerable skill on the part of the grazing manager, because of the differing seasonal patterns of growth of the plants and the selective preference exercised by the grazing animal. The provision of varieties of either grasses or clovers, or more complementary types of both species which would help to reduce the difficulties of the grazing manager would be of great value.

**Plants which Merit Selection to Meet Ideal Criteria for Improved Hill Pastures**

It is realised that the plants ideally required to improve hill pasture do not exist and may never exist since many of the specified characteristics are self-contradictory, e.g. extreme persistence is incompatible with high yield. However, it is encouraging that provided adequate water and soil nutrients are available, the biological potential of temperate grasses greatly exceeds current levels of production and also that sufficient genetic variation exists for the plant breeder to be able to increase this potential still further (Cooper, 1970).

Therefore, if money were available to enhance breeding of herbage plants for hill farmers the following would be important:

1. The selection of forms of white clover which have greater tolerance of high soil acidity and low soil temperatures and which have an active symbiosis with effective rhizobia so that nitrogen fixation is enhanced. Because of the emphasis on legumes in improved hill pastures, work on possible replacements for white clover should be continued; the work of the West of Scotland College (1972) on *Lotus* spp. is a good example.
2. The selection of winter hardy forms of perennial ryegrass which have a greater tolerance of low soil fertility.
3. The selection of forms of Timothy with a greater resistance to grazing, with earlier spring growth and with better regrowth characteristics in the autumn.
4. The selection of forms of tall fescue and cocksfoot with more palatable herbage and more prostrate growth forms.
5. The selection of improved genotypes of red fescue and smooth-stalked meadow grass; the former with better herbage characteristics and the latter with better establishment.
6. The multiplication of seed from the best pastures of indigenous *Agrostis-Festuca* spp. A detailed cost/benefit analysis and performance comparison with the other available grasses needs to be done to assess the potential value of this alternative.

**Present Research Work**

The plant breeding institutes in the United Kingdom are working on some varieties directly suited for hill land. The selection of more winter hardy perennial ryegrass, more palatable cocksfoot, of higher yielding meadow grass species, of more digestible red fescue and the crossing of Italian ryegrass and tall fescue being some of the projects under way. If there are insufficient resources to mount further selection programmes for the ideal specialist plants to suit the hill farmer then the requirement is for more general purpose types of plant with persistence and adaptability to a wide range of management systems.

**Scale of Seed Requirement**

The potential for increased sales of seed to hill sheep farmers can be judged using Scotland, the region with the largest proportion of hill land, as an example. In Scotland about 4000 tonne of grass and 250 tonne of clover seed are currently used each year of which possibly one-quarter (i.e. 1000 tonne grass and 60 tonne clover) is used to improve hill pastures. It has been estimated that about 0·4 million hectares of hill land in Scotland would respond to improvement by reseeding within the context of a two-pasture system. If half the farmers controlling this land decided to carry out improvements and with seed rates of 22 kg grass and 4·5 kg clover per ha, the total requirement to improve all this land would be about 5000 tonne of seed. If the improvements were spread over a ten year period this would mean a 50 per cent increase in the present annual supply of seed for the hills. Since the yield of herbage seed rarely exceeds 0·6 tonne/ha the additional land required to grow this extra seed would be 800 ha.

With the new certified seed regulations and production aid of the EEC which should result in the payment of higher premiums for seeds the provision of sufficient weed free land to grow the additional seed requirements should be an attractive business proposition. However, in order to compete with the Continental seed producers it will be necessary to try and achieve higher yields of good quality seed per ha than those hitherto achieved in the United Kingdom.

Thus, there appears to be considerable potential for the seed trade to expand its business for Scotland alone, without considering the quantities needed for the hills of England and Wales. This presupposes that the seeds are specially suited to the hill sheep farmer's requirements as outlined here or that they produce more widely adaptable plants. The size of this potential increase in trade would seem to justify some increase in efforts to select plant varieties better able to suit the climate, soils and grazing systems of hill pastures. In particular, if the arguments presented here have any validity there is an immediate case for intensifying work on White clover and other possible legumes. If the specialist species for the hill were also good amenity grasses for reseeding the sides of motorways, etc., the size of the potential market might be considerably increased.

