The Hill Farming Research Organisation

Biennial report

1979–81

The Hill Farming Research Organisation

Biennial Report 1979-81

edited by R. G. Gunn

Bush Estate

Penicuik, Midlothian.

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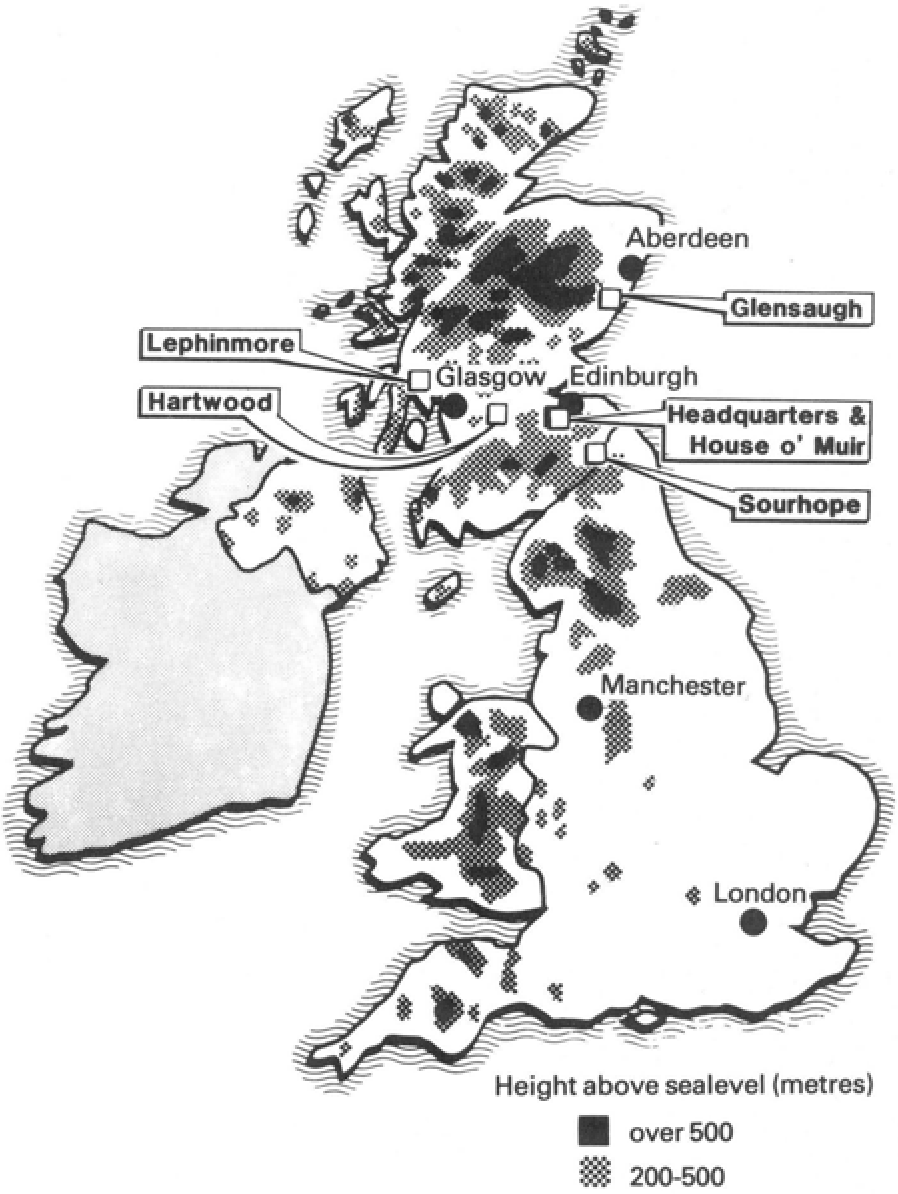
Location of HFRO research stations



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1st April 1978 - 31st March 1981

Mr R. David Ker — *Chairman*
Mr C. H. Armstrong
Professor D. G. Armstrong, MSc, PhD, DSc, FRIC, FIBiol, FRSE
Mr A. Evans
Mr J. W. Grant, BSc(Agr), NDD
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Professor J. H. D. Prescott, BSc(Agr), PhD
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as at 1st April 1982

Mr J. A. Parry, MA, VetMB, MRCVS — *Chairman*
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Professor J. H. D. Prescott, BSc(Agr), PhD
Mr G. Wilson, JP, NDA
Mr R. W. Weir

STAFF

1st April 1979 - 1st March 1982

Director

J. M. M. Cunningham, CBE, BSc(Agr), PhD, FIBiol, FRSE *(Resigned 26.9.80)*

J. Eadie, BSc(Agr) *(from 24.10.80)*

Animal Production Department

Head of Department T. J. Maxwell, BSc, PhD

R. D. M. Agnew, HNC, LIBiol
M. Begg *(resigned 30.9.81)*
A. M. Bryce
Miss E. V. Deans
J. M. Doney, BSc, PhD
A. R. Fawcett, AIMLS
R. G. Gunn, BSc(Agr), PhD
M. Hisbent, ONC *(resigned 26.6.79)*
I. D. Leslie, ONC
A. J. Macdonald, NDA
J. N. Peart, BSc(Agr), MSc *(retired 26.9.80)*
S. M. Rhind, BSc, PhD
J. Riva *(resigned 1.6.79)*
J. A. Rogers, BSc, PhD
Mrs C. Scott *(resigned 12.9.80)*
A. R. Sibbald, HNC
D. A. Sim, ONC
A. D. M. Smith, SDA, NDA
W. F. Smith, AIST
A. P. Thompson, BSc (Agr Biochem) *(resigned 14.6.80)*
A. Whitelaw, BSc, FRCVS

Beef Production Section

Leader A. J. F. Russel, BSc, MAgricSc, PhD
I. R. White, HNC
I. A. Wright, BSc, PhD

Visiting Workers

P. Alberti, Instituto Nacional de Investigaciones Agrarias, Zaragoza, Spain: June-August 1979

D. Zygoyiannis, University of Thessalonica, Greece: October 1979-October 1980

Animal Nutrition Department

Head of Department J. A. Milne, BA, BSc(Agr), PhD

Miss P. Colgrove, HND
Mrs H. A. Fisher, HNC
C. S. Lamb, BSc(Agr)
R. W. Mayes, BSc, MSc, PhD
Mrs A. M. Spence, BA
S. Wilson, BSc(Agr), MS

Post-graduate Student

Miss M. Lippert, BSc

Visiting Worker

H. Dove, BSc, PhD, Dip Ed, Division of Plant Industry, CSIRO, Canberra, Australia: December 1981-November 1982

Grazing Ecology Department

Head of Department J. Hodgson, BSc(Agr), PhD

Richard H. Armstrong, BSc(Agr)
G. T. Barthram, BSc
M. M. Beattie, HNC
T. G. Common, HNC
Miss S. A. Grant, BSc, MSc
W. G. Souter, ONC
Miss L. Torvell, BSc

Post-graduate Students

J. Arosteguy, IngAgron, MSc
J. S. Bircham, MAgrSc, PhD
T. D. A. Forbes, BA, MSc, PhD

Visiting Workers

F. S. Garcia, Instituto Nacional de Investigaciones Agrarias, La Coruna, Spain: July-September 1979

D. Havranek, Faculty of Agricultural Science, Zagreb University, Yugoslavia: August-September 1980

Snra E. Mateo, Instituto Nacional de Investigaciones Agrarias, La Coruna, Spain: September-October 1979

Miss B. P. Mosienyane, Department of Agricultural Research, Botswana: November 1979

J. J. Yates, PhD, University of Tasmania, Australia: June-November 1979

Plants and Soils Department

Head of Department P. Newbould, BSc, BAgr, DPhil

G. J. Baillie, ONC
R. J. Begbie, ONC *(resigned 29.8.80)*
G. R. Bolton, BSc(Agr)
A. R. M. Chambers, BSc *(resigned 30.4.80)*
R. A. Curtis, BSc
G. E. Davies, BSc *(retired 30.6.81)*
Miss V. E. Doughty
C. C. Evans, HNC
M. J. S. Floate, BSc, PhD, ARIC
A. Haystead, BSc, PhD
A. D. Ironside, ONC
J. King, BSc(Agr), PhD
W. I. C. Lamb, HNC, MIBiol *(resigned 15.2.80)*
Mrs J. M. Leask
Miss K. Logan, BSc, GRSC
Mrs C. Marriott, BSc
Miss A. Rangeley, BSc, PhD
Mrs E. M. Sim
D. E. Suckling, HNC, MIBiol

Post-graduate Students

J. R. Jebb, BSc
Miss R. M. Paynter, BA
Mrs L. J. Sheppard, BSc, PhD

Analytical Services Group

Leader E. Skedd, HNC

D. R. Campbell, SDA, NDA, BA
Mrs S. Campbell
Miss P. E. Moberly, BSc
J. Mackenzie, HNC
M. D. K. McTeir
I. Moody *(resigned 30.9.81)*
R. E. Sellar, ONC
Miss H. Stuart, ONC
Mrs C. Thompson
Miss E. Tierney, ONC

Graphics Officer

I. Pitkethly, HND

Information Officer/Librarian

Mrs M. C. Pitkethly, BSc, MSc, MIInfSc *(resigned 30.10.81)*

Administration

Secretary H. C. M. McLeod

Assistant Secretary Mrs M. J. Williamson

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Miss J. A. Brown
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Mrs M. J. G. Purves
Mrs E. B. H. Reid
Miss L. A. Smith
H. Thompson
Mrs H. Tulloch
F. Ward, MInstP&S
Mrs J. Walter

Glensaugh Research Station

Officer-in-Charge W. J. Hamilton, BA, NDA, NDD, MIBiol
A. J. Senior, SDA

Hartwood Research Station

Officer-in-Charge A. L. Fairlie, BSc(Agr)
R. A. Hetherington, BSc(Agr)
C. D. Kerr, NDA
Mrs S. Denham

House o' Muir Research Station and Animal House, Bush

Officer-in-Charge N. W. Mortimer

Sourhope Research Station

Officer-in-Charge R. H. Armstrong, BSc, MSc, PhD, ARIC
T. K. Whyte, HNC, SDA
Mrs J. O. Treasure

Lephinmore Research Station

Officer-in-Charge D. C. Currie, NDA, NDD
D. N. McFarlane, BSc(Agr)

ARC Unit of Statistics

G. J. Davies, BA
Mrs Janet M. Dickson, BSc
E. A. Hunter, BSc, MPhil
Miss H. K. Smith, BA, MSc
R. Thompson, BSc, MSc
Mrs Jean Wood, BSc

DIRECTOR'S REPORT

This is the first of a new series of Biennial Reports and covers the 2-year period to the end of 1981. It succeeds a series of Triennial Reports which were produced between 1958 and 1977. To mark the Organisation's Silver Jubilee in 1979, a special Silver Jubilee Report was published and readers are referred to that publication for an account of the development of the Hill Farming Research Organisation up to that time.

The new Biennial Report is designed to meet the requirements of the Department of Agriculture and Fisheries for Scotland, who commission the Organisation's entire research programme, and the recommendations of the Agricultural Research Council. The heart of the report comprises short summaries of the work carried out during the period of the report in each of the projects which together make up the research programme. The longer research reports provide for more extended summaries of work which has advanced to the point at which it justifies a more lengthy exposition. Two review articles summarise progress and current thinking in important aspects of the Organisation's work.

Board Chairmanship

The new Chairman of the reconstituted Board of Management, appointed by the Secretary of State for Scotland, is Mr John A. Parry, MA, VetMB, MRCVS.

Mr J. A. Parry

Mr Parry is Principal of Messrs J. A. Parry and Partners, Veterinary Surgeons, Watergate Mill, Brecon. He has been a member of the Board of Management since 1972. He is a past-President of the British Veterinary Association and is a Council member of the Royal College of Veterinary Surgeons. Mr Parry is a member of the Secretary of State for Wales Agricultural Advisory Panel and Chairman of the BBC's Welsh Agricultural Advisory Committee.

Mr Parry succeeds Mr R. David Ker, Craigdarroch, Sanquhar.

Mr R. David Ker

Mr Ker was Chairman of the Board of Management from 1972 until March 1981. The period of his Chairmanship was one of considerable development for the Organisation. He presided over the official Opening of the new Headquarters on the Bush Estate by the Duke of Edinburgh in 1973 and his period of office saw the Organisation's research activities widen to include work on upland sheep and beef production from suckler cows. Mr Ker was Chairman when the decision was made to acquire Hartwood Farm in Lanarkshire.

His experience and wise counsel were greatly valued by his colleagues on the Board. Mr Ker took a deep interest in fostering the Organisation's relationships with the farming industry, and the research stations Open Days were a particular source of pleasure to him. His warm personality and his interest in the staff and their welfare combined to foster a good and mutually beneficial relationship between the Board and the staff and contributed greatly to morale. In a busy life he was unstinting in giving of his time and energies in the service of the Organisation.

Mr Ker was awarded the George Hedley Memorial Award in 1980 and the award of the OBE in 1981 gave particular pleasure to his friends on the Board and staff. Mr David Ker takes with him the best wishes of everyone connected with the Organisation.

Change of Director

Professor J. M. M. Cunningham, CBE, Director of the Organisation since 1968, resigned in September 1980 to take up the appointment of Principal of the West of Scotland Agricultural College and Professor of Agriculture in the University of Glasgow.

Mr John Eadie, formerly Head of the Department of Animal Production and Nutrition, was appointed Director in October 1980. Dr Peter Newbould, Head of Plants and Soils Department, was appointed Deputy Director in May 1981.

Professor J. M. M. Cunningham

Professor Cunningham graduated from the University of Edinburgh in 1945. After appointments in the West of Scotland and the North of England he returned to Edinburgh University in 1950 as lecturer in Animal Husbandry. He became Senior Farms Manager of the Edinburgh School of Agriculture in 1962, a post he held until his appointment as Director of HFRO in 1968.

In 1962, Professor Cunningham was awarded the degree of PhD in the University of Edinburgh. In 1974, he was elected to the Fellowship of the Royal Society of Edinburgh and, in 1978, the Senate of the University of Edinburgh elected him an Honorary Professor.

Professor Cunningham led the Organisation over a period of considerable change and development. He was the driving force behind the construction of the Headquarter's laboratory and office buildings and he supervised the transfer from temporary accommodation in Edinburgh to these purpose-built premises on the Bush Estate in 1973.

Professor Cunningham was the inspiration behind the expansion of the Organisation's remit to include upland farming in addition to its earlier responsibility for research in hill sheep farming. During his Directorship, the work of the Organisation was extended to include research on upland sheep and pastures and on beef suckler cow production. These changes eventually led to the acquisition, in 1979, of

Hartwood Farm, Lanarkshire, which is currently being developed by the Organisation as a research station. Professor Cunningham's foresight led to the initiatives proposed in respect of red deer research in 1970, finding their practical expression in the establishment of the deer farm at Glensaugh.

In addition to his qualities as an able and energetic leader, which did much to establish and enhance the Organisation's reputation, Professor Cunningham was an untiring advocate of HFRO's work. He forged and strengthened its links with the farming industry and related interests and made important contributions to the debate on hill land use. He found time, in addition, to serve the industry in a variety of other ways including membership of the Farm Animal Welfare Council and of the Hill Farming Advisory Committee for Scotland. He served as President of the British Society of Animal Production and as President of Section M (Agriculture) of the British Association for the Advancement of Science in 1978/9. In recognition of his services to the sheep industry, Professor Cunningham received the George Hedley Memorial Award from the National Sheep Association in 1974. He was awarded the CBE in the Queen's Birthday Honours in 1979.

Professor Cunningham takes with him to his new post the sincere good wishes of the Board of Management and staff of the Organisation.

Obituaries

Lord Stratheden and Campbell

Lord Stratheden and Campbell, who was Chairman of the Board of Management of the Organisation from 1958 to 1969, died in December 1981 at the age of 82.

Lord Stratheden was a man of great experience and shrewd judgement. He presided with great dignity and courtesy over the Organisation during a period when it grew from very small beginnings. The combination of qualities he brought to the Chairmanship were of inestimable value to successive Directors and contributed greatly to the Organisation's development into a mature and effective body.

Dr R. F. Hunter

Dr Hunter, who was the first Head of the Botany Department (now Plants and Soils) and who served the Organisation in that capacity from 1955 until he resigned in 1965 to farm in Fife, died in August 1980.

Bob Hunter was responsible for developing studies in the ecology of hill vegetation and in hill land improvement. His own unique contribution was in descriptive ecology. He was particularly concerned to describe aspects of the hill pasture ecosystem, including the relationship between the sheep and the varied vegetation of their pasture. His work and his thinking were of critical importance to the Organisation's subsequent work and the successful developments of recent years owe much to Bob Hunter's earlier contributions.

Mr J. N. Peart

Mr Peart, who retired from the Organisation in September 1980, died in February 1982 at the age of 63. During the war he served in Europe and the Far East and attained the rank of Major.

Jack Peart joined the Organisation's staff at its inception, having previously worked as a technical officer at Sourhope. He was Officer-in-Charge at Sourhope until 1962 when he transferred to headquarter's staff in Edinburgh. Earlier in his career he had worked on supplementary feeding of the hill ewe and on the role of cattle on hill grazings but his major contribution was the substantial volume of work he carried out and published on lactation performance in the hill sheep.

Jack Peart remained an active researcher right up to the time of his retirement and in recent years he had extended his interest in lactation to the beef cow.

Research Farms

The acquisition of Hartwood Farm in Lanarkshire in late 1979 was of major importance for the Organisation. Hartwood is an upland farm of some 320 ha. The farm was acquired to enable the Organisation to develop its research work on upland sheep production, pasture utilisation and beef suckler cow production. This work was initially developed at Glensaugh but the research programmes had begun to suffer because of the constraints of inadequate land and animal resources.

Much has been done to date to bring the fixed equipment and land resources of Hartwood into a state appropriate to the Organisation's needs. Much remains to be done but the farm now carries around 175 beef cows and 600 crossbred ewes. Over 2000 lambs were finished in the autumn and winter of 1981/2.

The development of the research programme began in the summer of 1980 and the station now carries work on pasture production and utilisation, upland sheep production and beef cow and calf nutrition. Work has begun on aspects of lamb finishing on grass and forage crops. All of these programmes will be further developed in the years ahead.

Whilst the intention at Hartwood is to carry out research of national relevance and importance, particular attention will be paid to fostering a good and mutually beneficial relationship with the local farming community in Lanarkshire and surrounding districts.

As a condition of obtaining Hartwood, DAFS requires the Organisation to relinquish part of its existing landholdings. After a thorough examination of the available alternatives and their implications for the future effectiveness of the Organisation, and after much heartsearching, the Board of Management decided to close Lephinmore and to dispose of some assets at Glensaugh. Lephinmore will therefore cease to be operated by HFRO from November 1982. Adjustments are being made to the programmes of the remaining research farms to minimise the adverse effects of the closure on the Organisation's efforts in the hill sheep sector. The Organisation remains firmly committed to maintaining a viable and effective programme of research on hill sheep production.

Open Day

A very successful Open Day was held at Sourhope in June 1981, when some 650 visitors were welcomed. The programme for the day centred on a hill sheep development project. The visitors were given accounts of the researches on which the project is based and the project and its results were described. A number of related exhibits were mounted and opportunities provided for comment and debate.

Visitors

Many visitors are received by the Organisation each year. They include groups of farmers, to whom Sourhope has been a particular attraction in recent years, advisors, scientists and students.

Lord Porchester, Chairman of the Agricultural Research Council, visited the Organisation in October 1980. He was taken to Sourhope, where he was shown the station's research and development work.

Lord Mansfield, Minister of State for Agriculture at the Scottish Office, visited Glensaugh in September 1981. The research and development programme on hill sheep farming was described and the Minister was shown ongoing work on hill sheep and red deer.

Honours and Awards

Mr R. David Ker, Chairman of the Board of Management until March 1981, was awarded the OBE in the Queen's Birthday Honours in 1981.

Mr Ker also received the George Hedley Memorial Award in 1980 for his outstanding service to the sheep industry.

Mr L. M. Howells, a member of the Board of Management from 1972 until March 1981, was awarded the MBE in the New Year's Honours List of 1982.

Dr John Hodgson, Head of the Grazing Ecology Department, was awarded the Sir John Hammond Memorial Prize in 1981. This award is made by the British Society of Animal Production to someone in research, teaching, advisory, farming or affiliated professions who has made a significant contribution to the science and development of animal production.

Post-graduate Degrees

The following candidates were awarded the Degree of Doctor of Philosophy in the University of Edinburgh:

Miss A. Rangeley	(1980)
Mr J. S. Bircham	(1981)
Mrs L. J. Sheppard	(1981)
Mr I. A. Wright	(1982)
Mr T. D. A. Forbes	(1982)

STAFF VISITS ABROAD

Mr Richard H. Armstrong	3rd Meeting of the European Grazing Workshop, Institute for Animal Feeding and Nutrition, Lelystadt, Netherlands, April 1979.
Prof. J. M. M. Cunningham	FAO research network on sheep production, Athens, 1979. Consultancy visit on sheep production to Colombia, May 1980. Sponsored by the Ministry for Overseas Development.
Dr J. M. Doney	IXth International Congress on Animal Reproduction, Madrid, Spain, July 1980.
Mr J. Eadie	Consultancy visit to Instituto Nacional de Investigaciones Agrarias, La Coruna, Spain, October 1979. Sponsored by the World Bank.
Dr M. J. S. Floate	Organising Committee member and attended the International Workshop on Terrestrial Nitrogen Cycles, sponsored by SCOPE/UNEP, Sweden, September 1979. Research Fellowship with CSIRO Division of Animal Production, Armidale, New South Wales, Australia, Nov. 1978-May 1979.

Miss S. A. Grant	European Grassland Federation Meeting, Zagreb, Yugoslavia, June 1980. Workshop on Mixed Grazing, Galway, Ireland, September 1980.
Dr A. Haystead	Invited participant at Symposium on 'Energetics of Symbiotic Nitrogen Fixation', Michigan State University, Ann Arbor, USA, April 1980. Visiting scientist at CSIRO Division of Land Resources Management, Perth, Western Australia, August 1980 - October 1981. Symposium on 'Managing the Nitrogen Economies of Forest Ecosystems', Mandurah, Western Australia, October 1980. International Symposium on Nitrogen Fixation, Canberra, Australia, November 1980. International Atomic Energy Panel Meeting on Use of Nuclear Methods to Improve Pasture Management, Vienna, Austria, December 1980. Visits to CSIRO Division of Soils, Waite; Monash University, Melbourne; CSIRO Pastoral Research Laboratory, Armidale; CSIRO Division of Tropical Crops and Pastures, Brisbane; Ruakura Soil and Plant Research Station, Hamilton, New Zealand; New Zealand DSIR Soils Bureau, Palmerston; Invermay Agricultural Research Centre, New Zealand; September-October 1981.
Dr J. Hodgson	Visit to Instituto Nacional de Tecnologia Agropecuaria, Balcarce, Argentina; and Instituto de Investigaciones Agropecuarias, Santiago, Chile; September-October 1979. Consultancy visit sponsored by the British Council. 13th International Grassland Congress, Lexington, USA, June 1981. Invited to participate in International Symposium on Nutritional Limits to Animal Production from Pastures, Brisbane, Australia, August 1981. Visit to research centres in Australia, August-September 1981.
Dr R. W. Mayes	5th International Symposium on Ruminant Physiology, Clermont-Ferrand, France, September 1979.
Dr J. A. Milne	Study tour of New Zealand and Australia, January-March 1980. New Zealand Society of Animal Production Annual Meeting, Christchurch, February 1980.
Dr P. Newbould	Invited participant in International Workshop on Terrestrial Nitrogen Cycles, sponsored by SCOPE/UNEP, Sweden, September 1979. Invited participant in EEC seminar on Nitrogen Cycling in Grassland, Brussels, Belgium, December 1979. Invited participant in Nutrient Cycling Symposium, University of Georgia, USA, January 1980. Visit to Range Research Laboratory, Fort Collins, USA, September-October 1980. Sponsored by DAFS. Invited participant in EEC Seminar on Soil Degradation, Wageningen, Holland, October 1980.

Dr A. J. F. Russel	Consultancy visit to Agricultural Research Institute, Iceland, October-November 1979. Sponsored by the International Atomic Energy Authority. Invited participant at the World Congress on Sheep and Beef Cattle Breeding, New Zealand, October 1980. Visit to research centres in New Zealand, October-November 1980.
Mr S. Wilson	5th International Symposium on Ruminant Physiology, Clermont-Ferrand, France, September 1979.
Dr I. A. Wright	Visit to Institut National de la Recherche Agronomique, Clermont-Ferrand, France, October 1980. Sponsored by the Frank Elsley Memorial Trust.

STAFF SERVING ON COMMITTEES

International Committees

Dr A. Haystead	International Atomic Energy Panel on Use of Nuclear Methods to Improve Pasture Management. Appointed Research Agreement Holder.
Dr P. Newbould	Scientific Advisory Committee Member to Swedish Project 'Ecology of Arable Land — The Role of Organisms in Nitrogen Cycling'.