**Conclusions**

While it is impossible to give a completely detailed description of an improved pasture that would be optimum for hill sheep production, it is reasonable to suggest that it should have the following characteristics.

Agronomically, it should be easy to establish, able to fix nitrogen, tolerant of sub-optimal soil fertility, early in spring, have cold resistant herbage, be winter hardy, be persistent over several years and have good recovery growth after a rest in the autumn, and seed should be readily available. Moreover, the plants should be perennial and able to reproduce themselves by rhizomes or stolons or by tillering since the grazing management proposed in the 'two-pasture' system of hill farming depends on the inhibition of flower heads and subsequent seed shed. Nutritionally, although we cannot specify the exact quantities of protein, carbohydrate and minerals which an ideal herbage should contain we can require it to be palatable, digestible, with high voluntary intake and with no toxic substances or imbalances of essential trace elements.

Because of the interaction between the seasonal pattern of grazing and the form and growth patterns of the pasture the choice of plant species and varieties cannot be considered in isolation from the management system. The best mixtures from seeds available at the present time will include small and medium leaved white clover, early, medium and late perennial ryegrass, timothy and red fescue.

Further work is required to find white clover strains which are more tolerant of low soil temperatures and acidity and which form effective symbioses with rhizobia. Perennial ryegrass varieties which are more winter hardy and persistent, and which are tolerant of low levels of soil fertility are also needed. Both red fescue and smooth-stalked meadow grass merit attention as alternatives to ryegrass at sub-optimal fertility levels. Varieties of timothy are needed which are less sensitive to heavy grazing and which have earlier spring growth, make better autumn recovery growth and which can withstand the competition of perennial ryegrass and white clover. Forms of tall fescue and cocksfoot which have a better growth habit for grazing and which are more palatable and digestible must also be considered. In addition, because of the successes achieved by fencing existing *Agrostis-Festuca* pastures and the impact of the resultant controlled grazing on DM production and animal performance, the provision of seeds of the species in these pastures might merit serious thought.

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# 6. THE PROBLEM OF WATERLOGGED SOIL

J. A. ROGERS, J. KING AND G. E. DAVIES

ON a considerable area of hill land, pasture production is limited by poor drainage and anaerobic soil conditions.

Four soil types are involved: deep peats such as blanket bog; shallow peats over podzolic profiles; surface water gleys and, lastly, ground-water gleys. In the surface water gley percolation is inhibited by impermeable lower horizons, so that water accumulates above these and tends to move laterally near the surface, while ground-water gleys have a true water table, which may rise to the soil surface and above.

The topographic occurrence of these soils is well known. The deep peats and podzols occupy the upper slopes and flatter hill tops while the gleys, which may also have a peaty surface horizon, are common on the lower slopes and valley bottoms. The size of the problem represented by anaerobic soils in the South of Scotland may be gauged from the area which they occupy and the proportion that this bears in relation to the total area of certain Soil Associations which are characteristic of hill land. Data for three Associations all found on hill land in the Southern Uplands of Scotland are shown in Table 1. Of these the Ettrick Association is the most widespread.

TABLE 1

*Area in square miles covered by three Soil Associations and the proportion of the major soil profile types within these*

| Profile types | Soil Associations | | | Total Area | |
|---|---|---|---|---|---|
| | Ettrick % | Sourhope % | Carter % | sq. ml. | % |
| Gleys | 21·4 | 9·7 | 82·1 | 154·0 | 22·2 |
| Brown forest soils | 44·9 | 65·2 | 5·8 | 320·4 | 46·2 |
| Podzols | 22·6 | 8·8 | 7·2 | 138·6 | 20·0 |
| Others | 11·1 | 16·3 | 3·8 | 80·4 | 11·6 |
| | 100% | 100% | 100% | — | 100% |
| Total area (sq. ml.) | 564·5 | 99·9 | 29·0 | 693·4 | — |
| Hill peat | — | — | — | 118·9 | — |

Soil Survey of Scotland Sheets 33/34/41, 17/18, 32/34* covering certain hill districts in the East and Central Southern Uplands (Counties of Roxburghshire, Peebleshire, Selkirkshire).