Committees in the UK

Dr Robin H. Armstrong	British Standards Institute Committee LEL/105 on electric fencing. Blackface Sheep Breeders Society — Council member. Hill Sheep Development Project — consultant.
Prof. J. M. M. Cunningham	Advisory Committee of the Rahoy Deer Farming Project for the Highlands and Islands Development Board. British Association for the Advancement of Science — President of Agriculture Section, 1978-1979. British Society of Animal Production — President, 1978-1979. DAFS Hill Farming Advisory Committee for Scotland. DAFS Deer Farming Working Group. Edinburgh Centre for Rural Economy — Board of Management. Farm Animal Welfare Council. Meat and Livestock Commission — Sheep Committee.
Mr J. Eadie	Advisory Committee of the Rahoy Deer Farming Project for the Highlands and Islands Development Board. DAFS Hill Farming Advisory Committee for Scotland. Edinburgh Centre for Rural Economy — Board of Management. Livestock Improvement Working Party for the Highlands and Islands Development Board.

Mr C. C. Evans	Scottish Agricultural Research Institutes Safety Officers — representative for HFRO.
Dr M. J. S. Floate	Royal Society Working Group on the Nitrogen Cycle. Catchment Studies Liaison Group.
Dr R. G. Gunn	Sheep Committee of the Consultative Organisation Animals Board — Technical Secretary (Disbanded 1979). British Society of Animal Production — Hon. Secretary for Occasional Publications.
Mr W. J. Hamilton	Advisory Committee of the Rahoy Deer Farming Project for the Highlands and Islands Development Board. British Deer Farmers' Association — committee member. British Deer Society — Scientific Panel member.
Dr J. Hodgson	Editorial Board of Animal Production (until 1979). Organising Committee for British Grassland Society Occasional Symposium No. 12, 'The effective use of forage and animal resources in the hills and uplands', Edinburgh, 1980. Organising Committee for British Grassland Society Occasional Symposium No. 13, 'Plant physiology and herbage production', Nottingham, 1981. Chairman of panel of editors of the Sward Measurement Handbook, a British Grassland Society publication, 1981. Member of panel of editors of the Herbage Intake Handbook, a British Grassland Society publication, due 1982.
Dr J. A. Milne	Scottish Group of Nutrition Society — Hon. Secretary and Treasurer. British Society of Animal Production — Executive Council member.
Dr J. A. Rogers	Botanical Society of Edinburgh — Council member and editor of Newsletter and Transactions. Botanical Society of British Isles — Recorder for West Sutherland.
Dr A. J. F. Russel	British Society of Animal Production — Hon. Treasurer (until 1980).
Mr A. R. Sibbald	Edinburgh Regional Computer Centre, Research Councils Users Committee — Secretary.

The following packages are currently the subject of contracts with DAFS.

Package 1. Performance of sheep in hill and upland environments

Objective: Understanding of the biological factors affecting sheep performance, including nutritional factors and their relationship to performance, with a view to determining means of improving performance.

Package 2. The synthesis of hill and upland farming systems

Objective: The development of systems of animal production, based on improved knowledge, to attain optimal use of available pasture and animal resources.

Package 3. Beef cattle in hill and upland environments

Objective: 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.

Package 4. Hill and upland pasture production

Objective: Improved production through understanding of plant nutrition and nutrient cycling in hill soils; effects of utilisation; pasture establishment.

Package 5. Husbandry of red deer

Objective: To explore the potential of the red deer as a domesticated animal and to investigate the utilisation of and effect on hill pasture.

Package 1. Performance of sheep in hill and upland environments

Project 01001 — Environmental and genetic factors affecting reproductive rate in hill and upland sheep

Pre-mating pasture intake and reproductive responses in Scottish Blackface and North Country Cheviot ewes in different body conditions

[RGG, JMD, WFS, DAS]

Earlier studies with Blackface and North Country Cheviot ewes have demonstrated that ovulation and lambing rates respond positively to a wide range of body condition but only respond to the level of pre-mating feeding at an intermediate level of condition (Gunn and Doney, 1975; Gunn, Doney and Smith, 1979; R. G. Gunn, unpublished). The importance of body condition in the control of reproductive performance is therefore undeniable and practical recommendations for the maximisation of lambing rate have stressed the need for adequate levels of condition at mating.

Recent studies have examined the application of research findings based on hand-feeding experiments in the context of grazing experiments. In hand-feeding experimentation, it appeared unimportant to the eventual reproductive response whether the required body condition was achieved early or late in the recovery period between weaning and mating (Gunn and Doney, 1973). In grazing experimentation, designed to examine the reproductive response of ewes in different levels of body condition to the provision of good nutrition in the form of adequate good quality pasture prior to mating, there were quite different responses according to the level of condition at the start of the period of good nutrition at 4 weeks before mating. Ewes in good condition more or less maintained their live weight and condition level over the 4 weeks, while ewes in intermediate and poor condition gained live weight and condition over the period, with the poor condition ewes gaining about twice as much as did the intermediate condition ewes. As a result, the differences between the ewes in the different condition classes at the start were reduced but not eliminated by mating time. The degree of reduction varied according to the quantity and quality of pasture available, the more and better the pasture, the greater the gain by the leaner ewes and the smaller the differences between them and the fatter ewes.

Since fat ewes failed to change in live weight and condition, irrespective of the pasture available, it may be assumed that they were eating less and therefore had a lower appetite drive than did ewes in intermediate and poor condition. Estimates of DM intake by North Country Cheviot ewes, based on faecal N, have demonstrated this to be the case. Ewes which were in good condition ($\geqslant$ grade 3) at 4 weeks before mating were eating only some 1.1 kg DM/day at mating, compared with 1.3 and 1.5 kg DM/day being eaten by ewes which had been in intermediate (grade 2.5/2.75) and poor ($\leqslant$ grade 2.25) condition, respectively, at 4 weeks before. On the basis of their live weight at the time of mating, intakes per kg live weight differed even more, being approximately 14, 17 and 22 g DM/kg/day for ewes originally in good, intermediate and poor condition.

Appetite and body condition are clearly related, even in circumstances of adequate high quality pasture, and their separate and combined effects on reproductive response are both important. In the North Country Cheviot breed, ovulation rate (2.21) of ewes initially in intermediate condition was as good as that (2.23) of ewes initially in good condition which were still heavier and fatter at mating, while lambing rate was even better (1.53 and 1.29, respectively). Lambing rate (1.33) of ewes initially in poor condition was as good as that of ewes initially in good condition although ovulation rate was less (1.87), which implies that wastage was higher in the fat ewes which were eating less.

These results confirm the importance of a dynamic nutritional effect in the pre-mating period, such as has been described previously in this breed, particularly in ewes in intermediate condition. The response in the Blackface breed, although in the same direction, was less obvious than in the North Country Cheviot breed, which also agrees with previous reports of the static nutritional effect of body condition being of greater importance in the Blackface.

The response to flushing in the pre-mating period may therefore be interpreted as being associated with the increase in voluntary intake, such as has been demonstrated by the North Country Cheviot ewes in poorer body condition. This interpretation may perhaps account for the old idea of reducing condition for a period prior to flushing. Provided it wasn't overdone, it may well have led to a stimulated appetite, an associated higher level of metabolic activity and a consequent better ovulation and lambing rate.

GUNN, R. G. and DONEY, J. M. 1973. A note on the influence of pattern of live-weight and body condition recovery between weaning and mating on food consumption and reproductive performance of Scottish Blackface ewes. *J. agric. Sci., Camb.* **81:** 189-191.

GUNN, R. G. and DONEY, J. M. 1975. The interaction of nutrition and body condition at mating on ovulation rate and early embryo mortality in Scottish Blackface ewes. *J. agric. Sci., Camb.* **85:** 465-470.

GUNN, R. G., DONEY, J. M. and SMITH, W. F. 1979. Fertility in Cheviot ewes. 2. The effect of level of pre-mating nutrition on ovulation rate and early embryo mortality in North and South Country Cheviot ewes in moderately-good condition at mating. *Anim. Prod.* **29:** 17-23.

The effect of live-weight and body condition recovery prior to mating on ovulation rate and early embryo mortality in Blackface and Cheviot ewes

[RGG, JMD, WFS, DAS]

As part of an on-going series of studies in this area, experiments were carried out to examine the rate of live-weight and body condition recovery prior to mating in relation to early embryo mortality. Previous studies have suggested that loss is likely to be high following high levels of pre-mating nutrition in ewes in initially poor body condition, whether or not their ovulation rate is increased. In one experiment, with Blackface ewes in poor condition (grades 1.5-1.75) at 8 weeks before mating, comparison of maintenance, $1\frac{1}{2} \times$ maintenance and $> 2 \times$ maintenance levels of nutrition during the last 3-4 weeks prior to mating, showed no effect on ovulation rate but a significant effect on ova wastage and potential lambing rate. The highest levels of pre-mating nutrition were associated with higher wastage and lower potential lambing rate.

In another experiment, with Blackface and Cheviot ewes in slightly better condition (grades 2.00-2.25), there was no difference within breeds in ovulatory or wastage response between $1\frac{1}{2} \times$ and $> 2 \times$ maintenance levels of nutrition during the last 4 weeks prior to mating. Indeed, the trend was, if anything, opposite to that shown by the first experiment, with the proportion of ewes returning to service increasing at lower levels of body condition. It may be that the experimental procedures required for the study on endocrine status (see below) caused stress and this is known to increase early embryonic wastage, particularly in leaner ewes.

The evidence on the effects of high levels of nutrition or high rates of live-weight and condition recovery on embryo mortality is clearly equivocal, although a similar result to that of the first experiment has been reported by Cumming, Blockey, Winfield, Parr and Williams (1975).

CUMMING, I. A., BLOCKEY, M. A. de B., WINFIELD, C. G., PARR, R. A. and WILLIAMS, A. H. 1975. A study of relationships of breed, time of mating, level of nutrition, live weight, body condition, and face cover to embryo survival in ewes. *J. agric. Sci., Camb.* **84:** 559-565.

Fertility in Greyface ewes

[RGG, TJM, JMD, WFS, RDMA, DAS]

Earlier work on the Greyface systems studies has demonstrated the importance of direction of live-weight change in the individual ewe at mating time in relation to lamb production (Gunn and Maxwell, 1978). Ewes which are gaining live weight produce more lambs than ewes which are maintaining live weight which in turn produce more lambs than ewes which are losing live weight.

Studies have continued in this area, mainly to determine the optimum live weight, condition and pattern of change for most efficient reproductive responses and to examine management methods of achieving these on pasture. Results have demonstrated considerable variation in response according to live weight and condition at weaning, stocking rate, herbage allowance and herbage accumulation during the recovery period. Work is continuing on alternative management strategies and the prediction and control of pasture requirements with a view to improved definition of decision rules for systems of upland sheep production.

GUNN, R. G. and MAXWELL, T. J. 1978. The effects of direction of live-weight change about mating on lamb production in Greyface ewes. *Anim. Prod.* **26:** 392 (Abstr.).

The effect of live-weight and body condition recovery prior to mating on endocrine status in early pregnancy in Scottish Blackface and Cheviot ewes

[SMR, JMD, RGG, WFS, DNMcF, DAS, DZ]

Most identifiable embryonic death in sheep occurs between days 14 and 30 of pregnancy. While a proportion of these deaths are undoubtedly due to genetic defects of the embryos, some may be attributable to an unsuitable uterine environment due to inadequate progesterone secretion. The incidence of embryonic death is affected by nutritional treatments before and after mating. The aim of this work was to determine the relationship, if any, between pre-mating nutrition and post-mating luteal activity and embryo survival during the first month of pregnancy in ewes of the two breeds Blackface and Cheviot.

Half of the ewes of each breed were fed to increase their body condition slowly over the 8 weeks prior to mating (H8) while the remainder were kept on a maintenance ration for 4 weeks and then fed *ad libitum* (M/AL), so that ewes of all groups were in a similar condition at mating. After mating, all ewes were fed a maintenance ration. Blood samples were collected on days 7, 11 to 30 and 46 and plasma progesterone and prolactin concentrations determined.

Preliminary results indicate that progesterone levels were similar in the two groups of Blackface ewes which were in turn similar to those of the M/AL group of Cheviots. Mean levels in ewes of the H8 group of Cheviots were, however, lower after taking the effect of ovulation rate into consideration. Prolactin results await statistical analysis.

Although ova wastage averaged only 11 and 12% in the two groups of Cheviot ewes, the results are interesting as they show that pre-mating nutrition can influence post-mating luteal activity. Thus, the results also demonstrate a possible mechanism by which nutrition could affect embryo survival.

The effects of body condition and stress on the endocrine status of ewes and on their associated ovulation and embryo survival rates

[SMR, JMD, RGG, WFS, ADMS, IDL, DAS]

The effects of body condition and of climatic or other stress on ovulation rate and lamb production have been well documented. These effects are probably mediated, at least in part, through changes in the pattern of endocrine events around the time of oestrus. The aim of this work was to investigate the effects of body condition (high and low) and stress on the patterns of secretion of follicle stimulating hormone (FSH), luteinising hormone (LH), oestrogen and prolactin at this time and on subsequent luteal activity, as measured by circulating progesterone levels, in early pregnancy in Blackface ewes.

At the time of mating, ewes in the 'high' group had a mean condition score of 2.8 compared with 1.8 for the 'low' group. They had been in these levels of condition for at least 4 weeks. For about 3 days before and 3 days after oestrus, half of the ewes of each group were subjected to stressful treatment which included harassment by dogs, soaking in a spray dipper and transportation in a cattle float.

There was no evidence of any treatment effect on plasma progesterone levels during early pregnancy, other than that which was attributable to the higher mean ovulation rate of the ewes in better condition.

Preliminary examination of prolactin levels around the time of oestrus, suggests that ewes in good condition had higher levels than did those in poor condition. However, there was no effect of stress on prolactin levels. There were large differences between animals, even within the same treatment group, on the pattern of prolactin production at this time.

Results of the FSH, LH and oestrogen analyses are not yet available.

Project 01002 — Early lamb growth in relation to ewe milk yield and intake of solid food

Factors affecting lactation yield and consequences on lamb growth

[JMD, JNP, WFS, ADMS, DAS]

The emphasis of this project is on the potential for growth of lambs, primarily during the suckling period but it also involves consideration of growth subsequent to weaning up to the finished product. Three phases of growth are considered and are distinguished by the lamb's main source of nutrient intake. In early lactation, milk forms the whole of the major dietary component (parturition to 6-8 weeks); in mid- and late lactation, the dependence on solid food is increasing and the availability of milk is declining (6-16 weeks) and, after weaning, the lamb depends completely on the intake of solid food. Earlier studies have established the wide range and shape of lamb growth curves which can be expected within the hill breeds and some selected crossbreeds associated with different management systems. A close relationship between these growth curves and the established ewe lactation curves has been shown. In this project, the factors affecting ewe milk yield and the effects of variation in milk supply on lamb growth have been studied separately and as interacting components in grazing systems.

Ewe lactation follows a characteristic 3-phase curve with an increasing phase reaching a peak or plateau, usually within 4 weeks, followed by a declining phase to the end of effective lactation, which may be reached as early as 8 or as late as 20 weeks after parturition. The shape of the lactation curve and the maximum daily production rate are influenced by a number of factors which have been studied in considerable detail in previous experiments. The importance of current levels of nutrition, especially during the early weeks, has been demonstrated but yields and pattern can also vary considerably with ewe genotype and with lamb demand. The effect of lamb demand may be expressed through the size and vigour of individuals but is more commonly seen in relation to the number of lambs suckled by a ewe and the genotype of the suckled lamb. Similarly, although there are considerable within-breed differences, the direct genetic effects on ewe lactation are most clearly seen in the differences between characteristic curves of what may be called the 'dairy' and 'mutton' breeds, the latter being characterised by a more sustained lactation pattern. Some studies on both these aspects have been reported previously and, in this report, further progress in studies designed to investigate the interaction of ewe potential and lamb demand will be discussed. Studies of the endocrine patterns associated with different lactation curves and differences in the partition of nutrients between milk and body-weight recovery have been initiated as a basis for the possible non-genetic manipulation of lactation patterns.

In the grazing situation, the lambs begin to consume significant quantities of herbage at about 3 weeks of age, the time depending on the milk supply in the early stages. From this stage, herbage consumption rapidly increases and the proportion of total nutrient intake derived from herbage depends on a number of factors such as the quantity and quality of available herbage, the level and change in potential milk availability and, probably, factors associated with the individual lamb such as achieved size and a relative demand for milk and/or herbage. Because of the complexities of the interactions between the variables affecting lamb growth, including progressive changes with time, different approaches may be needed to study different aspects of the question of lamb nutrition and growth during the lactation period. One such approach is the use of artificially-reared lambs offered a controlled pattern of milk intake and grazed on specifically defined pasture units. Two preliminary studies using this approach have been carried out.

Finally, although some lambs may reach slaughter weight and condition during the lactation period, the majority require further growth after weaning. Studies on the relationships between post-weaning and pre-weaning nutrition and growth have been initiated and are briefly considered in this report.

The interaction of ewe and lamb genotype affecting milk production and intake

[JMD, JNP, WFS, ADMS, DAS]

East Friesland × Scottish Blackface ewes (EFX), which are used as an example of the sustained lactation genotype, were mated to Suffolk rams while pure Blackface ewes (BF) of the same age and reared in the same environment were mated to BF rams after oestrus synchronisation. At parturition, further synchronised by administration of dexamethasone, all lambs were removed from their original dams and were cross-fostered to give eight experimental groups (two ewe breeds × two lamb breeds × single or twin suckling). In the early stages of lactation, to between weeks 5 and 7, the mean daily milk production was influenced both by ewe and lamb genotype. Within lamb breed type, the EFX ewes produced a greater yield of milk than did the BF ewes and, within ewe breed type, the crossbred lambs took more milk than did the pure BF lambs. The significance of ewe/lamb interaction was indicated by the fact that the demand of the crossbred lambs increased the yield of the BF ewes significantly as compared with the yield of BF ewes suckling BF lambs, whereas BF lambs suckled by EFX ewes did not utilise the full potential of those ewes as compared with the intake achieved by the crossbred lambs.

In later lactation, when the plateau phase was reached and when the lambs had grown, the effect of lamb genotype declined and maternal potential became the limiting factor of milk intake. As shown previously, the EFX ewes sustained a significantly higher level of milk intake by lambs in late lactation than did the pure BF ewes.

The consequences of the different lactation patterns on lamb growth were shown by the differences in mean 100-day live weight given in Table 1. The mean 100-day live weight was significantly affected by breed type of lamb, type of rearing as single or twin and breed of foster-dam.

Table 1

Mean lamb live weight at 100 days according to breed of lamb, breed of dam and type of rearing

	Single lambs			Twin lambs		
Breed of dam	EFX	BF	Mean	EFX	BF	Mean
Breed of lamb-Cross	43.6	41.0	42.3	38.0	36.3	37.2
BF	36.6	32.8	34.7	31.5	29.6	30.6
Mean	40.1	36.9	38.5	34.8	33.0	33.9

This approach confirmed the high milk yield and sustained lactation pattern of the EFX ewes, giving a high potential for growth to the lambs suckled by them. It also confirmed that demand by lambs, associated with their genotype, can have a significant effect on their dam's milk production and, hence, their own milk intake and growth rates. It appears that the effect of lamb demand on the establishment of lactation yield is confined to the early stage of lactation, a period in which previous studies have shown that level of milk production by ewes can show a significant response to variation in nutritional intake. The conclusion can be fairly drawn that, in order to achieve their growth potential throughout the whole of lactation, the management system must provide for an adequate nutrient intake by the ewes during early lactation. In later lactation, when milk yield is less responsive to high levels of nutrient intake, it has now been found that the higher demands imposed by well grown lambs cannot stimulate any further increases in milk production, nor can they prevent the natural decline which is largely determined by the genotype of the ewe. Poor ewe nutrition in this period, however, can reduce yield quickly and therefore depress lamb growth rate.

The use of artificially-reared lambs in the study of milk/herbage intake

[JMD, JNP, WFS, ADMS, DAS]

In 1979, a small trial was carried out to determine a suitable method for the individual rearing of lambs on milk substitute which would be suitable for a large-scale, field study. Following this, a field experiment was carried out to compare the grazing behaviour, herbage intake and growth of artificially-reared and naturally suckled lambs grazing on the same pasture. The results were used to identify problems in the management of experiments involving the grazing intake of young lambs and to give preliminary information on the relationship between milk and herbage and the effect of different patterns of intake on growth rate.

After a synchronised parturition, twin-born crossbred lambs (by Suffolk rams from East Friesland × Blackface (EFX) ewes) were removed from their dams and one lamb from each pair was fostered to an EFX ewe or a BF ewe. The other lamb from each pair was artificially reared on milk substitute using the pattern of milk intake determined from the measured yields of the EFX or the BF groups of ewes. Three weeks after birth, all four groups were transferred to a subdivided paddock of established ryegrass/clover pasture. Some problems in achieving and maintaining high levels of pre-determined intake of milk substitute were encountered in some lambs but, in general, the mean intake curves were similar to those of the suckled lambs. There were no differences in behaviour which would be sufficient to invalidate the use of artificially-reared lambs as experimental material for a study of the relationship between milk and grazing intake.

Milk intake of lambs suckled by EFX ewes and of the artificially-reared lambs offered similar levels followed the previously established pattern of a sustained lactation, whereas the lambs suckled by BF ewes and the corresponding artificially-reared lambs had the characteristic pattern of milk intake falling from a peak at around 4 weeks to a relatively low level at 12 weeks. Herbage intake showed a more rapid increase to a significantly higher level at 12 weeks in the lambs on the normal lactation pattern than in those on the sustained pattern of milk intake but, despite this compensatory difference, the combined nutrient intake from both milk and herbage was higher in the sustained lactation group. This higher intake, associated with sustained lactation, was reflected in greater live-weight gains to weaning at 85 days (33.4 kg and 29.2 kg, respectively, for lambs on the sustained or normal pattern of milk intake).

After weaning at 12 weeks of age, the lambs were used in a study of the effects of supplementation of herbage with a grain-based concentrate and of treatment with a commercial growth promoter. Herbage intake by all lambs increased rapidly after weaning and, by 3-4 weeks after weaning, nutrient intake had reached a level previously achieved by milk and herbage together. There was no direct effect of supplement on growth rate but the lambs treated with the growth promoter and offered a supplement established a higher mean intake and a more rapid growth rate than did the lambs on the other three treatments.

The approach to the investigation of relationships between milk supply, herbage intake and growth, using artificially-reared lambs, has been found to be a valid model of naturally suckled lambs at pasture. Some of the problems involved in this procedure have been identified. For example, a few lambs seem unable to adapt to the system and refuse to consume a reasonable ration of milk, which interferes with random allocations to treatments when high milk intakes are involved. Calculation of herbage intake from faecal output depends on certain assumptions on milk digestibility in a mixed diet. It is intended to test these assumptions in more detailed, pen-feeding, trials. Using the existing results at face value, however, the direct relationship between milk availability and growth rate has been shown to hold even under good grazing conditions and the increase in herbage intake does not fully compensate for a lower milk supply.

Endocrine studies of lactating ewes with normal or sustained lactation patterns

[JMD, WFS, SMR, ADMS, IDL, DAS]

The objective of these observations was to measure the patterns of change in several relevant hormones during the course of lactation in ewe breeds with contrasting lactation patterns and to investigate the relationship between hormones within breed type and the relationship between hormone status and milk production.

Insulin levels changed little during a 14-week lactation period but there were differences associated with ewe breed. The levels were consistently lower in the EFX ewes than in BF ewes rearing the same number of lambs. This inverse association between insulin level and milk production determined by ewe genotype or litter size is consistent with the anabolic role of insulin in the partition of nutrients which favours conversion to body tissue rather than milk.

There were no differences between breeds of ewe in growth hormone levels, which declined steadily during lactation. However, levels were generally higher in ewes suckling twin lambs than in those with singles at the beginning of lactation and they remained higher in mid-lactation. This result is consistent with a higher rate of tissue mobilisation and, consequently, with the increased availability of nutrients for milk production in ewes responding to the higher demands of twin lambs.

Project 01007 — Wool production from Blackface and crossbred ewes under improved management systems

Wool growth pattern, fleece structure and textile suitability of fleeces from Blackface and crossbred ewes reared under improved systems of hill management

[WFS, DAS]

This project, in collaboration with the Wool Industries Research Association (WIRA), Leeds, has been completed and the results will shortly be prepared for publication.

The objective was to determine seasonal wool growth patterns, fleece characteristics and total mean fleece weights of Border Leicester × Blackface (BLX), Texel × Blackface (TX) and Blackface (BF) ewes under similar semi-intensive rearing and production systems on two hefts at Glensaugh (Mid- and West Finella).

Included in this study was a full comparison of fleece structure, i.e. fibre types, distribution, dimensions and growth in specified periods (HFRO) and total fleece wool description (WIRA).

Whole fleece classification and textile testing have been completed on the crossbreds only and certain results are shown in Table 2.