* Within these areas the Ettrick, Sourhope and Carter Associations are almost entirely confined to hill land. In western districts peat tends to form where drainage is poor and much of the Ettrick Association, which occurs also at lower altitudes is mapped as 'Complexes'.

In the districts to which the table refers the area of poorly drained gley soils is rather more than that of hill peat and it accounts for between a fifth and a quarter of the total area. Since the proportion of gleys and other soil types varies greatly between Soil Associations the proportion will also vary between districts and in some localities poorly drained soils may predominate. In western districts a greater development of peat is found.

The limitations imposed by anaerobic soil conditions on pasture production might possibly be ignored in the context of a non-intensive grazing system. However, as more intensive management systems are adopted, decisions are required on the best way to utilise poorly drained land.

Three alternatives are open to the farmer. If sufficient freely drained land is available, he may find it possible to exclude water-logged areas from his hill enclosures. If this is not possible he may try to introduce species tolerant of anaerobic conditions or, alternatively, seek to improve soil conditions by drainage. The choice depends on technical considerations and on cost/benefit relationships.

Unfortunately there is very little information available on which a rational decision can be based. Drainage of surface-water gleys in areas of high rainfall is unlikely to be more than partially successful so that it is necessary to consider what degree of waterlogging is acceptable. This will be influenced by the degree of tolerance shown by individual species, which are at the same time acceptable to stock, and also by considerations of animal health and susceptibility to physical damage through treading.

It seems to be worth while, therefore, to consider at least some of the factors affecting pastures growing on these soils. Plant growth, for example, is limited principally by inadequate aeration or factors associated with this. The relationship between soil aeration and soil moisture tension is illustrated in Figure 1. Low moisture tensions and low oxygen concentrations are associated with waterlogged soils. As conditions become drier the oxygen concentration increases approaching 21 per cent near the point of field capacity. Beyond this, moisture tension may increase to high values with little furhert change in the oxygen concentration. Both soil moisture tension and oxygen concentration vary according to the weather conditions reflecting the balance between precipitation and evaporation. The range over which this variation occurs in the course of the season is greatly influenced by soil and site conditions and, in consequence, tends to be characteristic of the site type. The range of variation of three categories of site in terms of mean seasonal moisture tension is shown in Figure 1(*a*). The most poorly drained sites are found at