Table 2

	BLX	TX
Mean fibre length (cm)	18.3	16.6
Mean fibre diameter (μ)	42.8	47.8
Medullation (%)	56.2	58.5
Average fleece weight (kg)	3.40	3.16

WIRA results show that the BLX produced a heavier fleece than the TX. The TX wool is clearly a coarser type. A point worth noting in the grading and valuation of the fleeces was the downgrading as "arable" (i.e. containing dusty soil) of a high proportion of the BLX fleeces. It is not known where these animals grazed or whether they were more inclined to frequent the dustier areas of the hill than did the TX.

Spinning and yarn testing created no problems. The TX wool tested for the first time produced a satisfactory tufting yarn.

HFRO data obtained from six separate sampling periods throughout a full year agree closely with the WIRA results. All sample periods were kept as near as possible to equalise growth periods — approximately 60 days for each. Growth patterns over the year were very similar, with peak production in the period July/November and lowest production in the period January/March. The high and low production figures appear in all fibre structure and characteristic descriptions.

The secondary:primary ratio (fine to coarse and kemp fibres) showed a low ratio in the period April/May, whereas all the other results for fibre diameter, length, density and medullation percentage showed the period January/March as the low production point. Differences were apparent between the two hefts, with results indicating that both crosses on West Finella were producing finer and denser fleeces than the crosses on Mid-Finella. The BF on the other hand, produced very similar fleeces on both hefts. Table 3 shows maximum and minimum figures for selected fleece components for all three breeds from the two hefts at sampling periods one and four, respectively (July/September and January/March).

Ewe live weights were recorded at each sampling period and showed throughout that Mid-Finella ewes were heavier than West Finella ewes.

Results from this study indicate that fleeces from the two crosses used in this management system, process well and produce a satisfactory yarn. Growth rates and fibre type differences associated with seasonal variations showed similar patterns to those previously described for BF sheep at Lephinmore (Doney and Smith, 1961). Overall, the BLX produced a slightly finer fleece than did the TX and with a small kemp percentage. The TX fleece was similar to a Cheviot type with a little more kemp present but was still more uniform than that of the BF.

DONEY, J. M. and SMITH, W. F. 1961. The fleece of the Scottish Blackface sheep. 1. Seasonal changes in wool production and fleece structure. *J. agric. Sci., Camb.* **56:** 365-374.

Table 3

		Border Leicester ×				Texel ×				Blackface			
		f		c		f		c		f		c	
		max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.
Mean fibre length (cm)	W.F.	3.4	2.2	5.5	3.4	3.3	2.1	5.2	3.0	3.5	2.2	6.0	3.6
	M.F.	3.5	2.3	5.7	3.5	3.1	2.1	5.3	3.1	3.2	2.1	6.0	3.5
Mean fibre diameter (μ)	W.F.	33	20	66	36	36	24	77	40	32	20	97	41
	M.F.	37	21	86	38	38	24	82	43	34	21	96	45
Medullation %	W.F.	47.5	4.5	99.0	39.5	60.0	6.0	100.0	55.0	65.5	5.5	100.0	89.0
	M.F.	60.0	4.0	100.0	52.0	75.0	6.0	100.0	54.5	58.0	6.0	100.0	76.5

f = fine, c = coarse, WF = West Finella, MF = Mid-Finella.

Project 02002 — Studies on the nutritional physiology of the pregnant ewe

The early work in this area was concerned with the determination of the energy requirements of pregnancy in hill and upland ewes and with the related and more important question of quantifying the effects on production of failure to meet these requirements in full. This led to the concept of an acceptable nutritional state in late pregnancy. This is a state in which the ewe is fed less than full requirements and consequently draws upon body reserves but in which, at the same time, the severity of under-nourishment is controlled and restricted to a level at which the production penalty of reduced lamb birth weight is small and unlikely to have any significant effects on lamb mortality or subsequent performance.

These studies entailed the development of quantitative relationships between concentrations of circulating metabolites (plasma free fatty acids and 3-hydroxybutyrate) and energy status, which have allowed the results of the earlier work to be applied in the various development studies on in-wintering and year-round grazing systems. In addition to providing a means of ensuring satisfactory lamb birth weights, this approach has been particularly useful as a means of objectively achieving a degree of consistency in late pregnancy nutrition, both between projects and from one year to another.

This approach is now used routinely in most development projects and in a number of experiments. Blood collected from a representative sample of ewes is analysed by automated techniques for plasma 3-hydroxybutyrate concentrations. The results go directly to a computer to which information on ewe weights, stage of pregnancy and expected lambing percentage is also supplied and which uses a model based on results of earlier work to calculate the adjustment in supplementary feeding required to achieve and maintain the prescribed nutritional state.

The development projects in which this approach is used offer a means of testing rigorously and on a large scale the results of earlier research. They also, however, serve the equally valuable and important function of providing detailed information which can be examined to determine which areas merit further research effort — research likely to result in some modification of the system or its decision rules and which will make it more robust or lead to further improvements in the efficiency of production.

The effect on sheep production of the interaction between nutrition during mid-pregnancy and other phases of the production cycle

[AJFR, IRW, DNMcF]

One area of research which was identified from the above earlier studies was that of nutrition during mid-pregnancy. Low birth weights of lambs from the gimmer age-group in one particular development flock had been considered to be due to poor nutrition in late pregnancy but subsequent experimentation showed that this was not the case and indicated nutrition during mid-pregnancy as a possible cause of the problem. Subsequent work demonstrated an interaction between level of nutrition during mid-pregnancy and the weight/size/condition of gimmers at mating. In gimmers which were poorly grown and not in good condition at mating, a level of mid-pregnancy nutrition which maintained net maternal body weight resulted in heavier lamb birth weights, compared with a nutritional regime which caused a 6 kg loss of net maternal weight. However, in gimmers which were well grown and in good condition at mating, the effect was reversed, the higher level of nutrition causing a reduction in birth weight. It was considered that this effect was unlikely to be unique to one particular age-group, although it could be argued that mature ewes are likely to be better buffered against the extremes of nutritional treatment.

By the time the implications of this finding were being considered, it was apparent from some of the development studies that the question of nutrition during mid-pregnancy required general re-appraisal. In these projects, substantial areas of the potentially better hill land had been improved and were not available to the ewe flock for winter grazing. At the same time, ewe numbers had been substantially increased, with the result that, during the winter, more ewes were being carried on a smaller and, in terms of herbage quality, poorer area. The effect of this, not unexpectedly, was to increase the extent of the losses in weight and condition over the period between the end of mating and the beginning of late pregnancy feeding. Although there was no evidence of any production penalty from these more severe winter regimes, it was considered prudent, particularly in the light of the results of the work on gimmers, to examine this area in greater detail in the flock situation.

An experiment was set up with 360 Scottish Blackface ewes of the Low End flock at Lephinmore. Half the ewes were managed according to the traditional system, being maintained on unimproved hill grazings throughout the year, while the other half were managed on a two-pasture system, grazing improved pasture during lactation and again before and during mating. This provided two contrasting levels of what, for convenience, was termed "summer" nutrition. During mid-pregnancy, i.e. from early January to early March, the flock was divided into three "winter" nutritional treatment groups. Distinctly different patterns of live-weight change were imposed on these groups by varying inputs of supplementary concentrates. The experiment continued in this form for 4 years until autumn, 1980.

The results have not yet been fully analysed but at this stage it is clear that the major effect was due, as would be expected, to the contrasting "summer" nutritional treatments. Ewes on the higher level of summer nutrition (i.e. the integrated use of improved and indigenous grazings) had higher lambing and weaning percentages and produced lambs which were heavier at birth and weaning. This therefore led to substantially higher outputs of weaned lamb. The principal interest, however, was in the effects on production of the "winter" or mid-pregnancy nutritional treatments. Over the 4 years, differences in lamb birth weight between the extreme mid-pregnancy groupings averaged some 0.3 kg in favour of the high nutritional treatment. Ewes on this treatment also had an advantage of about 4% in number of lambs born. These differences in weight and number of lambs increased over the period from birth to weaning.

A second phase of this work was initiated in autumn, 1980. The design is similar to that of the first phase, with the middle level of winter treatment being dropped and a new early pregnancy treatment added. This latter is one in which some ewes on reseeded pasture before and during mating are allowed free access to both the reseeded and hill areas during the later part of the mating period and receive supplementary feeding at that time. In half of these ewes, this feeding is continued into mid-pregnancy and in the other half it is withdrawn. This aspect of the study is designed to restrict the relatively severe loss in weight which can occur on turning ewes out of the reseeds at a critical stage of the reproductive cycle. In the one full year of the second phase of this study there was no evidence of an effect on production of the early pregnancy treatment but effects of mid-pregnancy nutrition on lamb birth weight and lambing percentage, of similar magnitude to those observed in the first phase, were noted. Again, the high level of "summer" nutrition resulted in a substantial increase in output.

Further evidence of effects of mid-pregnancy nutrition on production comes from a recent study with another genotype. Greyface gimmers in very good body condition at mating (condition score 3.5) were subjected to three levels of supplementary feeding at pasture from approximately 50-110 days of gestation. There was no effect of treatment on lamb birth weight in this instance, probably because all animals lost weight between mating and the beginning of the treatment period. The highest level of feeding did, however, result in a significant reduction in lambing percentage of some 13%, which is considered to be due to increased foetal mortality.

The effect of diet quality on tissue mobilisation in pregnant ewes

[AJFR, IRW, DNMcF]

In many studies of the effect of nutrition during pregnancy, the effectiveness of different nutritional treatments is assessed in terms of ewe live-weight change. Little is known of the composition of such weight changes and such information as is available is apparently conflicting, e.g. early studies with ewes grazing unimproved hill pastures containing a substantial proportion of heather indicated that tissue loss in early and mid-pregnancy under these conditions contained a comparatively small proportion of fat. More recent studies with housed ewes fed poor quality hay have, however, indicated that tissue losses during mid-pregnancy were predominantly of fat. This poses the question as to whether the composition of tissue loss can be affected by dietary factors and, particularly, by the amount and/or quality of dietary protein.

Preliminary studies to examine this question were recently conducted at Lephinmore with pregnant ewes grazing predominantly heather vegetation. Two groups of ewes received equal quantities of isocaloric supplements, containing either 6.5 or 19.1% crude protein from about 30 days after mating until shortly before lambing. Ewes receiving the higher nitrogen supplement were markedly heavier, had higher plasma urea and 3-hydroxybutyrate concentrations and, on the basis of faecal chromic oxide analyses, appeared to eat more of the indigenous vegetation than did the ewes on the lower nitrogen supplement. A full interpretation of the results of this work awaits the completion of chemical analysis of body components and of statistical analysis of data on changes in endocrine status.

The shearing of housed pregnant ewes

[AJFR, IRW, TKW]

A further area of study recently initiated is that of the nutrition of shorn and unshorn housed pregnant ewes. Most published reports indicate that shearing of housed pregnant ewes appears to increase voluntary food intake and also lamb birth weight but there is a lack of information on effects on birth weight in situations where food intake is restricted. In an experiment at Sourhope, groups of shorn and unshorn housed pregnant ewes were offered and consumed identical amounts of food. Rectal temperatures, respiration rates and live weights of the shorn ewes were consistently lower than those of the unshorn ewes but plasma 3-hydroxybutyrate concentrations were very similar in both groups throughout the later stages of pregnancy, indicating that the shorn ewes were not under any greater nutritional stress than those in full fleece. There were no significant effects of shearing on the birth weights or subsequent performance of either single or twin lambs, suggesting that the increased birth weights reported in other studies were a result of increased food intakes. There were no indications from any of the measurements made of any adverse effects of shearing pregnant hill ewes at the time of housing.

Project 02005 — Studies on the supplementation of low-quality roughage diets for sheep

The low quality of indigenous hill herbages in winter is largely responsible for the need to feed a supplement to hill ewes in late- and (sometimes) in mid-pregnancy. For optimal economic use of supplements, it is important to be able to prescribe the composition and feeding level of a supplement for a given situation. Because of difficulties in estimating directly the amounts of supplement required, indirect estimates of energy deficit by measuring blood metabolite concentrations, in particular 3-hydroxybutyrate, have provided information on supplement requirements for hill sheep in late pregnancy. However, this technique is rather limited since it cannot be used for mid-pregnancy supplementation and also it gives no indication of the composition of the supplement required; furthermore, there is evidence that the supplement composition can itself influence 3-hydroxybutyrate concentrations independently of its ME content. In attempting to achieve the long term objectives of being able to characterise the ideal composition and feeding-level of the supplement in a particular situation, three lines of study are being pursued. Firstly, a study of the digestion of winter-quality hill roughages fed with and without supplements will, in terms of absorbed nutrients, assess the quality of the herbage and the influence of supplementation. Secondly, methods are being developed to enable the measurement of absorbed nutrients in grazing animals receiving supplements. Finally, field studies have been initiated on the effect of type of supplement fed during pregnancy on the nutrition, behaviour and performance of hill ewes; these studies should, with knowledge of the digestive and metabolic mechanisms involved, enable a better understanding of what supplements to feed to hill sheep in pregnancy.

Digestion of supplemented herbage diets

[RWM, CSL, PC]

Although hill sheep may ingest a variety of indigenous plant species, detailed digestion work has been confined to heather (*Calluna vulgaris*) and *Agrostis/festuca* (AF) herbage; not only do these types of roughage frequently exist together but they individually represent extremes in nutritive value of hill herbage. The low OM digestibility and voluntary intake of both herbages during winter leads to a low ME intake, thus suggesting a need for supplementation. However, preliminary work has suggested that the availability of the protein in heather may be very low, both in its degradability in the rumen (from low ruminal ammonia concentrations) and its poor digestion in the small intestine. The protein of AF appears to be much more available than heather protein. It is thus possible that the supply of absorbable amino acid in sheep grazing heather hills may be strictly limited. Also, ruminal fermentation rate may be limited by the supply of rumen-degradable N; despite low dietary available N, very little urea N is apparently recycled into the rumen when heather is fed. It is thus conceivable that a suitable supplement for a sheep grazing heather should contain both energy and rumen-degradable N.

It has been shown that feeding a supplement at a relatively low level (100g starch/day and 3g urea N/day) did not depress the voluntary intake of a heather (⅔)/AF (⅓) diet. A more detailed study of the effect of giving a similar supplement (120g starch/day and 3.5g urea N/day) to the same basal diet (500g DM/day) was performed using cannulated animals, which enabled ruminal volatile fatty acid (VFA) production rates and the digestion of OM and N in the forestomachs, small intestine and hind gut to be measured. Although the supplement increased digestible OM intake by 52%, the increases in the daily amounts of OM digested and VFA produced in the rumen were less than the potentially rumen-degradable OM supplied in the supplement. Supplementation caused a 39% increase in the amount of non-ammonia N absorbed from the small intestine and also considerably increased the amounts of both OM and N absorbed from the hind gut. These results, together with an observed decrease in rumen-degradability of herbage protein (derived from microbial protein estimates using ^{35}S), suggest that the supplement caused a shift in digestion of the herbage from the rumen to the hind gut. It is concluded that feeding a starch-based supplement containing rumen-degradable N to sheep receiving a mixed diet of heather and AF, can considerably increase the digestible nutrient supply. However, the dietary N is likely to be utilised less efficiently because of the considerable proportion which is digested in the hind gut.

Method development

[RWM, CSL, PC]

The application of results from indoor experiments, of the type described above, to outdoor conditions, depends upon the herbage offered being representative of the diet selected by a grazing animal. This is often difficult to achieve and thus an important objective is to gain the ability of measuring digestible nutrient intake outdoors. Any suitable technique must be capable of estimating nutrient supply from both grazed herbage and supplement, if given. As the rumen is the major site of energy absorption (as VFA), the initial approaches have been to obtain either direct or indirect estimates of ruminal VFA production rates.

Whilst conditions within the rumen might approximate to steady-state when only herbage is ingested, feeding a supplement could markedly upset such an equilibrium by differentially altering the production rates of individual acids throughout the day. This imposes problems in VFA production-rate estimation; not only is it likely that separate estimates of the different VFA production rates are required (to account for variable carbon conversion between acids) but also estimates of rates-of-change in pool size may be required for the determination of instantaneous production rates, using constant infusion of isotope under non-steady-state conditions. In consideration of these complications, an experiment was conducted indoors to establish if reasonable 24-hour production rates could be obtained under non-steady-state conditions. Concentrates were fed either once daily or continuously, together with continuously-fed dried grass, to four fistulated wethers. From separate ^{14}C infusions, 4-pool models were constructed in order to quantify carbon flows between ruminal acetate, propionate and CO_2 and blood CO_2 pools. In addition, two extra animals fed only dried grass (continuously) received $[1-^{14}C]$ propionate and $[2-^{14}C]$ propionate on separate occasions.

Results from the experiment suggested that instantaneous VFA production rates could be determined under non-steady-state conditions; the integrated 24-hour estimates were similar to those made under steady-state conditions. Also, if the rate-of-change functions were omitted from the instantaneous estimations, the resulting 24-hour estimate was identical to that obtained using the correct mathematical procedure. This suggests that for 24-hour rate estimates, non-steady-state measurements may be much easier to obtain than formerly believed. Although carbon flows, measured in steady-state conditions, between acetate and propionate and between acetate and ruminal CO_2 were small, there was considerable exchange between ruminal CO_2 and the [1−C] position of the propionate molecule. These results also suggested that a true measure of propionate production could be obtained from the use of [$2-{}^{14}C$] propionate; the use of [$1-{}^{14}C$] propionate required estimates of interchange with ruminal CO_2 for true propionate production rate to be determined.

Although outdoor estimation of VFA production rates is feasible, the need to take frequent discrete rumen liquor samples may present a practical problem. An alternative approach may be to obtain an indirect estimate of VFA production rate from a determination (using an isotopic method) of methane production rate. Not only is the response, in production rate, to feeding supplement likely to be less for methane than for VFA but the rumen gas pool is likely to be more homogeneous than rumen liquor, thus giving less variable estimates, within sheep, of specific radioactivity. A pilot experiment, conducted indoors, in which three fistulated wethers were given [${}^{14}C$] methane infusions under steady-state feeding conditions, has indicated that reasonable estimates of methane production rate can be obtained. Further work is in progress to obtain relationships between VFA and methane production rates in various dietary situations.

Supplements in mid-pregnancy

[ML, JAM, AJFR]

Of central importance in the development of the means of defining the ideal composition and feeding level of a supplement, is an understanding of the nature of the response to supplementation in grazing animals. Although the types of experiments described above may enable quantification of various digestible nutrients supplied by herbage and supplement, they give no indication of the behavioural implications on animal performance responses to supplementary feeding. There is thus a need to examine, under outdoor conditions, factors which possibly affect the nature of the production response. A series of studies has been initiated in which responses in ewe live-weight change and lamb birth weight to type of herbage supplement ingested in mid-pregnancy are being examined.

In experiments over 2 years on an area of 0.2 *Agrostis/Festuca*: 0.8 heather at a stocking rate of 2 ewes/ha, the supplementation of ewes in mid-pregnancy, which were then fed adequately in late-pregnancy, increased lamb birth weights by 10% and reduced ewe live-weight losses. The supplement was based on barley and urea and given at a level of 150-200g/day. A comparison was also made between the supplement fed once daily as a pellet and given as a feedblock. Although no differences in animal performance were observed between the forms of the supplement, variability in supplement intake between animals was greater with the feedblock. The high rank correlation coefficients between different occasions when intake of supplement by individual animals was measured suggest that a knowledge of the reasons for the variability in intake would lead to a reduction in this variability and these are currently being examined. The siting of the feedblock on either the heather or *Agrostis/Festuca* areas altered the grazing behaviour of the ewes so that they spent longer grazing those vegetation types on which the feedblock was placed. This resulted in changes in some of the nutritional parameters measured.

At present costs and prices, and based on assumptions about levels levels of mortality and growth rates of lambs from the birth weights achieved, the cost of feeding a supplement in mid-pregnancy would be balanced by the additional revenue from more lambs produced and at a higher selling weight under the conditions of the current experiments. To achieve the same levels of animal performance without feeding a supplement in mid-pregnancy in these experiments would, on the evidence from further treatments, require a halving of the stocking rate and a doubling of the proportion of *Agrostis/Festuca* on the hill area. The study of the nutritional and behavioural implications of the composition and form of the supplementation is being continued.

Project 02009 — Mineral nutrition and animal performance

Induced copper deficiency in lambs grazing improved hill pasture: Studies in prophylaxis

[AW, AJFR, CCE, ES, ARF, AJM, JM with GJD]

The clinical entity of hypocuprosis in suckling lambs, characterised by a severe hypocupraemia, lower liver copper values, poor fleece quality, osteoporosis, depressed red cell counts, packed cell volumes and haemoglobin values and accompanied by poor liveweight gains in comparison with copper replete animals, has been linked to elevated molybdenum and sulphur levels in the herbage of improved pastures as a consequence of liming and reseeding. This resulted in the formation of tetrathiomolybdate complexes in the rumen of affected lambs. The original studies utilised repeated injections of copper to maintain animals in copper sufficiency and subsequent work has had the objective of seeking a method of prophylaxis more suitable for application in the commercial field. These studies were carried out using the Alderhope flock at Sourhope.

In 1979, the work sought to evaluate three possible approaches. The first was based on the rationale that administration of copper to the dam at the time of parturition would elevate the copper concentration of the milk and thereby supply sufficient copper to the neonate lamb to meet its high requirement for copper at this time. Copper is necessary for the formation of copper dependent enzymes essential for fleece growth, bone formation and erythropoeisis. The second study sought to evaluate the substitution of a single dose of injectable copper, linked to a normal gathering time for hill sheep, in place of the repeated copper injections used in the original studies and to compare the single doses with the repeated injections in terms of protection against hypocupraemia and of maintaining live-weight gain. The two gathering times studied were at marking, when the lambs were approximately 5 weeks of age, and at clipping, when the lambs were approximately 10 weeks of age. The third study was to evaluate the oral administration of cupric oxide needles which are retained in the abomasal folds and which, by persisting there for approximately 70 days, supply a slow steady release of copper available to the animals' copper pools in the liver, tissues and circulating plasma. Needles were administered to ewes at the time of parturition and a single dose to lambs at marking time.

The administration of 90 mg copper methionate to ewes at the time of parturition resulted in two benefits. The ewes themselves did not exhibit the hypocupraemia encountered in control ewes and remained normocupraemic until 1 month before weaning. It must be noted, however, that there have been no observable clinical or body weight differences between treated and control ewes — hypocuprosis and poor performance have only been related to growing lambs. Milk copper values of treated ewes were significantly higher than those of control ewes and the effect on the lambs of the treated ewes was to delay the onset of hypocupraemia by 3 to 4 weeks compared with that in the control lambs. The effect, however, was transient and was related to the decline in milk copper level, which occurs as lactation progresses, and to the transition of the lamb from its monogastric state to that of a ruminant, which decreases the availability of copper to the lamb. In addition, the commencement of grazing by the lamb results in intakes of herbage molybdenum and sulphur leading to the formation of tetrathiomolybdates.

The study, involving single injections of copper given to lambs at two different times, compared lambs derived from ewes all given copper at marking time. The results were as follows:—

(a) Lambs given repeated injections of copper remained copper sufficient until weaning at approximately 16 weeks of age.

(b) Lambs given a single injection at marking time remained copper sufficient until about 4 weeks prior to weaning when they became hypocupraemic.

(c) Lambs given a single injection at clipping time were hypocupraemic between marking and clipping but thereafter remained copper sufficient until weaning.

(d) Lambs not given copper were hypocupraemic from marking until weaning.

In live-weight gains, lambs given an injection at marking (b) showed a similar response to those given repeated injections (a), were superior to those given copper at clipping (c) and markedly superior to those not given copper (d). However, the fact that lambs given copper at marking became hypocupraemic before weaning requires some reservation, in that such lambs would have a poor copper status and, if retained in the reseeds for a longer period, might have experienced a decreased live-weight gain.

The use of cupric oxide needles administered orally to ewes and lambs gave extremely satisfactory results. In ewes given cupric oxide needles at the time of parturition, the response in plasma copper concentrations was superior to that obtained with a single dose of injected copper methionate, in that the longevity of response extended to weaning when the ewes were still normocupraemic. In lambs given a single oral dose at marking, the responses in plasma copper concentrations were at least equal to those obtained with repeated injections of copper to lambs and were maintained till weaning when they were high in the normal range. The performance in live-weight gains was at least equal to that of the group given copper by repeated injections.

In 1980, the studies at Sourhope concentrated wholly on the use of copper needles as offering a simple and superior means of prophylaxis suitable for use in the commercial field.

Twin lambs from ewes given cupric oxide needles 10 days before the commencement of lambing were divided into two groups, balanced on weight and sex. One twin was given oral cupric oxide needles at marking whilst its sibling was untreated.

Twin lambs from undosed ewes were treated similarly. The lambs treated at marking by a single oral dose were maintained in normocupraemia until weaning. The lambs not themselves dosed became hypocupraemic, with those from undosed ewes becoming hypocupraemic more rapidly than those from dosed ewes.