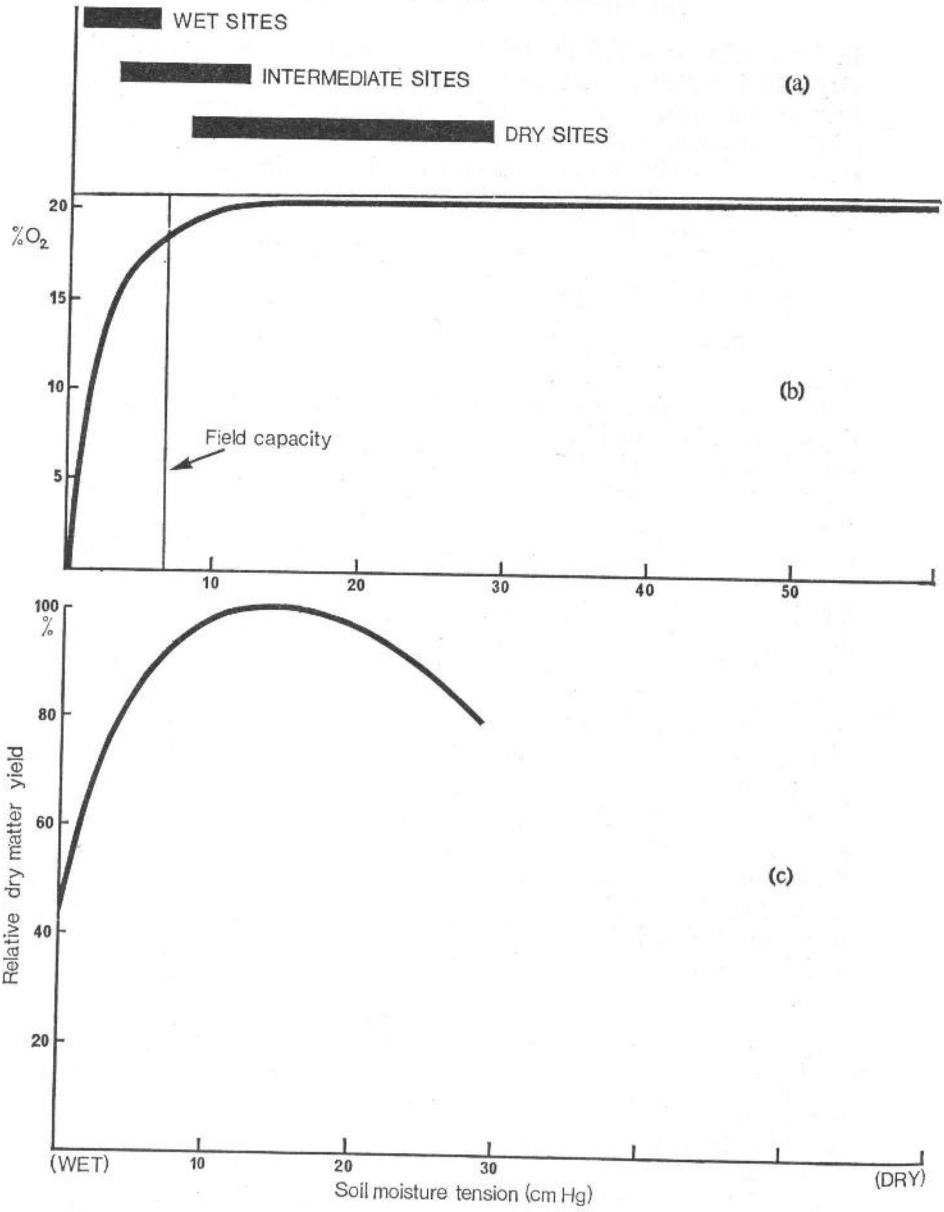


FIG. 1.—(*a*) The range of mean seasonal moisture tensions between wet and dry years, in a wet, an intermediate and a dry site; (*b*) the relationships of soil oxygen concentration, and (*c*) plant dry matter yield with soil moisture tension. Soil oxygen concentration is expressed as the percentage oxygen in the soil atmosphere in equilibrium with the soil solution.

the lowest part of the curve and only dry out to field capacity in the driest weather. On freely drained sites the mean moisture tension rarely falls below the level of field capacity even in a wet year, while on sites of an intermediate nature it tends to be above field capacity in a dry season, but to fall below this level when conditions are wet. In an experiment at Sourhope, Rogers and Davies (1973), showed that yields of pasture species were directly proportional to soil oxygen concentration when moisture tension was below field capacity. Yields increased rapidly as soil moisture tension increased until a maximum was reached at a point near field capacity, declining again as the soil became drier and moisture tension increased to high values (Fig. 1(*c*). Data for the yields of perennial ryegrass on a number of sites of contrasting drainage characteristics are shown in Figure 2. All the sites, which were on mineral soils ranging from freely drained brown forest soils to gleys were at pH 5·0 and were well fertilised with mineral nutrients. The highest yields were found on the freely drained sites in a wet year, whereas in a dry year they occurred on sites of an intermediate nature. The greatest reduction in yield below the optimum level, attributable to waterlogging, was 53 per cent in the wet and 33 per cent in the dry year. For the group of three most poorly drained sites the mean reduction was 52 per cent and 21 per cent respectively for the two years. In contrast, the dry year yields on the freely drained sites were depressed by 26 per cent.

This data is for S.23 perennial ryegrass, which is by no means the species best adapted to the conditions. The responses of four grass species to soil oxygen concentration are shown in Figure 3 and it is apparent that both Tall Fescue and Timothy suffered relatively less from anaerobic conditions than ryegrass. If this means that the competitive ability of these species on poorly drained soils is less severely reduced than that of ryegrass, they may have greater value for wet-land pastures.

So far distinction has been made between wet, intermediate and freely drained sites. The indigenous vegetation associated with these sites is summarised in Figure 4. As the diagram shows, indigenous *Agrostis-Festuca* pastures predominate on the freely drained soils, while wet-land species predominate on poorly drained soils. *Agrostis* spp. and *Festuca* spp. are found over the full range of environments encompassed by the diagram, but on the wettest soils are completely dominated by one or more wet-land species, of which the following are the most important: *Carex nigra*, *C. panicea*, *Juncus communis* sl, *J. acutiflorus*, *Molinia coerulea*, *Deschampsia cespitosa* and *Holcus lanatus*. Of these species *C. panicea*, *D. cespitosa* and *H. lanatus* have

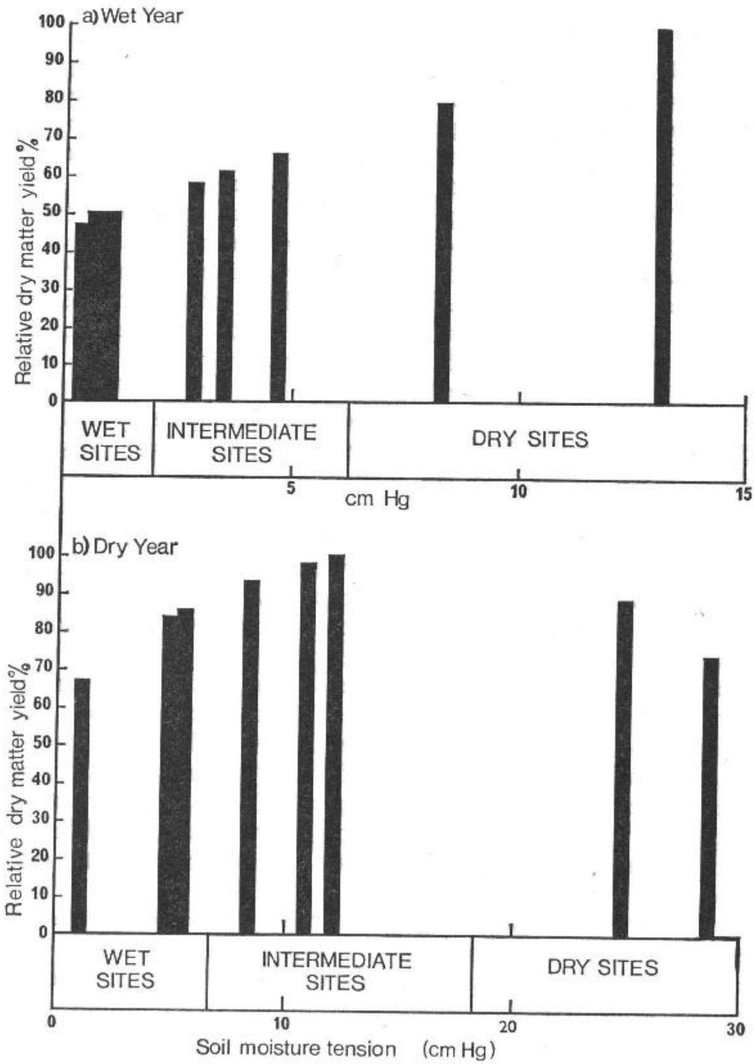


FIG. 2.—The relative annual dry matter yield of Perennial Ryegrass (*Lolium perenne*) at eight sites of differing mean moisture tension in (*a*) a wet year, and (*b*) a dry year.