The lambs given cupric oxide needles showed a live-weight gain advantage over the undosed lambs of 3.25 kg. The lambs from dosed ewes obtained copper from two sources; their liver copper reserves were boosted in the pre-partum period and they obtained additional copper from their dams' milk in the post-partum period. The response in the ewes dosed pre-partum contrasted with the response in ewes dosed at the time of parturition, in that they became hypocupraemic halfway through lactation. The reason for this is not yet clear but one postulation is that, in the lactating ewe, there is a hypertrophy of the abomasum and increased parietal cell activity which may relate to the difference in copper absorption encountered.

Additional studies of dosage rates and responses obtained in plasma copper and liver copper concentrations have confirmed that the needles remain in the abomasal folds for approximately 70 days, by which time they have disappeared, while dosage rates considerably in excess of those employed at Sourhope have not been attended by any evidence of toxicity. These studies have shown that a dosage rate of 1 g/10 kg live weight will sustain animals in normocupraemia with adequate liver copper reserves to protect them against copper deficiency for a period of about 6 months and with no attendant dangers of copper toxicity.

Project 02010 — Studies of the metabolism of the grazing ewe

Considerable effort has been expended in the past on observing the responses in animal production to different pastures and sward conditions and to the feeding of supplements. In many of these experiments, it has been difficult to explain the responses obtained or there has been conflict between the findings of similar experiments. One reason has been our imperfect understanding of the amounts of digested nutrients absorbed but, with our ability to measure the amounts of energy absorbed, mainly as volatile fatty acids (VFA) from the rumen and of amino acids from the digestive tract (See Project 02005), this is no longer such an important factor. The other main reason is that the ewe may use the fat and protein content of her tissues when the diet does not adequately meet the demand for nutrients. This use of tissues is impossible to estimate adequately by simply measuring live-weight change, particularly in later pregnancy and in lactation. The development of isotope techniques has enabled a better understanding of these processes to be achieved. This enables responses in animal production to variation in pasture conditions or to supplementary feeding to be more adequately explained. In pregnancy, two problems have been examined where studies of whole-body metabolism were required.

Glucose metabolism

[JAM, SW]

When supplementary feeding is given in late pregnancy, one of the aims is to increase the amount of propionic acid produced in the rumen, as propionic acid is considered to be the most important glucose precursor produced by the ewe. Glucose is the principal energy source for the foetus. Experiments were conducted to determine how the amount of glucose produced by the ewe is affected by the number of lambs the ewe is carrying and by stage of pregnancy and how the proportion of glucose derived from propionate changes with these factors. Ewes were fed a constant diet throughout pregnancy and it was found that glucose production rate increased as pregnancy progressed. It was also higher for ewes bearing twin lambs than for those bearing single lambs. However, the proportion of the glucose production rate derived from propionate remained constant (0.35) throughout pregnancy, with less than half of the propionate produced in the rumen apparently converted to glucose. This implies that the fat and protein tissues of the ewe were providing the remainder of the precursors of glucose. The results also suggest that increasing the propionate supply may not substantially increase glucose production rates in late pregnancy and that other forms of supplement may require examination. The levels of glucose production rate which are required to produce lambs with an adequate birth weight are currently being examined.

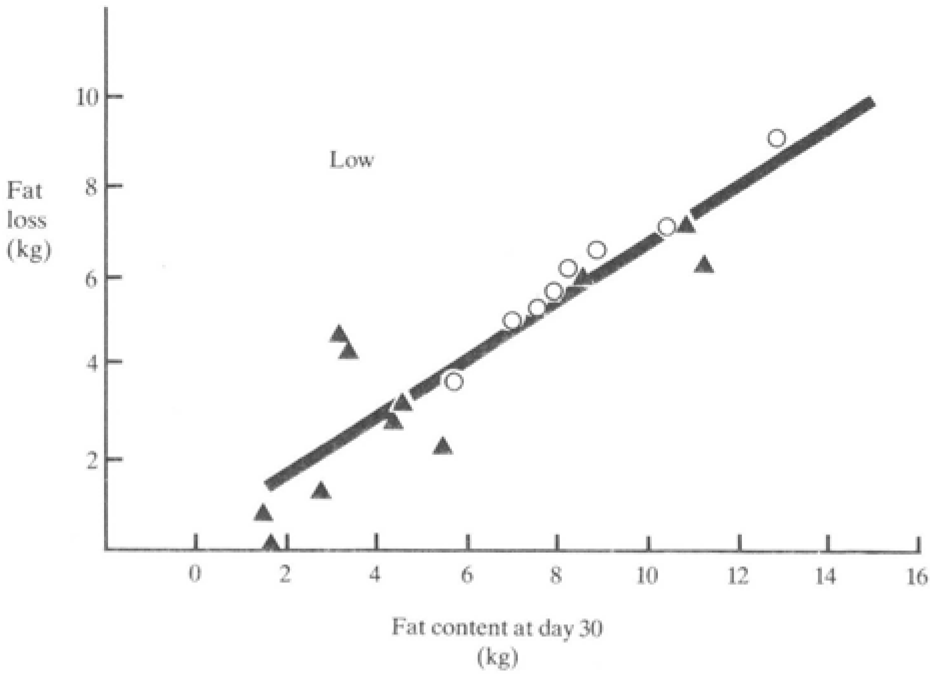
Factors affecting the rate of fat mobilisation by the pregnant ewe

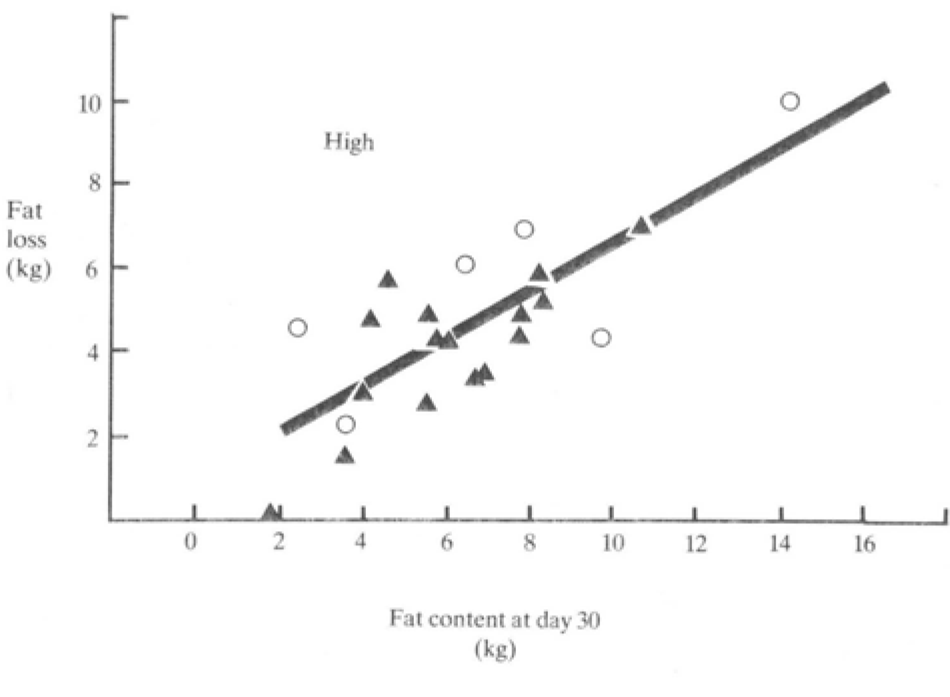
[JAM, AMS, HAF with HKS]

The hill ewe may lose as much as 20% of her live weight during the winter period and may catabolise more than half of the fat content of

Fig. 1

Estimated fat loss between days 30 and 100 for low and high levels of feeding





her tissues. The factors affecting the rate at which fat is catabolised in pregnancy are not well understood. One of these factors, the fat content of the ewe at mating, was examined in an experiment with single- and twin-bearing Scottish Blackface ewes. They had a wide range of fat content (15 to 55% of empty body weight) and were fed according to their live weight at two levels of feeding, to produce a moderate and a more severe level of undernourishment during pregnancy, similar to those experienced under field conditions. In mid-pregnancy, ewes with more fat at the beginning of the experiment had the greater losses of fat from their tissues at both levels of feeding (see Figure 1).

The differences in late pregnancy between ewes with different amounts of fat in their tissues were less marked, probably due to the smaller range of fat content and the proportionally greater errors involved in its measurement. A possible explanation for why fat ewes lost more fat than did thin ewes at the same level of feeding lies in the positive correlation between fat content and lean body mass found in this and several other experiments. This would mean that there could have been a higher metabolic rate in the fatter ewes and a greater need to utilise their fat tissues. There was no relationship between birth weight of the lambs and the fat content of the ewe at the start of the experiment. Consequently, a higher fat content at the start of pregnancy appeared to confer little advantage to the ewe during pregnancy. The principal advantage of achieving a high content of fat in the body by mating would be in terms of having a greater chance of conceiving more lambs. There may also be an advantage in having fat tissues to utilise during lactation and this is currently under examination.

Project 03003 — Improvement of utilisation of hill and upland swards by grazing cattle and sheep

The studies in this project depend upon close collaboration between members of the Animal Production and Nutrition Departments and the Plants and Soils Department. They involve comparative studies on cattle and sheep grazing on enclosed, improved, swards where there is great scope for management control and on indigenous hill plant communities where the scope for control is limited. Work has been concentrated at the level of understanding the influence of sward characteristics and grazing management upon diet selection and nutrient intake by grazing animals; the associated studies on herbage production and utilisation are reported under Package 4, Projects 04006 and 04010. The objective is to define management procedures appropriate to particular circumstances on the basis of an understanding of sward and animal responses to known or assumed management options.

Sown pastures

[JH, JAM, TDAF, JSB, JCA, WGS with GJD, RT]

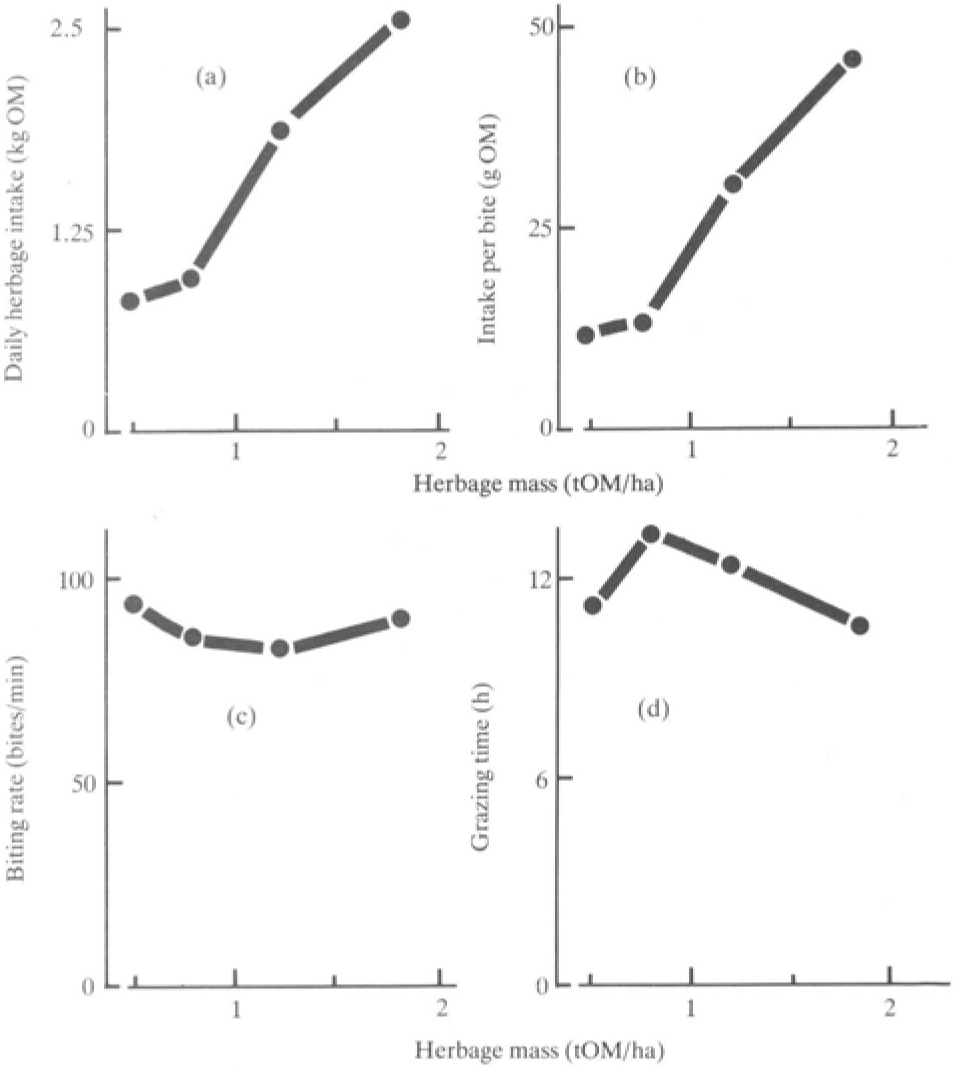
Studies have been concentrated on the association between herbage intake and ingestive behaviour (principally intake per bite, rate of biting during grazing and grazing time) and on their response to variations in sward characteristics, with particular reference to sward structure. Measurements have been made mainly on continuously-stocked swards. Because of the importance attached to measurements of ingestive behaviour, equipment for the automatic monitoring of biting activity has been developed and tested and a report of this work has now been published (Chambers, Hodgson and Milne, 1981). Complementary information on the influence of animal variables on the herbage intake of grazing suckler cows is reported under Package 3.

Ingestive behaviour and herbage intake

Observations on grazing sheep have confirmed that variations in intake per bite exert a dominant influence on daily herbage intake and are only partially offset by compensating variations in grazing time and, to a lesser extent, biting rate. Intake per bite declines progressively with declining herbage mass; grazing time at first tends to increase but then declines with further reduction in herbage mass below about 1000 kg DM/ha. The consequence is a substantial decline in daily herbage intake (Figure 2). Patterns of response appear to be similar in cattle and sheep but the depression in herbage intake at low levels of herbage mass is more serious in cattle. Biting rates in excess of 100 bites/min and grazing times in excess of 14h/day have been recorded for mature lactating ewes in these studies.

Fig. 2

The influence of variations in herbage mass (kg OM/ha) on (a) herbage intake (kg OM/day), (b) intake per bite (g OM), (c) biting rate (bites/min) and (d) grazing time (h) of lactating ewes grazing continuously stocked swards. From Bircham (1981)



Previous evidence indicated that intake per bite declines with declining sward height and declining herbage bulk density. Our results suggest that the response to variations in sward height may reflect the influence of the depth of the surface horizons of the sward containing mainly leaf material. Sheep are reluctant to graze into the lower horizons of vegetative swards containing sheath and dead leaf and, in detailed studies on grass swards, close correlations were observed between sward surface height, the depth of the leafy horizon and the depth of the grazed horizon (Barthram, 1981).

Diet selection

In common with the results of most other observations, our evidence indicated that animals selected a diet containing higher proportions of leaf and of live material than those in the sward as a whole. However, in contrast to the results from indigenous swards (see below), the difference could be attributed to the distribution of plant tissue within the sward canopy and did not necessarily reflect deliberate selection by the animal. Sheep selected a diet containing somewhat more live leaf than did cattle in similar circumstances.

In one detailed, short-term, study on a series of swards containing varying proportions of grass and clover, it was shown that apparent selection for the clover component by grazing sheep could also be explained largely by the fact that clover leaves were predominantly arranged close to the sward surface. Thus, differences between the clover content of the diet and of the sward largely disappeared when the comparison was based on the clover content of the surface horizons of the sward within which the sheep were observed to graze (Figure 3). This study has been extended to examine the influence of variations in clover content of the sward upon diet selection, herbage intake and growth rate in sheep over the grazing season.

The results of these studies demonstrate the influence of the structure of the sward canopy upon the ingestive behaviour and nutrient intake of grazing animals. Work is continuing to investigate the associative effects of variations in sward height, leafiness and herbage bulk density on herbage intake. It is, however, clear that high rates of intake are likely to be associated with swards with an erect growth habit and with a high bulk density in a relatively deep, leafy, surface horizon. Comparison with the results described under Package 4 will show that these are not necessarily the conditions likely to maximise herbage production. The accumulating evidence on plant and animal responses to variations in sward management now provides a firmer basis for determining the compromises necessary to meet the requirements of particular production systems.

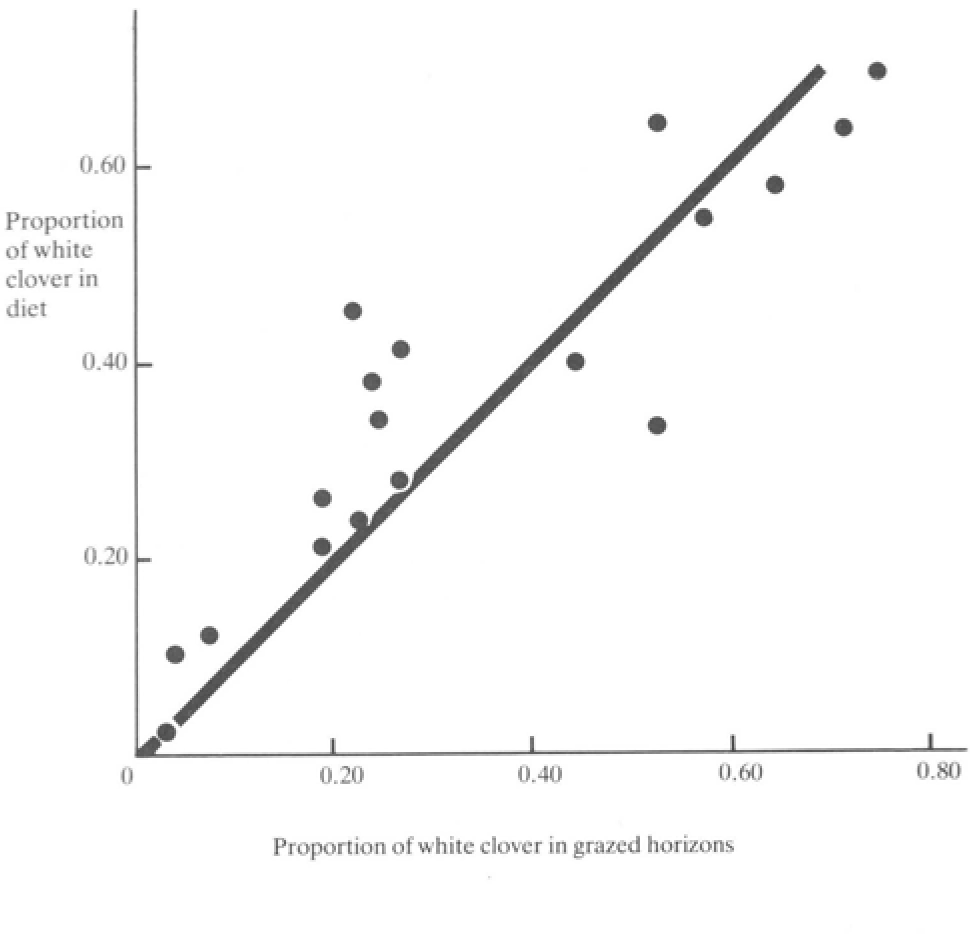
BARTHRAM, G. T. 1981. Sward structure and the depth of the grazed horizon. *Grass and Forage Sci.* **36:** 130-131.

BIRCHAM, J. S. 1981. Herbage growth and utilisation under continuous stocking management. *Ph.D. Thesis, Univ. Edinburgh.*

CHAMBERS, A. R. M., HODGSON, J. and MILNE, J. A. 1981. The development and use of equipment for the automatic recording of ingestive behaviour in sheep and cattle. *Grass and Forage Sci.* **36:** 97-105.

Fig. 3

The relationship between the proportions of clover (% by DM) in the diet of grazing sheep and in the grazed surface horizon of the sward



Indigenous hill plant communities

Ingestive behaviour, diet composition and nutrient intake in sheep and cattle grazing a series of plant communities at different seasons of the year

[JH, SAG, RchdHA, TDAF, MMB, TGC, RAH, GRB, LT, DES with RT]

The first phase of this project, designed to study diet selection and nutrient intake by cattle and sheep grazing a representative series of hill and upland plant communities at different seasons of the year, was set up in 1977 and completed in 1980. A succeeding phase, due to start shortly, will be concerned with the influence of controlled grazing upon the botanical composition of these communities, their herbage production and nutritive value and the nutrient intake from them. Information of this kind is needed in order to make objective decisions about efficient systems of hill pasture management. When the project started, the only available information related to *Agrostis*/*Festuca* pasture (Eadie, 1967; Nicholson, 1967) and *Calluna*-dominant heather moor (Grant, Barthram, Lamb and Milne, 1978; Milne, Bagley and Grant, 1979) grazed by sheep alone, although since that time some comparative information from mixed hill plant communities in France has been published (Groupe de Recherches INRA, 1979).

Measurements were made on relatively uniform areas of selected plant communities grazed by mature beef cows and hill ewes on three or four occasions during the year and, in each case, grazing pressures similar to those in traditional management systems were used. The communities chosen were:

1. *Agrostis*/*Festuca* grassland.
2. Dry grass heath dominated by *Nardus stricta*.
3. Wet grass heath dominated by *Molinia caerulea*.
4. Heather moor dominated by *Calluna vulgaris*.
5. *Calluna*/*Eriophorum*/*Trichophorum* blanket bog.
6. Sown pasture dominated by *Lolium perenne*.

The *Lolium* sward was included to act as a link with other work on sown swards at HFRO and elsewhere. Detailed observations were made on aspects of ingestive behaviour on the grass and grass heath communities and on the associations between sward structure and botanical composition, ingestive behaviour, diet selection and herbage intake.

There were many similarities in the selective grazing behaviour of the cattle and sheep, including selection for broad-leaved grasses like *Agrostis tenuis* and *Poa pratensis* and selection against such plants as *Nardus stricta* and *Calluna vulgaris*. However, the sheep showed a much greater selection than did cattle for low-growing components of the sward like herb species or, in the spring, the immature flowers of *Eriophorum*. Sheep diets contained very little grass flower head or stem, constituents which were common in cattle diets, reflecting the fact that, in the taller swards, cattle tended to graze the upper horizons of the sward whereas sheep grazed deeper within the sward canopy.

The state of the sward had an important influence on the extent to which the animals selected similar or contrasting diets. For example, when grazing the *Nardus*-dominant pasture, sheep and cattle selected similar diets when herbage mass on the intertussock vegetation was high, concentrating their grazing activity on the intertussock vegetation and avoiding *Nardus*. When herbage mass on the intertussock areas was low, the cattle ate substantial amounts of *Nardus* whereas the sheep continued to concentrate their activity on the intertussock vegetation. Overall, the results clearly showed that, as herbage mass declined, or as the contrasting components were more finely dispersed rather than aggregated, so cattle tended to become progressively less selective. Sheep, on the other hand, maintained their selection for live material, or preferred species, particularly in the autumn and winter. Despite the differences in botanical composition, the digestibility values of the diets selected by cattle and sheep were very similar, except on swards with a high proportion of senescent material when the digestibility of cattle diets fell sharply.

Sheep had lower bite rates than cattle, reflecting their more selective grazing habits, and spent more time grazing. There were no consistent differences between swards in ingestive behaviour. When the results from all observations were pooled, the main effect of a reduction in sward height was a reduction in intake per bite in both sheep and cattle. When intake per bite fell, sheep responded by increasing grazing time whereas cattle tended to increase rate of biting. The fact that sheep were more selective grazers than cattle meant that they showed greater variation in intake per bite and nutrient intake during the spring and summer but, on senescent swards in the autumn and winter, nutrient intake was depressed to a greater extent in cattle than in sheep. Variations in nutrient intake were much greater between seasons than between swards for both cattle and sheep, with intakes being highest in the summer and lowest in the winter.

In general terms, the evidence indicates that cattle and sheep may be complementary grazers to the extent that they concentrate attention on different horizons within the sward canopy but that, with the major exception of differences in selection for some of the lower-growing components of the sward, differences in the species composition of diets selected under common grazing management are relatively small. Preliminary accounts of some aspects of this project have been published (Grant and Hodgson, 1980; Hodgson and Grant, 1981; Armstrong, Forbes, Suckling, Grant and Hodgson, 1981).

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Indoor studies: *in vivo* and *in vitro* digestibility of the diet and voluntary herbage intake

[RchdHA, TGC, DRC with GJD, HKS]

Investigations into the digestibility of the diet and the amount of herbage consumed by grazing animals are heavily dependent upon estimates of the *in vivo* digestibility of samples of grazed herbage recovered as extrusa from cattle and sheep fistulated at the oesophagus. Consequently, it is necessary to understand the relationships between *in vivo* and *in vitro* digestibility of herbage harvested at different stages of maturity from different plant communities. In interpreting the results of grazing studies, it is also helpful to know the potential intake of herbage from different communities and at different stages of maturity.