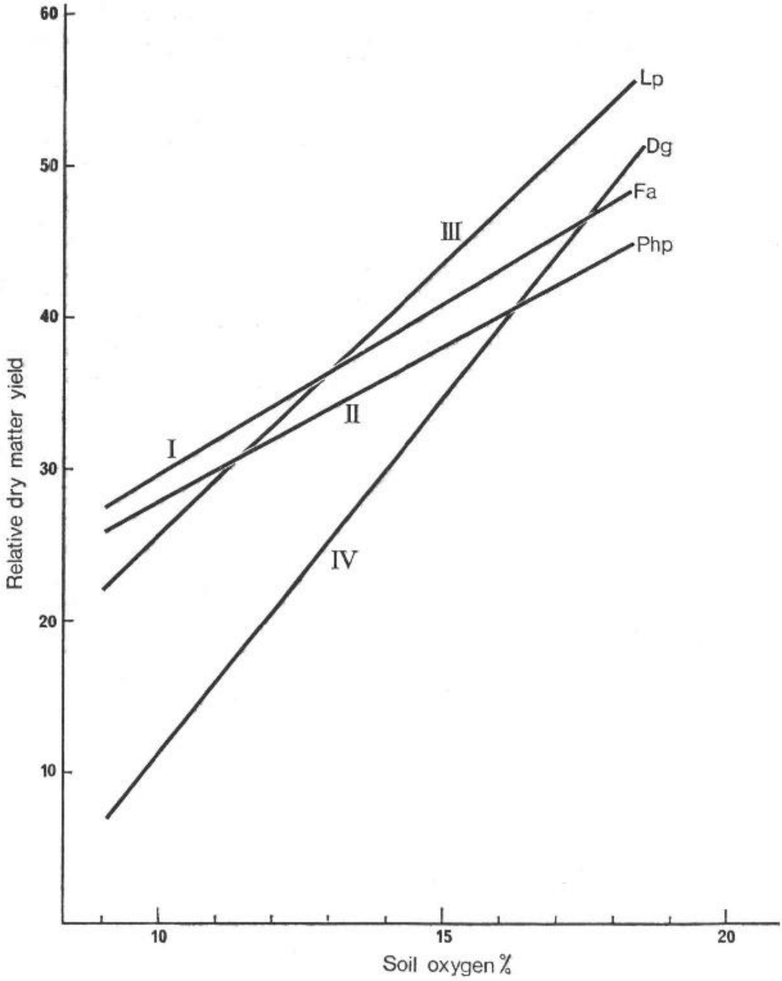


FIG. 3.—The response of four grass species to soil oxygen percentage in a wet season during which soil moisture deficits were not limiting growth. I Tall Fescue (*Festuca arundinacea*) (Fa). II Timothy (*Phleum pratense*) (Php). III Perennial Ryegrass (*Lolium perenne*) (Lp). and IV Cocksfoot (*Dactylis glomerata*) (Dg).