Critical investigation of these factors was made using herbage harvested from communities of *Agrostis* and *Festuca* spp., *Nardus stricta, Molinia caerulea, Eriophorum vaginatum* and *Trichophorum caespitosum* and also from sown swards of *Lolium perenne* and *Trifolium repens*. Each community was harvested on three occasions through the year, giving 21 feeds in all, and fed frozen to penned sheep in conventional intake and digestibility studies. *In vitro* digestion was carried out on samples of herbage as fed to the sheep and also on samples of the same herbage recovered as extrusa from sheep and cattle fistulates.

There was a common positive relationship between voluntary herbage intake (g OM/kg $LW^{0.75}$, I) and *in vivo* OM digestibility (OMD) which embraced all plant species and stages of maturity (Equation 1),

$$I = -39 + 147\,(\pm 18.4)\,OMD \qquad r^2 = 0.78 \qquad RSD = \pm\ 8.39 \quad \ldots\ldots (1)$$

indicating that digestibility is a useful criterion of herbage quality and potential intake for a range of indigenous hill plant communities, as it is for sown species. The overall relationship between the *in vivo* (OMD) and *in vitro* (OMD_F) digestibilities of the feeds (Equation 2)

$$OMD = 16 + 0.78\,(\pm 0.044)\,OMD_F \quad r^2 = 0.94 \quad RSD = \pm\ 2.64 \quad (2)$$

was broadly similar to that described elsewhere but the results indicate the need to use prediction equations appropriate to particular communities. The evidence also indicates that adjustment of *in vitro* estimates for extrusa effects is advisable.

Detailed statistical evaluation of the results of a series of *in vitro* digestibility runs indicated that systematic variation in the organic matter content of the rumen liquor delivered to sample tubes from an automatic syringe was an important source of within-run variation in the estimates of digestibility. The experimental routine has been altered to take this into account.

Herbage mass studies

[RDMA, TJM]

The effects of herbage mass, sward structure and supplementary feeding in early lactation on lamb growth and ewe live-weight change

The effects of maintaining a constant herbage mass throughout the lactation period of Greyface ewes on ewe and lamb performance and on the amounts of herbage conserved in two conservation periods

Since 1978, following the Upland Greyface Systems Experiment (Project 03008, 1974 to 1977), particular emphasis has been given to investigations of the effects of differing herbage mass on the performance of ewes and lambs at pasture. Sward structure and herbage quality have been monitored annually. In 1979, aspects of supplementation were examined, while in 1980 the procedures explored the balances between provision of winter feed from within the system and animal performance over a range of maintained herbage masses.

The objective of controlling herbage mass on grazed pasture with some precision was partially achieved in 1978 and 1979 by stock adjustment and the strategic use of nitrogenous fertiliser applications. In 1980, the grazing area was adjusted weekly so that herbage mass remained constant. Areas thus removed from grazing were used for conservation.

The experiments in 1979 and 1980 ran for the duration of the lactation period (early April to mid-August), which can be considered as three phases of 6 weeks. The first involved supplementation of grazing intake when herbage mass had not risen to 'target' levels, the second coincided with the conventional period for conservation and the third extended through the weaning period.

Table 4 summarises the herbage mass data for both experiments. Each set of figures represents a mean value in kg of herbage dry matter available per ha for each of the three phases of lactation.

Table 4

		Early lactation weeks 1-6			Mid-lactation weeks 7-12			Late lactation weeks 8-13		
	Treat-ment	Target		SE of mean	Target		SE of mean	Target		SE of mean
1979	A	0-1200	525	122	1200	1004	96	1200	1238	94
	B	0-1200	552	144	1200-750	1021	60	750	1257	127
	C	0- 750	561	136	750	841	61	750	992	70
	D	0- 750	580	128	750-1200	940	91	1200	1294	92
1980	600*	600	618	34	600-1200	651/849*	9/15	600-1200	935*	33
	800	800	683	50	800	744	28	800	810	24
	1000	1000	846	101	1000	978	69	1000	1040	36
	1200	1200	874	70	1200	1080	50	1200	1173	18

* Treatment modified from week 11

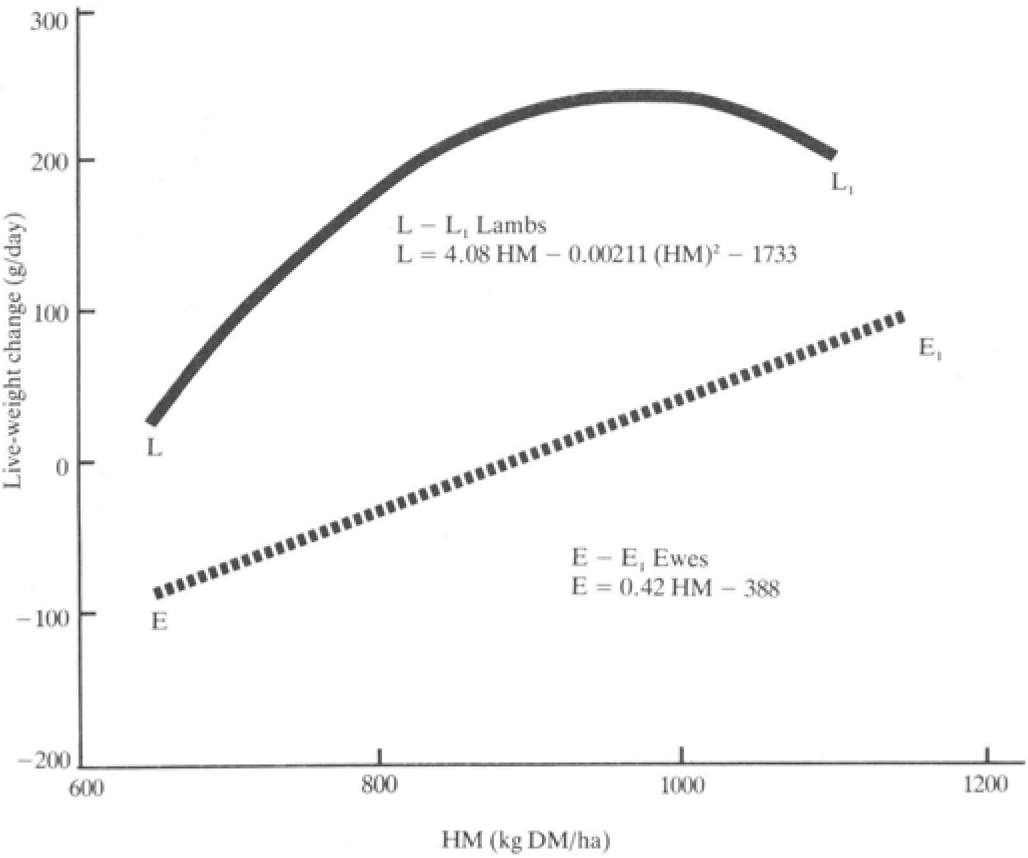
The 1979 values conceal considerable short-term fluctuation, while in 1980 herbage mass remained close to the target value once this was achieved during the first 6-week period.

Early lactation phase (weeks 1-6)

There was evidence from both experiments that supplementation affected ewe live-weight change but had little apparent effect on lamb growth. In 1980, target herbage masses were achieved by the second week of lactation on one replicate, allowing the suspension of supplementary feeding. The ewes on these four treatment paddocks showed a positive live-weight response to the prevailing herbage mass.

Fig. 4

The relationship between mean live-weight change of ewes and lambs and mean herbage mass



Mid-lactation phase (weeks 7-12)

Herbage mass was positively related to ewe live-weight change and lamb growth rate. The relationship for ewes was linear and coincided closely with data for the same period in 1978. The lamb growth response was curvilinear, with a steep decline below 800 kg DM/ha.

The relationships between mean live-weight change of both ewes (E) and lambs (L) (g/day) and mean herbage mass (HM) are shown in Figure 4.

Late lactation phase (weeks 13-18)

The third 6-week period was characterised in both years by poor ewe and lamb performance, neither of which appeared to be related to prevailing herbage mass. Decreases in organic matter digestibility of available herbage were associated with live-weight loss of ewes and low growth rate of lambs (Table 5).

Table 5

	Weeks 7-12			Weeks 13-18		
	OMD%	g/day		OMD%	g/day	
		Ewes	Lambs		Ewes	Lambs
1979	75	40	225-250	65	−160	50
1980	70	−40	160	67	−150	60

Changes in sward characteristics

In both years, treatment groups were replicated on two types of ryegrass sward, one of which had been established for 7-8 years and grazed exclusively by sheep. The other was recently established (1-2 years) and had been lightly grazed by cattle during its first year. The 'sheep sward' was characterised by dense plant populations (14-28 thousand/m^2) and low sward height (2.1-3.7 cm). Conversely, the recently established sward had lower plant populations (6-20 thousand/m^2) with some bare ground and had a greater sward height (2.3-4.7 cm) for a given herbage mass. A tendency to convergence of characteristics was observed during each grazing season. No distinct differences in animal performance were detected which could be attributed to the type of sward grazed.

Strong correlations were observed for a given enclosure between sward height and herbage mass measured on the same date. Hence, when animal performance varied with herbage mass it did so according to sward height. Where performance was less clearly attributable to herbage mass, as in late lactation, there was some evidence that it was more closely associated with changes in sward height and OM digestibility.

Balance of grazing pressure, herbage mass and area conserved (1980)

Observations of herbage mass changes on grazed swards during the conservation periods of the 1974-77 systems experiment provided the basis for controlling herbage mass by area adjustment. In the same environment and with identical nitrogen applications, a stocking rate of 17 ewes with twin lambs per hectare was shown to arrest increments in the herbage mass of grazed swards.

The proportions of the area that could be closed for conservation were associated with 'target' herbage masses, set for grazing the stock number to be carried throughout the grazing season and the production characteristics of individual paddocks. Rates of net herbage accumulation in areas closed for conservation were lower (34 kg DM/ha/day) in July and August than in May and June (62 kg DM/ha/day). Assuming that this differential was reflected on grazed swards, it is probable that, under conditions of constant herbage mass, intake was depressed during late lactation, coinciding with the period of poor animal performance.

The balance achieved between winter feed provision from within the system and animal performance was clearly in favour of the former. On the basis of previous winter feeding practice (90 kg DM/ewe was typical) the systems overall were fully self sufficient but wide differences between treatments and replicates were recorded. Treatments, where basic stocking rate was 14 ewes with twin lambs per hectare, were less than 50% self sufficient, whereas, at 10 ewes with twins per hectare, more than 150% self sufficiency was achieved. The second conservation period (43 days) provided less than one third of the total but it should be noted that the first period was longer (65 days). However, OM digestibility of the regrowth (70-75%) compared favourably with that of the first growth (69-73%). The inference is that where two conservation periods are contemplated the first should be shortened in the interest of quality and the second should begin earlier in the interests of quantity.

Package 2. The synthesis of hill and upland farming systems

The purpose of the Systems Development Programme is to test the principles which determine the integration of resources in improved systems of sheep production from hill land. Field scale studies have been carried out in the widely different but limited range of environments represented by the Sourhope, Lephinmore and Glensaugh Research Stations.

The aims of the programme have been, firstly, to establish that the systems could be operated satisfactorily from a management point of view; secondly, to measure the responses of total output and individual animal performance to specified changes in inputs over a range of stocking rates; thirdly, to provide biological data for quantification of the relative contribution that each component of the system makes to the output of the whole; and fourthly, to assess the input/output relationships in economic terms. It has been important that the ultimate assessment of the systems studies should be economic; the costs of pasture improvement, supplementary feeding and increased stock numbers have to be considered in relation to the increases in output that can be expected from an improved system.

The studies have been closely monitored in terms of ewe and lamb live-weight change, mortality, reproductive performance, level of nutrition during late gestation, disease and, in some cases and from time to time, in terms of the changes in the botanical composition and nutritive value of pastures.

The process of evaluation is not concerned with achieving a single acceptable and satisfactory level of total output and individual animal performance but with a need to establish where limits lie. The level of output achieved from a system will be a function of its stocking rate and level of individual performance for a given level of inputs, although individual performance and stocking rate are often inversely related. To achieve more efficient use of existing or enhanced pasture production, it is necessary to increase stocking rate. To identify the limits of increased stocking rate, increases have been made in our studies to identify, firstly, the stocking rate at which total output reaches a maximum and, secondly, the stocking rate at which individual animal performance declines significantly.

In summary, the method of evaluation used has measured the responses to a given set of inputs and associated management procedures on a given area of hill land over time and over a range of stocking rates which have encompassed the maximum level of total output and individual animal output achieved. It has been possible to use this method because output responses have been sufficiently great (not less than 50%). The significance of the changes in performance can also be related to the data collected from the programme of biological monitoring.

Project 03004 — The development of improved systems of animal production from hill pastoral resources; year-round grazing systems (YRGS)

In these studies, two kinds of pastoral resources are identified. One, of high nutritional quality, is used during lactation and lamb growth and again, after a mid-season rest, in the period before and during mating. The other, of poorer quality indigenous hill pasture, is used throughout the winter and again between weaning and pre-mating. Lambs are removed from the system at weaning, as occurs traditionally, then, as ewe hoggs, they are removed to an enclosed grazing during the winter or are off-wintered and, in the following summer, graze on the unimproved hill. Other management changes which are associated with this system of controlled grazing are the provision of better management of rams which are raddled at mating, the provision of semi-permanent winter feeding points and lambing in the enclosed areas.

YRGS I Low capital input on a grassy hill — Hairney Law/Auchope (Sourhope)

[RbnHA, JE, TJM]

This study has been based on indigenous hill vegetation improved by grazing control. Initial capital inputs were restricted to fencing and the retention of extra stock ewe lambs to allow a build up of stock numbers. The area chosen for the study extended to 283 ha, rising from 250 to 490 m, with 35 to 40% of the area being *Agrostis/Festuca* pasture and the remainder a *Nardus/Molinia*-dominant grass heath. Originally, the unit carried 390 Cheviot ewes and 25 suckler cows. This study has been reported in detail up to and including 1976 (Armstrong, Eadie and Maxwell, 1978). In 1974, a programme of reseeding was initiated and two previously reseeded areas which had been used as lambing paddocks were incorporated into the project. By 1981, there were five production paddocks comprising some 100 ha of enclosed hill vegetation in which *Agrostis/Festuca* predominates and within which a total of 33.2 ha have been limed and top-dressed with phosphate, 10.5 ha have subsequently been reseeded after bracken spraying and 7.9 ha have been over-sown with grass and/or clover seed. In total, including the areas used for lambing and lacation, there are 17.8 ha of reseeded ground.

Between 1974 and 1981, stock numbers were increased only slightly from 600 to 631 ewes; pre-mating live weight of the ewes increased from 53.7 kg in 1974 to a maximum of 59.1 kg in 1979; weaning percentage increased from 91.5% in 1974 to 113.3% in 1979 and to a maximum of 118.2% in 1980. The total weight of lamb produced from the unit at weaning has increased from 14329 kg in 1974 to 19471 kg in 1980 and the lamb weaned per ewe mated has increased from 23.9 to 30.9 kg over the same period. The total annual weight of wool has increased by 433 kg.

The net capital input, after allowing for 50% grant, over the period 1968 to 1973, amounted to £689 and from 1974 until the close of 1980 a further £5657 has been invested; raising the total capital invested to £6346. The flock gross margin during the period 1974 to 1980 has increased from £5607 to £11907.

The cash flow at prevailing costs and prices has resulted in a positive cumulative balance of £19515 at the close of 1980. In addition to this, there should be added the extra stock valuation of £7898, giving an overall total cumulative balance of £27413. The timing of the capital inputs appears to have been soundly based, with initial low cost inputs allowing capital to be generated from within the system for subsequent re-investment in further land improvement.

YRGS II On blanket bog - Midhill (Lephinmore)

[TJM, JE, DCC, DNMcF]

The Midhill unit (444 ha), rising from sea level to around 500 m, has an average rainfall of 2000 mm. Most of the hill is covered by blanket peat and the vegetation is dominated by heather *(Calluna vulgaris)*, draw moss *(Eriophorum vaginatum)* and deer grass *(Trichophorum caespitosum)* with a little *Molinia* but it is broken in places by flush areas carrying a *Juncus*-dominated grass community.

A previous study (1967-68) on this unit had increased ewe numbers from 205 to 372. Weaning percentage declined with increasing flock size from a peak of 98% in 1960 to 70% in 1968 (Nicholson, Currie, Paterson and McCreath, 1968).

The objectives in terms of grazing management from 1968 onwards were those as outlined for year-round grazing systems above and different from that outlined by Nicholson *et al.* (1968).

Ewe numbers were reduced to 339 in 1968. By 1972, they had been increased to 384; pre-mating live weights increased, as did weaning percentage (103.6%). Total lamb output increased from 7207 kg (1969) to 9924 kg (1972). The new system of grazing management had effectively increased total output by 2700 kg at a similar stocking rate.

After a further input of 14 ha of improved pasture, ewe numbers were increased to 434 in 1975. However, pre-mating live weights fell from 49.9 to 47.9 kg with a consequent decline in weaning percentage (91.0% in 1975) although total output of lamb peaked at 10870 kg in 1974.

Since 1975, the objective of the study has been to establish whether the limitations to increasing output from the unit are due either to inadequate nutrition from improved pasture between marking and weaning or to inadequate recovery between weaning and pre-mating while ewes are grazing indigenous hill pasture. Ewe numbers have been increased and have remained at around 450. In 1978, 3 to 4 ha of the more recently created reseeds received 350 kg per ha of a compound fertiliser (15:15:21, N:P:K) and basic slag was applied to 10 ha of the permanent pastures. A hill paddock was also created for the feeding of gimmers separately from the rest of the flock in late pregnancy.

Despite these inputs and modifications, live-weight recovery in early lactation has not improved although there has been some improvement in late lactation recovery. Latterly, recovery on the hill after weaning has been significantly less than that experienced during the period 1969-72 and less than that experienced in the two good seasons of pasture growth in 1976 and 1977. Recovery on the reseeds prior to mating, however, has been substantial at around 2.5 kg. Up to 1980, pre-mating live weights have remained at about 48kg and weaning percentages up to 1979 have remained at between 91 and 93. In 1980, however, weaning percentage fell to 80.1.

The data relating the annual ewe live-weight cycle and levels of performance strongly suggest that substantial live-weight recovery needs to take place before weaning and certainly before October if lamb growth rate during lactation and ewe reproductive performance are to remain at relatively high levels. In recent years, the relationships between sheep numbers and the area, quantity and quality of herbage available on the improved land have not been such as to allow ewe live-weight recovery to reach levels which would sustain higher levels of lamb growth and ewe reproductive performance.

YRGS IV On heather moor — Cairn (Glensaugh)

[TJM, JE, JAM, RDMA]

The land resources comprise 182 ha of heather-dominant moorland rising from 200 to 460 m and include 23 ha of permanent grassland. Up to 1978, a system of management similar to that outlined for previous studies was used relative to the seasonal allocation of stock to the enclosed permanent grassland and hill areas. During 1978 and 1979, two areas, each of 20 ha, with eight one-hectare blocks of reseeded pasture, distributed evenly throughout each area, were created and enclosed by fencing.

These areas have been used during lactation, stocked at a level which did not require the ewes to graze the heather to any great extent but which ensured effective utilisation of the grass on the reseeds. Their main purpose has been to maintain and improve ewe live-weight recovery between weaning and mating. During this period, stocking rate has been set to use up to 40% of the current season's shoots of heather within these areas. This system of management, which has been introduced without making any increase in stock number, has resulted in increased ewe pre-mating live weights, increased numbers of lambs weaned and greater lamb weaning weights. The study continues.

Project 03005 — The development of improved systems of animal production from hill pastoral resources; in-wintering systems (IWS)

Stocking rates in traditional systems are determined by the need to maintain certain minimum levels of winter nutrition from grazed pasture. Systems based on off-wintering offer possibilities of substantial increases in output as a consequence of the removal of this constraint.

The increased expenditures involved by off-wintering are mainly in the form of increased winter feed costs. Evidence suggests that these may be recouped by improved individual sheep performance to only a very limited extent. The substantial increases in individual ewe performance which have to be achieved to justify off-wintering are more likely to be brought about by including land improvement. Where in-wintering is contemplated, the improvement in individual ewe performance that has to be obtained to justify the capital cost of sheds is considerably greater.

The following study has attempted to quantify the relationships between stocking rate and individual performance from systems of production in which ewes are in-wintered and either graze or do not graze improved and reseeded land in the summer.

IWS I On a grassy hill — Rigg and Gairs (Sourhope)

[RbnHA, JE, TJM]

The Rigg and Gairs are two similar areas, each of 101 ha of hill land, which were traditionally stocked with 130-140 ewes and gimmers. Both sheep stocks are in-wintered for the same time in the same wintering house. On the Gairs, an area of 15 ha of *Agrostis/Festuca* pasture has been enclosed, limed, slagged and oversown with clover. A further 10 ha of *Molinia/Nardus* grass heath at 450 m was also limed, slagged, enclosed, sprayed with Paraquat, rotovated and direct reseeded with a further application of high phosphate compound. The improved pasture areas are used and integrated with the unimproved hill in a similar way to that outlined for the year-round grazing systems. The ewes are housed from the beginning of January and latterly have been lambed in the sheds.

South Country Cheviots were originally carried on both the Rigg and the Gairs. Stock numbers have been increased on both equally. By 1974, it was concluded that performance on both was very similar, despite the improved land associated with the Gairs, and that performance in terms of numbers of lambs weaned had reached a maximum in relation to the live weight which the two areas could reasonably be expected to sustain at mating. Thus, the breed of ewe was changed and Scottish Blackfaces have been progressively introduced since 1975, the flocks becoming wholly Blackface in 1979. During 1979 and 1980, with similar numbers of ewes in each flock, the number of lambs weaned on the Gairs has been greater than that on the Rigg by some 6-8% and has been substantially greater on both than in previous years. Output of lambs during 1979 and 1980 has been greater by between 1000-1400 kg of lambs weaned on the Gairs as compared to the Rigg. The study continues.

ARMSTRONG, ROBIN H., EADIE, J. and MAXWELL, T. J. 1978. The development and assessment of a modified hill sheep production system at Sourhope, in the Cheviot Hills (1968-1976). *HFRO 7th Report,* 1974-77, 69-101.

NICHOLSON, I. A., CURRIE, D. C., PATERSON, I. S. and McCREATH, J. B. 1968. Hill grazing management and increased production. *Scott. Agric.* **47:** 123-131.

Project 03010 — The collection and analysis of statistical information on hill and upland farming and land use

Hill sheep farming in Scotland. A study of the agricultural statistics

[ADMS, JE]

The principal objective of this study was to identify the extent of hill land, number of hill farms, stocking rate and flock range groupings within defined categories. This was achieved by analysing statistics drawn from the Department of Agriculture and Fisheries, Scotland, and linking the Hill Sheep Subsidy and Hill Livestock Rearing Winter Keep Grant to the DAFS, June 4th, official Census returns. The year 1974 was chosen and only full time farms were analysed.

In Scotland, 3443 farms were included in the definition of hill sheep farming which extended to 3.1 M ha, 2.8 M ha of which were rough grazings or naturally uncultivated grassland. The remaining 0.19 M ha of land in crop and grassland comprised 0.052 M ha mown grassland, 0.14 M ha permanent grassland and 0.034 M ha crop. These farms, in total, carried 1.89 M hill ewes and gimmers.

From these basic data, it was possible to construct the average Scottish hill sheep farm. In size it is 899 ha, has 826 ha rough grazings and 65.1 ha in crop and grass. The farm carries a breeding hill ewe flock of 548.

In hill agriculture, full time farms can be grouped into three classes depending on land type, grazing season, stocking rate and other natural characteristics. Three classes were identified, A, B and C.

Class A farms showed a higher proportion of land in crop and grass than did Class C, while Class B was intermediate. By far the largest land area was considered to be Class C.

Distribution of hill land and livestock by farm types is shown in Table 6. The high stocking rate density on Class A farms may be broadly associated with relative proportions of land in crop and grass. These farms also showed a higher capacity to conserve winter fodder.

Table 6

Distribution of hill land and livestock by farm types in Scotland

	A	B	C	
No. of farms	480	922	2041	3443
%	13.9	26.8	59.3	100
Land area (ha)	172001	505896	2418458	3096435
%	5.5	16.3	78.1	100
Crop and grass	59827	76463	87759	244049
% of land area	34.8	15.1	3.6	7.9
Rough grazing	109388	423317	2309929	2842635
% of land area	63.6	83.7	95.5	91.8
No. of sheep	177968	390373	1317229	1885570
% of total	9.4	20.7	69.8	100
No. of cattle	41281	67561	103776	212618
% of total	19.4	31.8	48.8	100
Stocking rate ha/ewe	1.0	1.3	1.8	
Land area ha/cow	4.2	7.5	23.3	

By subdividing hill ewe breeding stocks into flock range groupings, it is possible to present a pattern of hill sheep farm size and ewe flock distribution (Table 7). Approximately 25.5% (877) of the farms in the survey carried less than 200 ewes. This was less than half the size of the ewe flock carried on the average hill farm referred to earlier. However, these farms in total only extend to 0.157M ha or 5.1% of hill land in the Census and carry only 5.4% of the total breeding ewe stock. At the other end of the range, only 5.8% (200) of the farms had flocks with more than 1500 ewes but these flocks were distributed over 28% (0.867 M ha) of the hill land.

Intermediate flock sizes showed considerable variation of farm size in relation to flock size. The relationship between rough grazings, crop and grass gave a clear indication of farm structure.

Table 7

Flock size	Farms no.	Farms %	Land area ha	Mean ha	%	Sheep no.	Sheep %	Cattle no.	Cattle %
< 200	877	25.5	157294	179	5.1	101317	5.4	39586	18.6
201-300	483	14.0	155676	322	5.0	120057	6.4	26711	12.6
301-400	404	11.7	217196	537	7.0	140648	7.4	22269	10.5
401-500	357	10.4	253303	709	8.2	161621	8.6	20882	9.8
501-750	571	16.6	577671	1012	18.6	349778	18.5	38264	18.0
751-1000	258	7.5	341645	1324	11.0	222465	11.8	17962	8.4
1001-1250	180	5.2	287374	1596	9.3	200324	10.6	15586	7.3
1251-1500	113	3.3	238599	2111	7.7	154472	8.2	10895	5.1
> 1500	200	5.8	867676	4338	28.0	434888	23.1	20463	9.6
	3443	100	3096435		100	1885570	100		100

A more detailed farm-class analysis of two flock size groupings provided basic information of within-class ranges of crop/grass: rough grazings and associated sheep stock (Table 8). Farms in the three classes of hill farm with flocks of less than 200 ewes were compared with those with more than 1500 ewes. A similar pattern emerged within each class for both groupings. In both cases, Class A farms showed higher stocking rates.

Table 8

	Farm size (ha)	Mow (ha)	N/Mow (ha)	Crop + grass (ha)	Rough grazing (%)	Mean herd size (no.)	Mean flock size (no.)
Flock size 1-200							
Class C	233.9	9.6	19.7	34.4	83.6	38	114
Class B	139.9	12.7	28.4	49.8	63.0	44	118
Class A	133.3	19.0	46.4	82.0	36.6	62	112
All types	179.3	12.6	28.2	49.5	70.7	45	115
Flock size 1500							
Class C	4494.5	16.2	39.6	61.8	97.9	90	2188
Class B	3921.7	41.8	113.2	176.0	94.9	176	2120
Class A	1751.5	48.8	161.3	269.2	82.5	189	2006
All types	4338.3	20.0	51.5	81.0	97.4	102	2174

Hill sheep account for approximately 70% of breeding ewes in Scotland. Scottish hill ewe stocks increased during the 1950's and reached a peak of 2.47M ewes (Cunningham, Smith and Doney, 1970). During a 12-year period, 1966-78, there was a decrease in absolute numbers by 0.25M breeding ewes (21000/annum), the most significant changes occurring between 1966 and 1974 (Table 9).

Table 9

Hill sheep eligible for subsidy 1952-78 (000)

		1952	1956	1960	1964	1966	1967	1970	1974	1978
Highland	(a)	993	984	1072	1074	1090	1069			
	(b)					1090		1039	988	
	(c)								988	950
North East	(a)	101	98	101	108	126	122			
	(b)					126		120	120	
	(c)								120	117
East Central	(a)	299	288	311	316	325	323			
	(b)					325		314	305	
	(c)								305	301
South East	(a)	288	280	283	277	283	277			
	(b)					283		264	252	
	(c)								252	252
South West	(a)	632	620	631	641	648	640			
	(b)					648		622	594	
	(c)								594	597
SCOTLAND	(a)	2314	2270	2398	2417	2472	2431			
	(b)					2472		2360	2259	
	(c)								2259	2217

a = 1952-1967 b = 1966-1974 c = 1974-1978 (Source : DAFS)

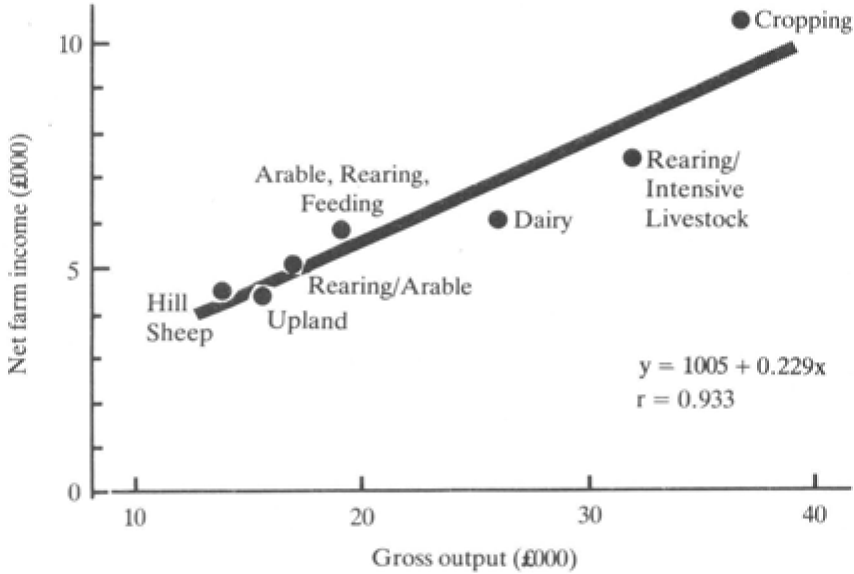
Regional flock decline was not uniform. Relatively minor changes in North East and East Central contrasted with a more pronounced downward trend in the South East. The two regions with the largest area in Scotland devoted to hill farming, Highland and South West, each had a sharp reduction — approximately 10% — of breeding ewes. Between the years 1974 and 1978, this decline in hill ewe numbers slowed down to the extent that there was a slight increase in the South West. Other regions maintained relatively stable breeding flocks.

The Scottish Agricultural Colleges provide annual financial results for the main farm enterprise types. Data were used to assess

Net income/Gross output trends and within farm types over a 9-year period, 1969-1978 (Figure 5). Statutory production grants were included and the retail price indicator used to adjust values to 1978 monetary standard.

Fig. 5

The relationship between net farm income and gross output by main farm types : Scotland 1969-78



Although not shown here, net income values on hill farms increased substantially between 1971 and 1974 as a result of improved lambing percentages and store price returns. A sharp fall in store prices, 1974-75, had a severe effect on net income but improvement in market prices, 1976-78, was reflected by increased net incomes. Lower net incomes on hill farms result from a smaller size of farm business in relation to other enterprise types but income/output relationships are not significantly different from other farming types.

Small business size on these farms is, in the main, due to size of operation, which could be increased by amalgamation or by intensification (Eadie and Smith, 1978). Intensification, with the attention currently being given to land improvement, would appear to offer the most hopeful line of approach.

CUNNINGHAM, J. M. M., SMITH, A. D. M. and DONEY, J. M. 1970. Trends in livestock populations in hill areas in Scotland. *HFRO 5th Report, 1967-70,* 88-95.

EADIE, J. and SMITH, A. D. M. 1978. The impact of technical advance on hill and upland sheep production. In *The future of upland Britain* (ed. R. B. Tranter), pp. 22-33. Centre for Agricultural Strategy, Paper 2.

Package 3. Beef cattle in hill and upland environments

Project 02008 — Beef cattle: characterisation of nutritional state under different systems of management; studies on reproduction, lactation and calf growth

The objective of the beef cattle research programme is to quantify and obtain an understanding of the biological factors influencing production from suckler cows, with the ultimate aim of improving the efficiency with which hill and upland resources are used for beef production. This objective has been pursued through two related lines of research, the first dealing with nutritional studies conducted mainly with housed cows and the second concerned with aspects of grazing management and herbage utilisation conducted at pasture with cows and calves.

Earlier nutritional studies had shown that, given relatively high levels of energy intake, both the Blue Grey and Hereford x Friesian genotypes were capable of high levels of milk production (means of approximately 9 and 10 kg, respectively, over 22 weeks). Examination of the relationship between calf growth rate and level of milk production indicated that increases in milk production beyond these levels would result in only relatively small increases in rates of calf live-weight gain, of the order of 25 g/day/kg increase in milk production. The same relationship also suggested, however, that with cows producing similar levels of milk and suckling two calves, the marginal response in calf growth rate to increased milk production would be some three times greater.

The influence of nutrition in early lactation and single- or twin-suckling on the performance of beef cows and their calves

[AJFR, JNP, IAW, IRW with EAH, Janet MD]

The effects of nutrition in early lactation on the performance of cows suckling one or two calves were examined in an experiment at Glensaugh.

Charolais-cross calves born to Blue Grey and Hereford x Friesian cows were cross-fostered, so that no cow reared her own calf. In addition, a purebred Friesian calf was fostered on to each of 12 cows of both genotypes. Despite considerable care in the screening of sources from which additional calves were purchased and in the provision of colostrum to all calves as soon as possible after birth, mortality rates of both home-bred and purchased calves were high, and the early growth rates of even the calves reared as singles were lower than normal. Improving the level of nutrition in early lactation over a range of about 60 to 140 MJ ME/day increased milk production and reduced cow live-weight losses. Cows rearing two calves lost weight while those rearing only one calf gained weight. The higher level of milk production from the cows with two calves failed to attain statistical significance. Growth rates of twin-reared calves were considerably lower than of those reared as singles. Following turnout to good quality pasture, growth rates of all calves improved and the differences between those reared as singles and as twins diminished.

More recently, workers at the Animal Diseases Research Association have been engaged in the development of a vaccine against rotavirus and *E. coli* (K99), two of the principal organisms implicated in the problem encountered in the experiment. Tests of this vaccine in subsequent studies with the same cows indicated that this approach could be extremely effective in preventing outbreaks of scour. The experiment itself also provided considerable useful experience of the technique of fostering calves and showed that this need not constitute a problem in future studies.

Studies on the energy requirements of suckler cows and on the use of blood metabolites as indices of energy status

[AJFR, IAW, IRW with EAH, Janet MD]

Other recent nutritional studies have concerned, firstly, the determination of the maintenance energy requirements in non-pregnant, non-lactating, suckler cows and of how these requirements are affected by genotype and body condition and, secondly, the quantification of the relationships between the circulating concentrations of certain blood metabolites and energy status. The results of this work indicated that there were no differences in maintenance requirements between the Blue Grey and Hereford x Friesian genotypes but showed clearly that maintenance requirements were affected by both live weight and body condition, the effect of the latter being negative when requirements are expressed per unit live weight or metabolic live weight. It is hypothesised that this latter effect is attributable to protein turnover having a higher energy cost than that of fat turnover. This work also provided an estimate of the dietary energy equivalent available from tissue catabolism of some 26 MJ ME/kg tissue loss. The related studies on blood metabolites indicated that plasma 3-hydroxybutyrate concentrations in undernourished, non-pregnant, cows are not elevated to the same degree as in pregnant cows of an equivalent energy status but the relationships between plasma free fatty acid concentrations and energy status can be described by a single equation applying to both pregnant and non-pregnant cows.

Studies on the *in vivo* estimation of body composition of suckler cows

[AJFR, IAW, IRW with EAH, Janet MD]

A large part of the nutritional programme on suckler cows has been concerned with the effects of low levels of feeding and the consequent use of body reserves, while the recovery of live weight and replenishment of these reserves has featured prominently in the grazing studies programme. Although the technique of condition scoring had been used extensively in both programmes for some time, the lack of information whereby this could be related quantitatively to changes in body fat has been a major constraint to progress. Recent studies on the *in vivo* estimation of body composition in suckler cows have yielded results which will remove this constraint. The information is based on data obtained following the slaughter of 80 cows comprising Blue Grey, Hereford x Friesian, Galloway, Luing and Friesian genotypes. This work has produced much useful information on the body composition of suckler cows, including, for example, differences in the partition of body fat between genotypes. The results show that, in combination with live weight, measurements of condition score, back fat thickness (determined ultrasonically) or deuterium oxide space, can provide estimates of body fat and protein with residual standard deviations of some 13 and 3 kg, respectively. Differences between genotypes in the partition of body fat are such that, in estimating total body fat from *in vivo* measurements involving subcutaneous fat (i.e. condition score or ultrasonic measurements), it is essential that prediction equations developed for the particular genotype are used.

These techniques of estimating body composition *in vivo* have been used in a recently completed nutritional experiment for which results are not yet available. The objectives of this work were to examine the effect of body condition at calving on milk production and body compositional change in two genotypes of suckler cows and on how these effects are modified by diet quantity and quality.

Cow and calf response to contrasting sward conditions at different stages in the grazing season

[JH, RAH with EAH, Janet MD]

During the period under report, the process of transferring the main suckler cow work to the recently acquired research station at Hartwood was begun. The grazing herd cows moved to Hartwood and the first beef cattle experiment was conducted there during the 1980 grazing season. This was, of necessity, a relatively simple and straightforward study of cow and calf responses to contrasting sward conditions at different stages of the grazing season. The results showed markedly superior performances of both cows and calves grazing a sward maintained at 5 to 6 cm surface height as compared with animals on a 3 to 4 cm sward in the first half of the season but not in the second and also demonstrated strong residual effects of the initial treatment when animals were switched from one treatment to the other. This work has been continued in a more recent experiment in which more detailed assessments of performance have been obtained.

Package 4. Hill and upland pasture production

Project 04003 — Nutrient requirements of white clover and sown grasses in hill soils

[PN, AR, CCE, JML with HKS, Jean W]

Hill soils are high in total amounts of nitrogen and phosphorus but very little is immediately available for uptake by plants because very large proportions of these nutrients are in organic forms which have to be broken down by micro-organisms to release 'available' nutrients and, additionally in the case of phosphorus, some is present in insoluble organic compounds (i.e. 'fixed'). To improve the quality and quantity of pasture, it is necessary to introduce improved pasture species, with higher nutrient demands than native species, and fertilisers are therefore needed. Because white clover can provide a source of nitrogen by atmospheric fixation, emphasis has been directed on the other nutrient elements which are needed to establish and maintain this plant. It has been assumed that the provision of a soil environment which is adequate in nutrients for the growth of white clover will meet the lower nutrient demands of companion grasses. Since the costs of all fertilisers are rising, it is necessary to know the biological response curves of white clover to a wide range of additions of nutrients, so that levels appropriate for practical use can be determined. To achieve optimum economic effectiveness, these are unlikely to be those that produce maximum biological production.

Early work with representative examples of the main hill soil groups concentrated on assessing the requirements of white clover for phosphate, potassium, calcium and magnesium. Attention was also directed at the amounts of lime needed to adjust the acidity of the soil to that (i.e. pH > 5.2) suitable for the establishment and growth of nodulated clover plants. During the course of these studies, interactions between lime and phosphate and between phosphate and potassium, particularly when growing in deep peat soil, were observed. Experiments in the last 2 years have been designed to explore the mechanisms of these interactions. From these it appears that the depression in growth which follows the application of large amounts of lime at the same time as phosphate fertiliser, may cause a lowering in the availability of phosphate. It is also evident that the main variations in yield with differing combinations of amounts of phosphorus and potassium are due more to changes in the number of leaves rather than their size. Both phosphorus and, to a lesser extent, potassium, affect the rate of production of leaves while potassium affects the length of life of a leaf.

Since basic slag, once the main fertiliser used for hill pasture improvement, is now difficult to obtain, some experiments have been carried out to see what material or mixture of materials would be best to replace it. Superphosphate alone, ground mineral phosphate alone and a 50:50 mixture of the two have been compared. Plant uptake data showed the mixture of superphosphate and ground mineral phosphate to be almost as effective as superphosphate alone and both were superior to ground mineral phosphate on both soils used in the experiment; however, a full evaluation depends on a determination of the residual value of these fertilisers over a period of time. Analysis of the stored soils is still in progress.

A consequence of adding lime and fertilisers to a peaty podsol soil at Sourhope and then sowing ryegrass and white clover, was that, when grazing the pasture, ewes and lambs were found to be deficient in copper (Whitelaw, Armstrong, Evans and Fawcett, 1977, 1979). Chemical analysis of herbage showed this to be an induced rather than a direct deficiency. Thus, there was little difference in the copper content of indigenous and improved plant herbage but, in the latter, the amounts of sulphur and molybdenum were much greater. An experimental programme has been started to investigate the effects of lime and fertilisers on uptake of copper, molybdenum and sulphur by white clover and ryegrass in hill soils, with a view either to avoiding the problem or to devising methods for soil or plant amelioration with copper or other materials which will lessen its severity. Results of a glasshouse experiment showed interactions between treatments in the contents of sulphur, molybdenum and copper in plant tissues using the Sourhope peaty podsol soil. The effect of copper application was to increase the copper concentration of perennial ryegrass (S23) and, to a greater extent, white clover (S184). However, calculations to predict the true copper available to sheep indicated that mixed herbages derived from these two species would still not fully meet the copper requirements of young lambs. Further experiments with a wider range of hill soils were planned to investigate these interrelationships in more detail. It is also hoped to conduct a limited survey of soil and herbage in a number of recent hill pasture reseeds throughout Scotland, to ascertain the extent to which problems of induced copper deficiency occur. Previous work has concentrated mainly on copper alone but it is now evident that all three elements (copper, molybdenum and sulphur) must be assessed, since they interact in the rumen to reduce the availability of copper for utilisation by the ruminant.

WHITELAW, A., ARMSTRONG, R. H., EVANS, C. C. and FAWCETT, A. R. 1977. An investigation into copper deficiency in young lambs on an improved hill pasture. *Vet. Rec.* **101:** 229-230.

WHITELAW, A., ARMSTRONG, R. H., EVANS, C. C. and FAWCETT, A. R. 1979. A study of the effects of copper deficiency in Scottish Blackface lambs on improved hill pasture. *Vet. Rec.* **104:** 455-460.

Project 04004 — Effect of bracken control on herbage production and pasture formation

[GED, PN, GJB]

The initial aim of work in this project was to measure changes in the amount of herbage produced from hill pastures dominated by bracken, when the latter plant was controlled by spraying with asulam. It was shown that aspect and the proportion of broad-leaved hill grasses (*Agrostis* sp. and *Poa pratensis*) were the main factors which determined the magnitude of change in herbage production following spray application. Increases in production ranged from 18% on a site with poor aspect and dominated by fine-leaved grasses (*Festuca ovina* and *Deschampsia flexuosa*) to 47% on a site with good aspect and with a larger proportion of broad-leaved grasses.

Subsequently, interest has centred on any additional responses in herbage production and quality that follow the application of lime and phosphate to the sprayed areas; use of the latter at a rate of 628 kg/ha is the minimum necessary if the bracken clearance scheme is to qualify for a grant of 50%. At the sites described earlier, addition of phosphate had little effect on herbage dry matter production but the proportion of green herbage was significantly increased in the years immediately after treatment and there was a tendency for the concentration of calcium, phosphorus and nitrogen in herbage to increase also. The significance of these small changes in herbage quality on herbage utilisation by grazing sheep is not known.

An additional experiment at a site in the Pentland Hills was set up in 1977 to further investigate the effects on pasture production of spraying bracken and applying both lime and phosphate. This experiment is still in progress. As in the earlier trials, spraying reduced bracken cover by 98% and it also initially reduced the proportion of broad-leaved grasses in the pasture. In the first year after application, lime and phosphate had no significant effect on herbage production although there was some evidence of a response to phosphate in the absence of lime. Spraying bracken increased the seasonal accumulative production of DM from pasture by 68% although this subsequently fell to 29%. The highest level of production was obtained in 1979 (2436 kg DM/ha) on the sprayed treatment with the addition of phosphate only. Work has continued in 1981, to elucidate the reasons for the contrasted responses to lime and phosphate at the Pentlands site and further details are given in the longer research report on p. 113.

Project 04005 — The utilisation of moorland vegetation

The effects of grazing by sheep on the structure, stability and productivity of blanket bog

[SAG, GRB, LT]

Blanket bog vegetation is thought to be especially vulnerable to damage if it is overgrazed. In regions dominated by bog vegetation and where traditional year-round, set stocked, systems are practised, very few stock are carried and any overgrazing is usually the result of the localised concentration of grazing following on from bad burning management. The intensification of sheep production systems in such areas is likely to involve the introduction of two-pasture systems because of the poor level of nutrition afforded by blanket bog. As these systems involve both changed patterns and levels of use of the unimproved hill, it seems prudent to gather information which would enable the limitations to the use of the unimproved vegetation to be more closely defined. The present study arose from this need and is a stocking rate experiment on blanket bog with the seasonal patterns of grazing conforming with that of the unimproved hill in a two-pasture management system.

The study was begun in 1971 at Lephinmore. The experimental area lay at 244 m OD and the experimental design was restricted by the difficulties of finding suitable areas of reasonable floristic uniformity. Three sites, each large enough to supply three 0.1 ha plots and surrounded by similar, although slightly more variable, vegetation which could be used for holding paddocks, were chosen for the study. The community types were all variants of *Calluna/Trichophorum/Eriophorum* bog. Two areas had been burned 2 years previously so that the heather stands were in the building phase while the third carried a mature stand of heather.

Two sites were grazed as if they were the hill component of a two-pasture year-round grazing system while the third was grazed as though it were part of an off-wintering system, i.e. identical spring, summer and autumn management but rested from grazing in winter. At each site, three stocking rates were provided; in the year-round systems, the low rate was equivalent to 1 sheep to 1.54 ha, the intermediate rate to 1 sheep to 0.73 ha and the high rate to 1 sheep to 0.45 ha. At these stocking levels, utilisation of the annual DM production was expected to range from 10-15% to 45-55%.

In the early years of the study, detailed records were collected of the seasonal patterns of use of the various species (Grant, Lamb, Kerr and Bolton, 1976). Samples of the main food plants were also collected, including some species not present on the plots, for laboratory methods of feed quality evaluation (Grant and Campbell, 1978).

Throughout the experiment, which is still in progress, trends in species composition, standing crops and yields of current season's shoots of the heaths and of green leaf of grasses and sedges have been monitored. These data clearly show that the high stocking rate is damaging to bog vegetation; the area of bare ground has increased and the amount of cover of the main winter food plants, viz. *Calluna vulgaris* and *Eriophorum vaginatum* has decreased compared with that of more lightly stocked plots. Green yields in late July/early August (current shoots and green leaf) on plots at the high stocking rate were reduced by 22%, 27% and 42% in years three, six and nine, respectively, compared with more lightly stocked plots, i.e. the effects of overgrazing were progressively more damaging with time. There were no differences in cover or green yields between plots at the low compared with the intermediate stocking rates, although standing crops were lower on the latter because of the effects of the higher utilisation levels leading to a reduced build-up of woody stems of heaths and of uneaten dead leaves of grasses and sedges.

During the course of the study, the vigour of growth of the different species was affected by climatic variation, e.g. heather grew much more vigorously and *E. angustifolium* less vigorously during the dry summers of the mid-1970s compared with more usual wetter years. Early signs of overgrazing of heather disappeared during the dry spell, only to reappear again later. This variation emphasises the dangers of short-term studies when assessing species trends in native vegetation in response to management.

GRANT, SHEILA, A. and CAMPBELL, D. R. 1978. Seasonal variation in the *in vitro* digestibility and structural carbohydrate content of some commonly grazed plants of blanket bog. *J. Br. Grassld Soc.* **33:** 167-173.

GRANT, SHEILA, A., LAMB, W. I. C., KERR, C. D. and BOLTON, G. R. 1976. The utilisation of blanket bog vegetation by grazing sheep. *J. Appl. Ecol.* **13:** 857-869.

Project 04006 — Regrowth of hill grass species

Project 04010 — Effects of utilisation by grazing hill sheep and beef cattle on growth and production of hill pasture

The experimental programme under these project heads has been developed in collaboration with members of the Animal Production and Nutrition Department (see Package 1, Project 03003). Studies covered by Projects 04006 and 04010 are concentrated on understanding the influence of sward characteristics and grazing management upon herbage production and utilisation, with a view to defining management procedures likely to contribute to long-term stability of production associated with efficient herbage utilisation.

Sown pastures

[SAG, JK, GTB, JSB, LT, WICL, EMS, JH, WGS with HKS, RT]

This work arose because of the lack of firm evidence about the effects of alternative management strategies on either herbage production or the efficiency of its utilisation by grazing animals. Net herbage accumulation appeared to be remarkably insensitive to variations in grazing management, an observation at variance with predictions based on the known positive associations between crop growth rate and leaf area. It became clear that estimates of herbage production in most grazing trials, which were essentially estimates of net change in herbage mass over time, were inadequate for calculation or interpretation. Little was known about the rates of herbage growth and of losses via herbage consumption or senescence and decomposition, which together determine net accumulation and the efficiency of herbage utilisation.