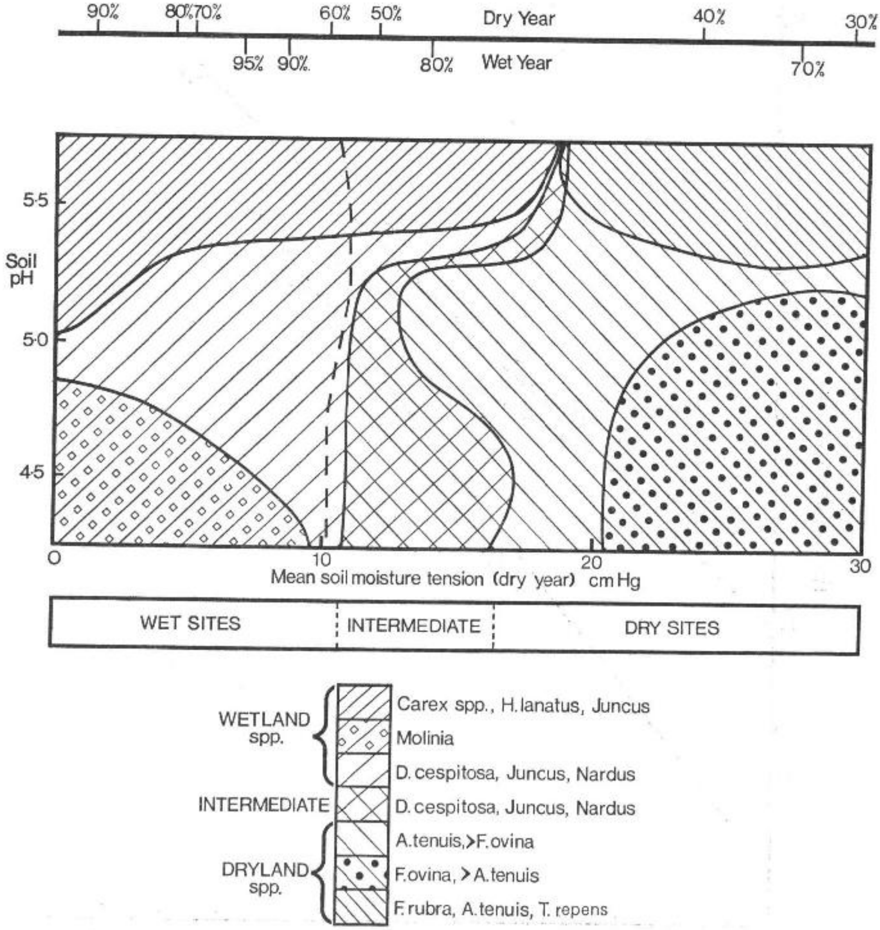


FIG. 4.—The distribution of indigenous vegetation types in relation to soil acidity and soil moisture tension. The broken line represents the moisture tension below which *Juncus* spp. might be expected to invade improved pastures. The scale at the top shows the percentage of time in two growing seasons, one wet and one dry, during which the soil remained wetter than field capacity.

wider ranges and extend onto the less poorly drained soils where *Agrostis* spp and *Festuca* spp. are more plentiful, giving rise to a type of wet *Agrostis-Festuca* pasture intermediate between the extremes of the wettest and driest sites. *Nardus stricta* may sometimes be abundant, but since its distribution is largely determined by biotic factors it has little value as an indicator of waterlogged conditions. These three classes of pasture correspond fairly well to the three groups of sites distinguished in Figure 2 and whose range in terms of the moisture axis is shown in Figure 4. The intermediate group of sites is associated mainly with the intermediate class of wet *Agrostis-Festuca* pastures but do extend marginally into the wet-land pasture type (Rogers and King, 1972).

The technical and economic feasibility of drainage to improve pasture production and utilisation on these soils has not been investigated experimentally. Experience indicates, however, that no more than partial drainage will be possible and it is therefore necessary to consider what degree of waterlogging is acceptable and whether or not at least some of the sites are usable without drainage.

Assuming that pasture improvement is carried out, the intermediate sites in Figure 2 and 4 might be acceptable without further drainage especially if species tolerant of anaerobic conditions could be introduced. Of the species found in the indigenous vegetation *Festuca rubra*, and to a lesser extent white clover, stand out as being relatively tolerant of anaerobic conditions. Both species, but especially *F. rubra*, are found in relative abundance on poorly drained gley soils above pH 5·5 (Rogers and King, 1972), and should be able to form a major part of improved pastures on these sites of intermediate drainage. Reduced yields would have to be accepted relative to those on freely drained soils. For example, in terms of the data for some lowland species the loss would be negligible in dry years rising to a mean of between 20 and 30 per cent in wet years. The maximum loss on the wettest of the intermediate sites would be rather more than this at 30 to 40 per cent. Whether or not this loss of yield and vigour in wet seasons represents a handicap sufficient to prevent the introduced species maintaining its dominance on the sward against competition from *Carex*, *Deschampsia*, *Holcus* and *Juncus* species is not known. Such data together with information on the associated effects on pasture production will be obtained only from experiments with grazed grass-and-legume swards.