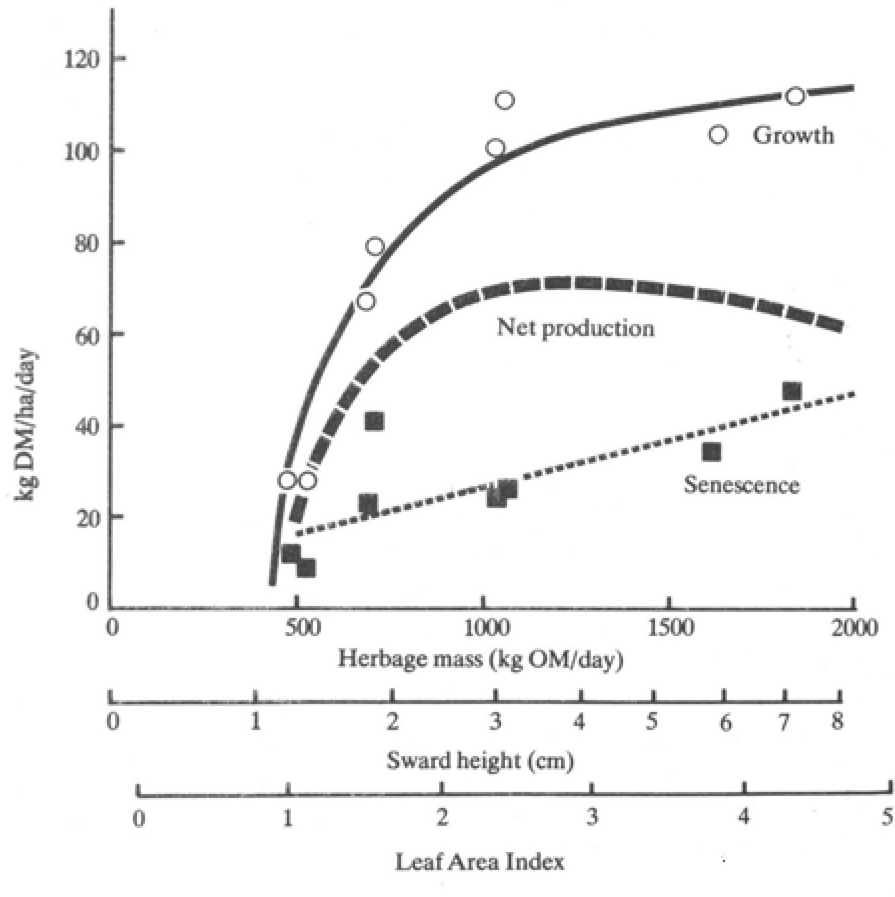
Tissue turnover in grazed swards

In order to study the impact of sward conditions on rates of herbage growth, utilisation and senescence, detailed measurements were made on a series of field plots in which swards were maintained at a range of steady-state herbage masses under continuous stocking with sheep or cattle. Measurements were also made on box-grown swards in a glasshouse study with frequent clipping treatments to maintain specified leaf area index (LAI) values. Observations on tissue turnover were based on a detailed tiller measurement technique, several variants of which have been developed at HFRO (Bircham, 1981; Grant, Barthram and Torvell, 1981). In some experiments, additional measurements of carbon exchange were made on sample turves in a laboratory-based, infra-red, gas analyser, in order to determine the photosynthetic potential of the swards and to obtain additional measurements of growth rate.

The results of four field trials have been consistent in demonstrating that rates of net herbage production per ha are greatest at a maintained herbage mass in the range 1000 to 1700 kg OM/ha, with a rapid decline at lower levels of herbage mass but relatively small changes above 1000-1200 kg OM/ha. This reflects the balance between a growth rate response to increasing herbage mass which is essentially

Fig. 6

The influence of variations in herbage mass (kg OM/ha) on rates of herbage growth, senescence and net production (kg DM/ha/day) in continuously stocked swards grazed by sheep. The associations between herbage mass, sward surface height (cm) and leaf area index on these swards are also shown. From Bircham and Hodgson (1982)



asymptotic and a progressive increase in senescence losses with increasing mass. The results shown in Figure 6 are typical of the series of studies which encompass simple perennial swards in which treatments have been imposed from the beginning of the grazing season or following a common spring grazing treatment. In a major field study, there were similar patterns of response in total lamb growth per ha and net herbage production per ha to variations in herbage mass.

The relative insensitivity of net herbage production to a wide range of variation in sward conditions under continuous stocking is a consequence of rapid adaptive changes in sward characteristics. Thus, a reduction in herbage mass from 2000 to 1000 kg OM/ha results in a reduction in the size of individual tillers but a compensatory increase in tiller population density to levels as high as 60000 tillers/m^2 and a marked reduction in tiller and leaf angle. These adaptive changes help to maintain the effectiveness of light interception and photosynthetic efficiency in closely grazed, continuously stocked, swards of low LAI. Net herbage production only starts to decline markedly at low levels of herbage mass where falling tiller population density and production per tiller reinforce one another.

The results indicate that responses are similar on sheep-grazed and cattle-grazed swards maintained at comparable levels of herbage mass but that cattle grazing eventually leads to a lower tiller population density, which is reflected in lower net herbage production. This work is now being extended to a study of herbage production and utilisation on swards grazed by sheep and cattle, alone or in combination, under controlled conditions.

Laboratory measurements of net canopy photosynthesis at a range of irradiance levels and of dark canopy respiration have been used to calculate net carbon assimilation on a daily basis for a range of swards. Net carbon assimilation above ground is approximately equivalent to gross OM accumulation (herbage growth as defined above) but, to obtain a measure of net OM accumulation (net production), it is necessary to measure independently losses due to senescence and decomposition. At present, this cannot be done by carbon flux methods alone. Procedures to estimate rates of disappearance of dead tissue in the field and rates of carbon dioxide release during the respiration of dead tissue are currently being investigated.

Adaptive changes in grazed swards

Adaptive changes in tiller population and leaf turnover per tiller serve to maintain rates of net herbage production on continuously stocked swards. The magnitude of these changes over a relatively short period of time is illustrated by the changing pattern of response in net carbon assimilation to variation in LAI over a period of weeks following the imposition of controlled grazing treatments on a series of swards (Figure 7). Changes in tiller population density can be rapid at any time of the year but the effects of differences in maintained sward conditions are much greater after the summer solstice, with declining light density, day length and temperature, than they are before the solstice, when environmental conditions are improving (Table 10). These observations suggest that transient advantages to net herbage production might result from changes in the balance of herbage growth and senescence under intermittent grazing, or following deliberate changes in herbage mass under continuous stocking. Work has been started to investigate this possibility.

Fig. 7

The relationship between leaf area index and net canopy photosynthesis ($gCO_2/m^2/h$ at 320 W/m^2) in ryegrass swards before (————) and after (— — — — —) a 4-week period of adaptation to continuous stocking with sheep

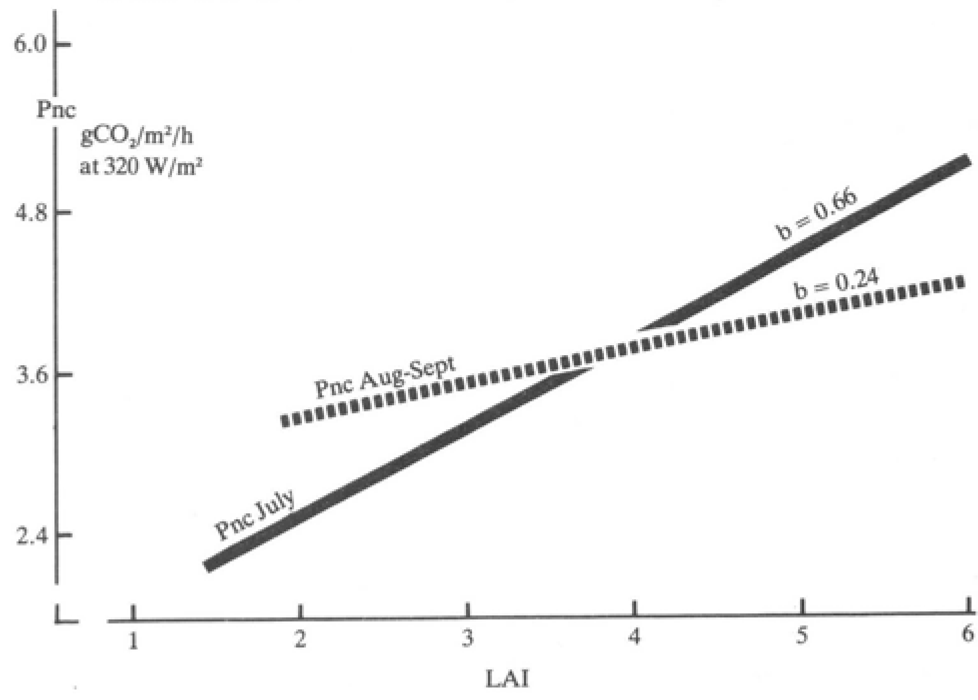


Table 10

Changes in tiller population density in continuously stocked swards in response to variations in herbage mass imposed at different times of year

	Initial tiller population (tillers/m²)	Herbage mass maintained (kg DM/ha)	Change in tiller population relative to base line (=100) after one month of treatment
(a)	Treatments imposed 18 June	950	175
	$28\text{-}34 \times 10^3$	1230	152
		1480	131
		2080	121
(b)	Treatments imposed 2 May	1640	142
	$18\text{-}23 \times 10^3$	2230	145
		2760	128
		2730	138

These studies demonstrate that there is little advantage to be gained in terms of net herbage production or in production of weaned lamb by maintaining continuously stocked swards at a herbage mass higher than 1200-1500 kg OM/ha (LAI 3). However, more information is needed to define optima for cattle or mixed sheep/cattle systems and to define the potential advantages to herbage and animal production of intermittent grazing or of deliberate changes in herbage mass under continuous stocking.

BIRCHAM, J. S. 1981. Herbage growth and utilisation under continuous stocking management. *Ph.D. Thesis, Univ. Edinburgh.*

GRANT, SHEILA, A., BARTHRAM, G. T. and TORVELL, L. 1981. Components of regrowth in grazed and cut *Lolium perenne* swards. *Grass and Forage Sci.* **36:** 155-168.

Carbon exchange measurements on continuously grazed pastures

[JK, EMS]

Carbon exchange measurements have been made on continuously grazed swards in some of the experiments described above. The object was two-fold. First, to examine the relationship between net canopy photosynthesis and leaf area index (LAI) in a variety of situations, to see how it was affected by grazing pressure and seasonal changes in sward structure. Second, to measure net carbon accumulation on a daily basis for swards of different LAI.

The technique involved measuring net canopy photosynthesis (Pnc) and dark canopy respiration (Rdc) on sample turves brought from the field to the laboratory. Measurements were made at a range of irradiance levels at constant temperature. The turf was then dissected to give data on herbage mass, tiller density and LAI. If net carbon accumulation was to be measured, additional measurements were made in the field. Changes in sward LAI were monitored weekly and a continuous record was made of irradiance and of air temperature at sward height.

To calculate daily net carbon accumulation, a response surface was derived for Pnc on irradiance and LAI and an equivalent function for Rdc on temperature. Using hourly values for irradiance and temperature from the field, daily gross and net carbon accumulation was then calculated for swards of any LAI.

Data for net canopy photosynthesis and LAI from a number of continuously grazed swards have shown that the relationship between these is substantially linear over the range LAI 2-6.

For measurements made at 350 W/m^2 visible irradiance, the linear coefficients were approximately as follows:

$$\mathrm{Pnc}\ (g/CO_2/m^2/h) = 1.92 \pm 0.6 + 0.72 \pm 0.12\ (\mathrm{LAI})$$

No significant variations have been found amongst sheep-grazed swards measured at intervals from May to July. Nor have any consistent differences yet emerged between cattle- and sheep-grazed swards measured from July to September. However, the latter were young swards with low tiller densities of less than 32000/m^2.

Significant variations in the Pnc × LAI relationship have been found to occur where there has been a rapid development of new tillers in closely grazed, low mass, low LAI, swards giving rise to high tiller densities of about $50000/m^2$. Such a change has been recorded in one experiment associated with an influx of new tillers in the period July to August. The following relationships were found:—

July: Pnc ($gCo_2/m^2/h$) = 1.2 + 0.78 LAI
Aug/Sept: = 3.0 + 0.30 LAI

The regression coefficients were significantly different and the effect was to reduce quite markedly the difference in photosynthetic rate between high and low LAI swards.

More recent data indicate that the linear relationship of Pnc to LAI found in continuously grazed pastures does not occur with swards regrowing after defoliation. On such swards, the relationship appears to be curvilinear.

Net carbon accumulation has been calculated on a daily basis for a period from July to September for four pastures continuously grazed at a range of herbage masses. Net carbon accumulation was greatest on the high LAI swards and smallest on the low, the size of the difference reflecting the form of the Pnc × LAI relationship used. Variations in the rate from day to day are largely a function of irradiance level and, to a lesser extent, temperature. The method seems to provide a useful way of measuring pasture growth rate but at present has only limited application. Net daily carbon accumulation above ground is equivalent to gross OM accumulation. To obtain a measure of net OM accumulation, it is necessary to measure losses by senescence and, at present, this cannot be done by carbon flux methods alone. It is hoped that further development of the technique will make this possible.

Net photosynthesis of indigenous grass species

[JK, EMS]

The rate of net canopy photosynthesis has been measured for swards of different grass species regrowing in a 14-day cutting cycle. At the same leaf area index (LAI), the rate for *Agrostis tenuis* was found to be significantly lower than that for S23 ryegrass. The difference at LAI 3 was about 25% and was observed at both high and low nitrogen level. No significant differences were found to occur among *Cynosurus cristatus, Poa pratensis* and ryegrass.

When comparisons were made between species after the same regrowth interval, no significant differences were found. However, LAI of *Agrostis* was significantly greater than that of ryegrass and this compensated for the lower photosynthetic rate per unit LAI.

Measurements were then made of the photosynthetic rate of single leaves and the results are shown in Table 11. These measurements were made at 140 W/m² visible irradiance on leaves of single plants grown in perlite in a controlled environment room (150 W/m² × 12h and 15°C). The data appear to confirm that differences exist between species although they may not always be manifest in terms of sward growth.

Table 11

Rates of photosynthesis of single leaves of indigenous grass species compared with S23 ryegrass (g CO_2/m^2 leaf area/h)

Leaf 1 and 2 = youngest and next youngest fully expanded leaves

Data for 4-11/2/80	Leaf 1	t	Leaf 2	t
S23 ryegrass	2.89	—	1.66	—
C. cristatus	2.26	3.11*	1.52	0.64ns
P. pratensis	1.84	4.32*	1.49	0.78ns
A. tenuis	1.83	4.67*	1.37	1.53ns
F. rubra	2.36	1.94ns	2.11	1.79ns
Data for 19-29/2/80	**Leaf 1**	**t**	**Leaf 2**	**t**
S23 ryegrass	2.33	—	1.76	—
C. cristatus	2.13	1.09ns	1.93	0.71ns
P. pratensis	1.88	2.19*	1.16	2.36*
A. tenuis	1.76	2.76*	1.25	2.10*

* $P < 0.05$

Indigenous hill plant communities

[SAG, JH, TDAF, GRB, LT, DES, RchdHA, MMB, TGC, RAH with RT]

The results of the first phase of an inter-departmental study, involving measurements of diet selection and nutrient intake by cattle and sheep grazing a series of indigenous hill plant communities at relatively low grazing pressures, are reported under Package 1, Project 03003. Phase two, which is due to start in 1982, will be concerned with the improvement of herbage production and nutritive value by manipulation of grazing management. The choice of managements appropriate to particular communities will be based on the results of phase one and measurements will be made of consequential changes in herbage production and nutritive value as well as in sward composition and structure and in nutrient intake by the grazing animals.

Project 04007/03002 — Cycling of nutrients in grazed hill pastures and its influence on requirements for lime and fertilisers

The underlying objectives of this programme are to quantify and understand the contribution of nutrients, re-cycled via grazing animal excreta, to the continuing needs of improved pastures, so that appropriate allowance can be made in assessing long-term maintenance requirements. One part of this programme is associated with improvement-response experiments on three sites at Sourhope (Input-Output experiments). Another part of the project has developed from earlier experiments on deep peat at Lephinmore and is now concerned with the phosphorus and potassium requirements to maintain re-seeded pastures in that environment. Some additional and related laboratory studies have also been undertaken.

Input-Output experiments at Sourhope

[MJSF, RAH, TGC, ADI, JE]

A cumulative, stepwise, series of improvement treatments, including grazing control, lime, phosphorus, oversown white clover and perennial ryegrass, were applied to *Agrostis/Festuca, Molinia/Nardus* and *Nardus/Festuca* pastures in 1969, 1970 and 1971, respectively, on acid brown and peaty podsolic soils at Sourhope. These long-term experiments were conducted in the context of the need to improve selected areas of hill land for use in a two-pasture system of management and our objectives included an assessment of the most appropriate combination of improvement treatments for each soil/pasture type. For this reason, grazing pressure (herbage allowance/sheep/day) was equalised across all treatments and grazing periods coincided as nearly as possible with the times when improved pastures would be grazed in the two-pasture system (Eadie, Hetherington, Common and Floate, 1981).

Pasture production responses over 10 years were described by Eadie *et al.* (1981), who concluded that the most useful overall comparative estimates of treatment effects were given by carrying capacity expressed as accumulated annual totals of sheep grazing days, where each grazing day is equivalent to between 1.3 and 1.5 kg ingested herbage.

Capacity ranged from 1800 days on control plots on the peaty podsol sites to 4500 days on the ryegrass/clover treatment on the acid brown soil in 1979, to between 2500 days on the control and almost 6000 days on the ryegrass/clover treatment in 1980. These capacities are equivalent to a range from less than 5 to more than 15 sheep/ha on a year-round basis. There tended to be relatively small differences between control, lime and phosphorus treatments on the grass heath sites but there were larger responses when improved pasture species were oversown. Production was higher on all treatments on the *Agrostis/Festuca* pasture and was consistently much higher on the ryegrass/clover oversown treatment.

A study of the decomposition rates of litter which was decomposing *in situ* on each of the treated plots, was conducted jointly with Dr P. J. Vickery (CSIRO) and showed that the loss rates of litter, nitrogen and phosphorus were closely related to soil pH. Soil pH and decomposition rate (and hence the release rate of plant nutrients) increased from peaty podsol to acid brown soil sites and there were highly significant increases in decomposition on all lime-treated plots at all three sites. There were, however, no significant differences among the various combinations of treatments with lime. Similar results were obtained using standard cotton strips ("pyjama strips") by measuring the loss in tensile strength which is related to the degree of decomposition. This part of the work was in collaboration with ITE, Merkwood.

Data on the amounts of nutrients re-cycled in excreta at each site and for each treatment over the first 6 years of the experiments were summarised for a paper given to the British Grassland Society Symposium on Hill Resources (Floate, Hetherington, Common, Eadie and Ironside, 1981). These data showed that, on all three sites, the amounts of nitrogen and phosphorus re-cycled via excreta had increased progressively with time and with each more comprehensive improvement treatment. The data also showed that when these amounts of re-cycling nutrients were expressed as a proportion of the total soil reserves, the proportions of both nitrogen and phosphorus re-cycled were more than doubled in a period of 6 years. It was concluded that the increasing proportion of re-cycling nutrients made a significant contribution to increased production.

EADIE, J., HETHERINGTON, R. A., COMMON, T. G. and FLOATE, M. J. S. 1981. Long-term responses of a range of grazed hill pasture types to improvement procedures. I. Pasture production and nutritive value. In *The effective use of forage and animal resources in the hills and uplands* (ed. J. Frame), pp. 167-168. *Br. Grassld Soc. Occ. Symp. No. 12, Edinburgh,* 1980.

Top-dressing experiments on reseeded pastures on peat

[MJSF, GRB, AR, ADI, JE with HKS]

Earlier work on the establishment requirements of reseeded pasture on deep peat and on the diagnosis of plant nutritional problems arising in grazing trials on these reseeds, has established the need for regular potassium and phosphorus maintenance fertilisers and has demonstrated the greater severity of potassium deficiency which may occur when only low rates of lime are applied (HFRO Jubilee Report, 1979, Ch. 3, and Floate, Rangeley and Bolton, 1981). The overall objectives of the present series of top-dressing experiments — both in cutting and in grazing trials — are to determine the minimum effective fertiliser requirements to maintain pasture production in the range 4000-5000 kg DM/ha. These requirements involve the need to determine both amount and frequency of application.

Two areas of grazed, reseeded, pasture, established in 1972, which had received the same total treatments of lime and fertilisers up to 1977, were treated again in the spring of 1978, '79 and '80 with a series of combinations of phosphorus and potassium fertilisers, including 0 and 30 kg P/ha, together with 0 or 50 kg K/ha applied annually or biennially. In all 3 years, it was found that the differences between the two replicate areas (I, II) were so great as to render mean treatment values worthless. Differences between I and II followed similar patterns in all 3 years and indicated significant responses to potassium on area I and significant, although smaller, responses to phosphorus on area II. These differences have been attributed to past differences in the timing of fertiliser treatments: area I received 105 kg P/ha and 66 kg K/ha in 1977, while area II received only 25 kg K/ha in 1976 and 10 kg P/ha together with 70 kg K/ha in 1977. The more recent phosphorus treatment on area I may explain the lack of phosphorus response until at least 1980, which suggests that it may be possible to space phosphorus maintenance treatments with at least 3-year intervals. No significant differences were recorded between annual and biennial potassium top-dressing treatments.

In 1978, tests were carried out to compare production estimates based on (a) the sum of a series of cut-herbage measurements taken throughout the season, with the total of sheep grazing days supported by each treatment, and on (b) the total intake by grazing sheep calculated from faecal DM and nitrogen regression equations. Good agreement was found between summation of herbage yield and results based on both sheep carrying capacity and calculated intake. This agreement between independent measurements of production adds support to the results for areas I and II, presented above, which were based on herbage yield data only.

In parallel with the grazed-plot experiments, trials have also been conducted on small cut-plots to determine responses of ryegrass/clover pasture to a wider range of annual phosphorus and potassium top-dressing treatments. In 1978, both ryegrass and clover responded up to 30 kg P/ha while clover but not ryegrass gave large responses up to 100 kg K/ha and smaller responses to 150 kg K/ha. The total herbage contained, on average, 64% of clover by weight and was also predominantly clover in 1979. Total herbage DM data for 1979 showed a response up to 100 kg K/ha.

Another area of ryegrass/clover reseeded pasture, established in 1972, when it was treated with 5 t lime/ha, has been the subject of a series of experiments since 1977. Among the most striking effects observed on this area has been the increasing divergence in yield between control areas and areas treated with a further 5 t lime/ha in 1977. The extra herbage production response to this further lime treatment was only 2% in 1977 but in 1978, '79 and '80 the responses have been 35%, 44% and 95%, respectively, greater than the control. These results were accompanied by a decline in the clover content of the pasture on the control areas which ranged between 1 and 15% in 1980 compared with 12-30% clover on the areas re-limed in 1977. From companion pH measurements, it may be concluded that it is necessary to maintain the surface water at above pH 5.5.

Although some interesting observations and some tentative conclusions have been drawn from the experiments on areas I and II above, the data lack precision with regard to amount and timing of necessary fertiliser requirements and it now appears that, because of past differences, these studies are not likely to provide information appropriate to the original objectives. Accordingly, a new area of reseeded pasture was established in 1980 and plans have been drawn up for a new study, based on the results from previous cut- and grazed-plot experiments, to define the amounts and frequency of fertiliser need.

FLOATE, M. J. S., HETHERINGTON, R. A., COMMON, T. G., EADIE, J. and IRONSIDE, A. D. 1981. Long-term responses of a range of grazed hill pasture types to improvement procedures. II. Nutrient cycling and soil changes. In *The effective use of forage and animal resources in the hills and uplands* (ed. J. Frame), pp. 147-149. *Br. Grassld Soc. Occ. Symp. No. 12, Edinburgh,* 1980.

FLOATE, M. J. S., RANGELEY, A. and BOLTON, G. R. 1981. An investigation of problems of sward improvement on deep peat with special reference to potassium responses and interactions with lime and phosphorus. *Grass and Forage Sci.* **36:** 81-90.

Project 04008 — Nitrogen fixation

[CM, AH]

In improved hill pasture, white clover must be managed so that it grows vigorously and fixes atmospheric nitrogen throughout the growing season, so that as much as possible of the fixed nitrogen is transferred to the associated grasses without adverse effect on the clover content of the sward. The rate of nitrogen fixation by nodulated clover depends ultimately on two factors: the rate at which the plant can produce sugars in its leaves and so supply energy to its nodules and the ability of the nodules to use this energy. Climatic factors, e.g. availability of sunlight, which affect photosynthesis in the leaves, will therefore affect the energy supply for symbiotic nitrogen fixation: similarly, management factors, such as grazing and cutting, which reduce the amount of foliage, affect the generation and transport of sugars to the nodules and will reduce the rate at which clover fixes nitrogen.

The specific areas we have investigated are the efficiency of nitrogen fixation in highly and moderately effective rhizobium/clover associations under conditions of differing photosynthate supply, the difference in efficiency of carbon use in leaves of plants fixing nitrogen and assimilating NO_3 and the response of the nitrogen economy of clover plants to defoliation. In addition to the laboratory studies, results of a field trial carried out to investigate the fixation and transfer of nitrogen in legume/ryegrass swards on deep peat are reported.