However, there must be a point on the scale of soil wetness below which the price, in terms of reduced yields and susceptibility to invasion by weed species, becomes too high. It may be that the point already suggested, corresponding to the lower limit of the group of intermediate sites in Figure 4 will be appropriate. The limit will vary depending on the tolerance of the sown species used. It will also be affected by which wet-land species are most likely to invade and on whether such invasion can be controlled by other means. Taking these qualifications into account it should be possible to set lower limits below which it would be undesirable to use sites for improved pasture. These limits may be recognised in the field either on the basis of vegetation using the appropriate wet-land species as indicators or on the basis of soil profile characteristics. Furthermore, it follows that if drainage is to be counted a success it should achieve at least this minimum standard and, if this is not possible, it may be wiser not to attempt it. The quantitative data on which such decisions ideally should be based is not available, but it is suggested that the approach outlined in this paper might form a reasonable framework for decisions on the best use of poorly drained sites in more intensive management systems.

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# HILL FARMING RESEARCH ORGANISATION

**Bush Estate, Penicuik, Midlothian EH26 0PY**
**Telephone: 031-445 3401**
(Founded 1954)

Director: J M M CUNNINGHAM BSc(Agric) PhD FRSE FIBiol

*Senior Scientific Staff:*

ANIMAL PRODUCTION AND NUTRITION
J EADIE BSc (Agric)

PLANTS AND SOILS
P NEWBOULD BSc BAgr DPhil

Secretary: D WARNE FCIS MBIM

The Hill Farming Research Organisation was established in 1954 as an independent state-aided institute with a Board of Management appointed by the Secretary of State for Scotland after consultation with the Minister of Agriculture and Fisheries and the Agricultural Research Council. It now has a scientific staff of seventy.

In the past the Organisation has been primarily concerned with sheep production from rough grazings but interest has been extended to include beef cattle and 'upland' sheep. Another feature is that the research programme includes systems development on the research stations, associated with econometric studies.

The four farms available to the Organisation—Glensaugh, Laurencekirk, Kincardineshire (2,430 acres); Lephinmore, Strathlachlan, Argyll (2,800 acres); Sourhope, Yetholm, Roxburghshire (2,765 acres) almost on the Border; and House o' Muir, Bush, Midlothian (600 acres)—offer a range of different soils and climates and provide the variety of experimental conditions essential for the Organisation's purpose. These are used for investigation of basic rather than local problems since knowledge is sought which is applicable to hill farming throughout Great Britain.

New laboratories and administrative accommodation were opened in 1973 and most of the scientific staff are centred at the new headquarters but are responsible for planning, visiting and supervising experiments on all the farms. Some of the research work is undertaken in collaboration with more specialised institutes interested in soils, plant and animal breeding and nutrition, and animal diseases.

The research programme is divided between two Departments—Animal Production and Nutrition, and Plants and Soils.

The Animal Production and Nutrition Department is concerned with nutritional studies on the various components of performance (fertility, lactation, lamb growth and pregnancy) in both sheep and cattle. The work of the department also includes studies on the nutritive value of hill plant material, diet supplementation and diet selection in hill sheep and cattle. The studies of systems development are also included in this department's programme.

The Plants and Soils Department aim is to improve pasture production on the hills and uplands in studying mineralisation of plant nutrients from soil, germination and establishment of seeds in hill soils, plant nutrition, nitrogen fixation by white clover, pasture formation by grazing control and/or use of herbicides, the growth of heather and its nutritional value to livestock in a joint programme, the effect of utilisation of pasture on its regrowth and nutrient cycling through plant-animal systems.