When white clover plants with highly and moderately effective rhizobium/legume associations were grown under two irradiances, 150 W/m^2 and 70 W/m^2, both associations showed low efficiency of nitrogen fixation (measured as gC respired/gN fixed/nodulated root) in the early stages of growth, with efficiency increasing as the plant grew. However, the moderately effective association did not attain the efficiency of the highly effective association, the peak values being 10 gC/gN and 5 gC/gN, respectively, at the lower irradiance. The difference was less at the higher irradiance, indicating that effectiveness of the rhizobium/legume association has a smaller effect when there is an ample supply of photosynthate.

The efficiency of nitrogen fixation in the rhizobium/legume association depends on the efficiency of reductant utilisation by the bacteroids and on the extent to which H_2 evolved by nitrogenase is recycled by the nodule uptake hydrogenase. Inefficiency in an ineffective association could be due to either or both of these factors. At the stage of growth where maximum efficiency had been reached, both associations lost over 50% of the electron flow available for nitrogen reduction in H_2 evolution. The difference in efficiency between the highly and moderately effective associations appears not to lie primarily in the evolution of H_2 but rather in the efficiency with which carbohydrate is used by the bacteroids.

Legume plants supplied with high levels of NO_3^- will reduce it to NH_4^+, even in the presence of an effective symbiosis and a supply of N_2. Moreover, in most cases they will grow faster and have a higher nitrogen content. We have found that white clover plants respire a higher proportion of their photoassimilate in fixing nitrogen than plants reducing an equivalent amount of NO_3-N. The effect of nitrate assimilation in photosynthetic tissue has been further examined by measuring CO_2 exchange by equivalent leaves on nitrogen fixing and nitrate reducing plants of *Vicia faba*. There appears to be no competition between CO_2 and NO_3^- for photosynthetically produced reductant and no increased rate of CO_2 loss in the light (photorespiration) in nitrate assimilating leaves. The greater efficiency of nitrate reduction in a plant with a nitrate reductase located in its leaves, compared with a nitrogen fixing plant, can perhaps be attributed to the fact that much of the reductant used in the reduction of NO_3^- to NO_2^- and NO_2^- to NH_4^+ would otherwise be lost from the system as heat.

As a pasture legume, white clover is subjected to regular defoliation by grazing animals. Severe defoliation can cause the cessation of nitrogen fixation, thus disrupting the nitrogen economy of the plants. An investigation of the response of the nitrogen economy of single clover plants to removal of leaf material was carried out, using nodulated plants which had been supplied with ^{15}N labelled nitrate or ammonium nitrogen prior to defoliation. The ^{15}N enrichments of different plant organs varied quite considerably, with greater enrichment of root material and lower enrichment of nodules, indicating incomplete mixing of mineral and fixed nitrogen within the clover plant. The root relies more heavily on mineral nitrogen, with 33% of the plant ^{15}N found in root material compared with only 12-20% of plant total nitrogen. The nodules, on the other hand, show a greater dependence on fixed nitrogen. The nitrogen levels in leaf material and growing tips were higher in plants which had been defoliated, showing these areas to be a priority sink for nitrogen supply in the post-defoliation period. There was little increase in plant total nitrogen in a 21-day period following defoliation, with the nitrogen for regrowth coming from redistribution of already assimilated nitrogen, mainly from stolon material.

The field trial to determine patterns of nitrogen fixation and transfer was conducted on established swards of lotus/ryegrass and white clover/ryegrass on deep peat. The swards were cut three times in the first season and once in the following spring. Immediately after each cut, ^{15}N labelled fertiliser was applied to the microplots to determine nitrogen fixation and underground transfer in the inter-harvest periods. A marked depression of nitrogen fixing activity (C_2H_2 reduction) was found in response to defoliation, superimposed on a seasonal pattern where nitrogen fixation was highest in the early summer. There was no nodule breakdown in response to defoliation, even at the autumn harvest. There was little isotopic evidence of nitrogen transfer from legume to grass, with the ^{15}N enrichments of grass in pure and mixed swards differing only slightly. However, there appeared to be more available nitrogen under the mixed sward than in legume-free areas, since grass from the mixed sward contained more total nitrogen than did grass from the pure sward.

Project 04009 — Studies of the relationship amongst mycorrhiza, rhizobia and the growth and performance of nodules on white clover roots

Microbial requirements of white clover growing in hill pastures

[AR, JML with GJD]

During the past 2 years, work on microbial interactions with white clover has been entirely on vesicular-arbuscular (VA) mycorrhizal fungi. The external hyphae of the VA fungi, in this mutualistic symbiosis, are thought to increase the surface area of the roots and to actively absorb nutrients. Therefore, when the supply of a nutrient in the soil restricts plant growth, mycorrhizal infection can increase the nutrient intake and so increase plant growth. The nutrient most commonly implicated is phosphorus and, since growth of white clover in hill soils, once the acidity has been corrected, is most likely to be restricted by a deficiency of phosphorus, there has been interest in manipulation of this group of fungi.

The experiments have compared the effects of inoculation of white clover with a number of species of VA fungi, after application of a range of levels of superphosphate, in field experiments and in a pot experiment conducted in a growth room. The aim of inoculation was to place mycorrhizal propagules close to the seed so that the introduced fungi could colonise the clover roots soon after germination and potentially be of maximum benefit to plant growth.

Three soils were used in the experiments, a deep peat from Lephinmore which had 0.32 propagules of indigenous VA mycorrhizal fungi per g of soil and was very low in available phosphorus (Index 1); a brown earth from Sourhope which had 2.47 propagules per g of soil and a moderate available phosphorus status (Index 3); and a brown earth from Cleish which had 5.42 propagules per g of soil and a low available phosphorus status (Index 1). The number of propagules was estimated by observing the presence or absence of infection in the whole of the root system of white clover grown in soil serially diluted by sterile sand.

The pot experiment used two of the soils, the Sourhope brown earth and the Lephinmore deep peat. The soils were limed, given potassium chloride and a range of levels of superphosphate, the nearest equivalents in a plant pot to 0 to 200 kg P/ha. Sand containing approximately 160 spores of either *Glomus mosseae* L1 or *Glomus etunicatus* or sterile sand was mixed with the clover seed (previously inoculated with *Rhizobium*) into the surface soil of each pot. Three plants were grown for 8 weeks at a temperature of 15°C day/10°C night for 11 hours with 95 W/m^2 of photosynthetically active radiation and 90% humidity.

With the deep peat soil, fertilisation with superphosphate increased growth of white clover at all levels of application but inoculation with VAM increased growth only at the 0 and 20 kg P/ha level and decreased growth at the 200 kg P/ha. However, at all levels of added P, inoculation increased the level of root infection, the higher the level of added superphosphate the smaller the increase. Inoculation with both VA endophytes produced similar effects.

In the Sourhope brown earth, there was a smaller DM response by white clover to applied superphosphate than in the deep peat and VA inoculation had no significant effect on growth when comparisons were made at any particular level of phosphate. However, averaged over all levels of applied phosphorus, white clover inoculated with *G. etunicatus* produced more growth than clover inoculated with *G. mosseae* L1. In this soil, infection with indigenous endophytes ranged from 30-50% of the root system. The indigenous species which colonised the roots had, in the main, fine hyphae and the introduced endophytes formed colonies with coarse hyphae. It was shown that, after inoculation, the proportion of coarse hyphae which colonised the root was increased from one tenth in uninoculated roots to between one-third to a half of the total amount of infection.

At Lephinmore, on the deep peat, an experimental site was cleared by cutting the indigenous vegetation. Lime and potassium fertiliser were applied to the whole of the site and three rates of superphosphate (0, 20 and 200 kg P/ha) were applied to the plots. Mycorrhizal inoculum (sand which contained fragments of infected root and fungal spores) or sterile sand were broadcast onto the surface of the peat with the white clover seed coated with *Rhizobium*. White clover did not establish in the absence of phosphorus. Inoculation with *G. mosseae* L1 had no effect on growth, when the site was harvested 1 year after it was sown, at any of the levels of applied superphosphate. However, the level of infection was doubled from 18% in the uninoculated clover to 42% in the inoculated plants.

A brown earth site at Sourhope was given a basal dressing of lime and potassium chloride and fertilised with 2 levels of applied superphosphate (0 and 40 kg P/ha). The soil was rotovated and the seed and inoculum were broadcast and then raked into the surface. In this experiment, the effect of *G. mosseae* L1 and *G. etunicatus* were again compared. The site was sampled for 3 years. At no time were the DM yields from the shoots of white clover affected by the superphosphate. In the year of sowing, inoculation with mycorrhizas had no effect on growth although the level of infection by coarse endophytes was increased after inoculation. In the subsequent 2 years, clover inoculated with *G. etunicatus* and given superphosphate produced significantly more growth than all other treatments. The reason for this is not clear since phosphorus did not limit growth. Possible explanations, such as uptake of other plant nutrients by the VAM and better growth of clover at the expense of weed grasses, do not account for the increase in growth of clover.

At a third site, on a brown earth at Cleish, the preparation was similar to that at Sourhope, except that the white clover seed inoculated with *Rhizobium* and the mycorrhizal inoculum were drilled into the soil to ensure a close contact between seed and inoculum. In the year of sowing and in the subsequent year there was a DM response to fertilisation with superphosphate (50 kg P/ha) but no statistically significant beneficial response to inoculation with any of the four types of VAM used. One of the inocula, *G. mosseae* L1, caused a depression in yield in the year of sowing but this detrimental effect was less in the following year. Plants inoculated with *G. clarus* looked larger than uninoculated plants or plants treated with the three other inocula in the spring of the first 2 years but there were no differences between treatments in DM yields when the site was harvested in early summer. In the third spring, the ground cover of white clover was intensively measured using point quadrats but there were no differences between mycorrhizal treatments.

Inoculation with VA mycorrhiza therefore increased growth of white clover at low levels of applied phosphorus in the pot experiment with peat but did not affect growth in the field. In the Sourhope brown earth, inoculation had little effect on the growth of white clover in the pot experiment but one of the inocula, *G. etunicatus*, increased growth in the field, while, in the brown earth at Cleish, one inoculum, *G. mosseae* L1, reduced growth. These results suggest that strains of fungi may differentially affect the growth of the host and that the effects may be influenced by environmental conditions. To be able to choose the correct inoculum, the environmental tolerances of the white clover/mycorrhizal symbiosis must therefore be assessed. The efficiency of colonisation and nutrient uptake by indigenous VAM must also be studied to assess the need of a particular site for inoculation.

Project 04011 — Soil chemistry — acidity

In this project, we are seeking an improved understanding of the factors which influence acidity in hill pasture soils and control soil pH response to lime. The objectives include the development and application of improved methods of predicting the lime requirements for establishment and maintenance of improved pastures on typical hill soils. Additionally, a short-term project on the interactions between acidity, soil aluminium and soil phosphorus availability was conducted by a post-graduate student (LJS) supported by an ARC Post-graduate Studentship.

The work is described under three sections — laboratory studies, field studies and effects of acidity on phosphorus availability — but there is considerable overlap between these approaches.

Laboratory studies of soil acidity and lime response

[KL, MJSF]

Work leading to an improved understanding of the relationship between OM and acidity in hill soils and also to the proposal to use calculations based on part-saturation of the cation exchange capacity (CEC) of these soils measured at pH 7 for the prediction of lime requirement (Floate, 1978), is described elsewhere in this report.

With the resignation of Dr M. S. Pimplaskar in 1978 and the absence abroad of MJSF in 1979, little laboratory work was carried out on this project until KL was appointed in August, 1980. The work described here was done in the latter part of 1980, when priority was given to an investigation of the pH-dependent component of CEC.

Four of the soils used in this study were selected so as to form two pairs, one with less than 25% and the other with more than 50% OM. Within each pair, one soil had less than 50 meq./kg exchangeable aluminium while the other contained about 100 meq./kg or more exchangeable aluminium. The remaining six soils were from a former lime trial in N. Wales, where the long term residual effects of earlier lime treatments had been shown to have effects on the amounts of exchangeable aluminium for a period of at least 20 years (see Acidity Review).

These soils broadly fell into two groups, with OM contents in the range 15-20% and 60-80%, respectively. CEC measured at pH 2.5, 3.5, 5.0 and 8.0 increased with increasing pH but increased much more rapidly for the organic group of soils (more than 550 meq./kg as pH increased from 3.5 to 8.0) than for the less organic soils, where the corresponding pH-dependent increase in CEC was only between 200 and 300 meq./kg over the same pH range.

The CEC of each soil, measured at any given buffered pH, appeared to be independent of the natural pH of that soil or of its past liming history. This observation was confirmed when it was found that adjacent limed and control soils from the same site gave the same value for CEC at pH 7.

This finding suggests that the proposal to use calculations based on CEC at pH 7 as a basis for predicting lime requirement, may have a limited value for virgin soils only and that some function of pH-dependent CEC may be more generally useful for predictive purposes. (For more recent developments see Acidity Review).

FLOATE, M. J. S. 1978. The reclamation of acid hill soils in Britain. *11th Int. Congress, Int. Soc. Soil Sci.* Commission II (Soil Chemistry). Section 6. Chemistry of soil reclamation, Vol. I, 365-366 (Abstr.).

Field studies of soil response to lime

[MJSF, KL, ADI]

Two field experiments, of the same design, were started in 1974 and 1975, respectively, on deep peat at Lephinmore and on acid brown soil (Linhope Series) at Stanhope, in the Upper Tweed Valley (by courtesy of Animal Breeding Research Organisation). The objectives of these experiments were to measure the field soil pH response to rates of lime up to 5 t/ha, to provide samples to study the effects of lime on exchangeable acidity and exchangeable aluminium in the soil and to observe the persistence of sown ryegrass and clover as pH declined with time.

The experiment on deep peat was abandoned in 1978 and some reference is made to the results in the Acidity Review.

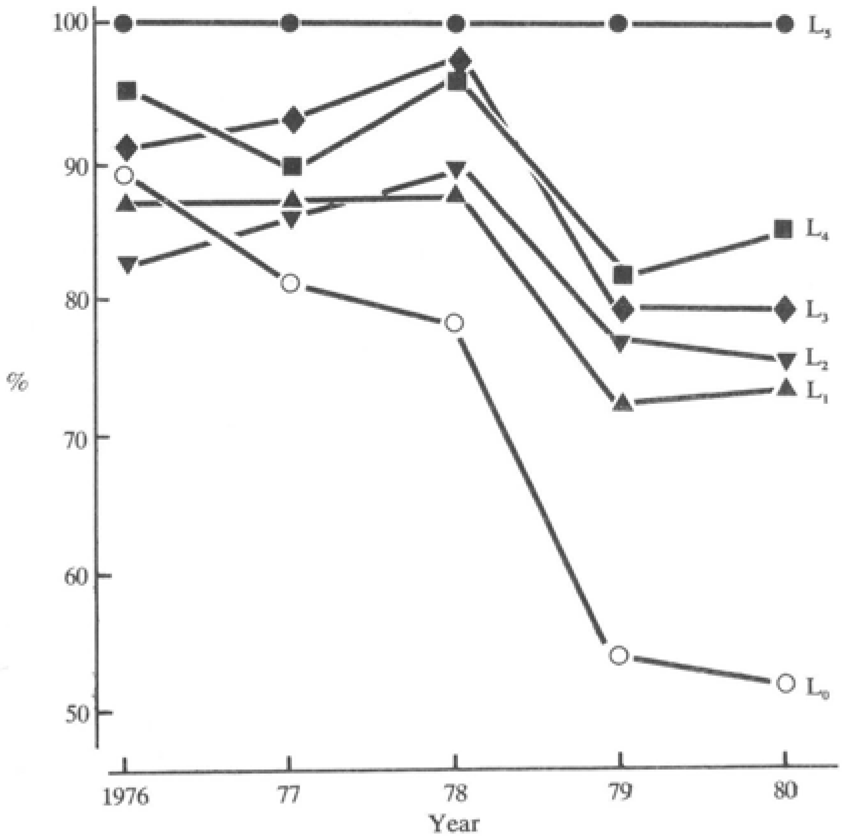
The experiment on the acid brown soil gave some rather surprising results in the early years, when no significant differences between treatments (including a control treatment with no lime, L_0) were observed until 1978. In that year, treatment L_0 yielded significantly less herbage dry matter than did treatment L_5 but no other treatment differences were significant.

The reasons for the persistence of production from reseeded ryegrass and clover for at least 3 years, even in the absence of any lime treatment on a soil whose natural pH was less than 4.5, appear to be: (a) the liming value of the basal dressing of 1 t basic slag/ha and (b) the small lime requirement (less than 1 t $CaCO_3$/ha) calculated as described above from CEC measured at pH 7.0. This provides field evidence for the applicability of the method to virgin soils.

Only since 1978 has the control treatment declined significantly in herbage production and, in 1979 and 1980, this was approximately half the yield on the highest (L_5) treatment (Figure 8). Also in 1979 and 1980, treatments L_1, L_2, L_3 and L_4 fell significantly in yield below L_5 but there were no significant differences among this group of treatments.

Fig. 8

Percentage relative herbage yield — Stanhope lime response experiment



The original treatments were retained in 1979, because it was intended that evidence be gathered as to when maintenance lime treatments would be necessary on the intermediate levels of treatment. With hindsight, that now appears to have been in 1979 (Figure 8). However, very similar relative levels of production were continued on these treatments in 1980 and, in that year, split plot maintenance treatments (a repeat of the original 1975 dressing) were applied to one half of each plot. Only slight increases in yield occurred as a result of the second lime treatment in 1980 and, on average, this amounted to an increase of 8% over the yield on the part of the plot without maintenance.

Vegetation records show that before maintenance treatments were applied in 1980, the proportion of clover in the sward was 0-10%

on L_0, 10-20% on treatments L_1, L_2, L_3 and L_4 and 20-30% on treatment L_5.

Work is continuing on this experiment to determine the minimum effective amounts and times of lime application to maintain improved herbage production on this soil type.

Interactions between acidity, soil aluminium and phosphorus availability

[LJS, MJSF]

Observations on the high levels of extractable and exchangeable aluminium in some acid hill soils were followed up with work on the possible impact of soil aluminium on the chemical and biological availability of phosphorus for pasture plants. This was the subject of a PhD project completed in 1980.

Details of the soils, analytical and biological methods used, results obtained and conclusions reached are available in the PhD thesis (Sheppard, 1981) and only some of the most important findings are described here.

Three forms of aluminium (extractable, exchangeable and soluble) all influenced plant growth but in different ways. Extractable aluminium influenced phosphorus availability through its strong affinity for phosphorus and was highly correlated with phosphorus sorption index (PSI) which was inversely related to phosphorus supply. Exchangeable aluminium was inversely related to pH and base saturation and so had an influence on the relative amounts of aluminium and calcium on exchange sites and in solution. Soluble aluminium inhibited root growth and nutrient uptake when its concentration exceeded 0.3 mmol and, in the range 0.1-0.3 mmol, root growth and nutrient translocation were partially impaired.

The amounts of exchangeable and soluble aluminium (in dilute $CaCl_2$ solution) generally decreased with increasing soil pH and were very low above pH 5.4 and 4.4, respectively, so that only in the most acid soils were the effects of aluminium on plant growth likely to be limiting: soluble aluminium was highest when aluminium saturation of CEC exceeded 80%.

Low phosphorus availability was a universal limitation in the soils examined and, in some soils, this was aggravated by high levels of aluminium. When ryegrass response to superphosphate was limited by the concentration of soluble aluminium, as described above, liming, to raise soil pH and lower soluble aluminium, was an essential prerequisite to maximum phosphorus response. The large increase in available phosphorus, arising from fertiliser application on all soils, was not matched by corresponding increase in phosphorus uptake by ryegrass when soluble aluminium was above the critical level. Under these conditions, an apparent increase in chemical availability was not matched by an increase in biological availability of phosphorus.

SHEPPARD, L. J. 1981. Studies of aluminium and phosphorus in hill soils. *Ph.D. Thesis, Univ. Edinburgh.*

Package 5. Husbandry of red deer (with Rowett Research Institute)

Project 05001 — Identification of the practical problems associated with the application of domestic animal husbandry methods to red deer kept under semi-intensive conditions

[WJH]

Longevity studies

These continue on the main and upper deer farms. All animals are fully monitored throughout the year and the data recorded. To date there has been no deterioration in the performance of the breeding herd. The oldest hinds, the 1970 cohort, have now reproduced for the ninth time, calf birth weights and calf growth rates are similar to those of earlier years. The hind body weights in the autumn have actually increased and are presently the highest ever recorded on the farms. The condition of their teeth remains good and there are no 'broken-mouthed' hinds in any of the cohorts.

Upland deer project

The results obtained from the herd on the indigenous pasture of the main farm and on the high altitude reseeded pastures of the Upper farm and their costs in relation to performance have prompted an investigation into the performance of red deer on good quality upland pasture. The experiment was set up in 1980 on the Lochhills area where the 5-year study on upland sheep production had been carried out. This provides an opportunity to compare the production of a red deer herd with upland Greyface ewes on similar land and with similar management inputs.

Two systems are being compared. System A has a heather hill outrun on which the hinds are mated and over-wintered. System B has a simulated courtyard where the hinds are kept over winter and fed their entire nutritional requirements. The 34 hinds in each system are stocked over the grazing phase at 10 hinds per ha. The System B hinds are mated on the pastures.

The hinds used in the study were moved from the main deer farm to the Lochhills area on 5th May and, after some restlessness, settled down to calving in June. All the hinds produced calves. However, one calf was rejected at birth, two hinds were assisted at parturition and four hinds adopted a second calf. These behavioural problems were probably associated with the shift from the hill grazings to a new environment in late pregnancy. The incidence of dystokia was higher than previously recorded. While birth weights were similar to those on the main hill farm, growth rates were higher and, in consequence, weaning weights were also higher, at 46.8 kg for stags and 39.8 kg for hinds. Calves on the hill farm were 41.6 kg and 37.0 kg, respectively.

The experimental area has a provision for accommodating the weaned calves on grassland in the first autumn and again in the following spring until 16 months of age. The weaned calves gained some 5 kg in body weight on the grass until housed in early December.

In-wintering studies

Weaned calves from the hill farms are housed immediately after the September stock gatherings. This has meant a long period indoors until there is sufficient grass growth in the spring, usually in May, when the animals can be returned to the grazings. In-wintering deer calves can cost up to £30 per head. Experiments have been carried out over 2 years to test the effect of different nutritional wintering regimes on the performance of the calves over winter and during the subsequent grazing phase to 16 months of age.

In the first year, stag calves were fed on low (250 g concentrate/head/day) and high (1000 g concentrate/head/day) planes of nutrition, both with hay on offer *ad libitum*. At turnout in May, the high plane calves were some 10 kg heavier than the low plane calves. During the summer grazing phase, however, the low plane calves expressed a degree of compensatory growth and had reduced the difference by some 40% at the time of slaughter in September. Feed costs were £27.63 and £16.10 for the high and low plane fed calves, respectively. In the second year an experiment was designed to examine whether savings could be made in feed inputs without affecting the 16-month body weight. Stag calves were fed 1000 g concentrate/head/day plus hay *ad libitum* from November until 14th December, when the concentrate ration was reduced to 500 g/head/day. The concentrate was held at this level until 28th February when the ration was increased again to 1000 g/head/day until turnout in May. There was no difference in the final weight achieved by this group of calves compared with another group fed at the 1000 g level throughout the winter period. These two groups and the high plane group of the previous year's experiment reached pre-slaughter weights of 74 kg.

From the results of the work completed to date there would appear to be three phases of wintering for deer calves. The first phase from weaning in September until housing in early December is a period of high potential growth and, on an economical and live-weight increase basis, is best met by the provision of adequate quality grazing. The second phase from December to the end of February would appear to be less important and inputs can be reduced to maintenance requirements. The third phase commences in March and is another period of high potential growth when inputs should be increased to allow the animals to grow to their potential.

Veterinary monitoring

[AW, ARF, AJM]

Planned veterinary programmes seek to promote positive health by the application of the available methods of prophylaxis to appropriate classes of stock at the correct times. These embrace the use of vaccines, anthelmintics and minerals, including trace elements; they also include husbandry procedures such as dipping, footcare and dry cow therapy. In particular, routine measures are applied to bought-in stock and stock transferred between the Organisation's farms. Where new systems of animal production are being appraised, the changes inherent in these can introduce factors that may have a profound influence upon disease patterns. Monitoring of the health of flocks or herds is an integral part of preventive programmes, in order to evaluate their efficacy, to detect emerging problems and to indicate both where adjustments are necessary and where investigations in depth are required. Examples of the latter include fascioliasis at Lephinmore, cobalt deficiency at Glensaugh and copper deficiency at Sourhope.

In cattle studies, the importance of enteric disease in housed suckled calves has led to collaborative studies with the Animal Diseases Research Association, Moredun Institute, in the development of vaccines.

Monitoring information is derived from two main sources. The first is concerned with the taking of samples from representative numbers of animals at suitable intervals; faecal samples to check endoparasite burdens and the presence of enteric disease, and blood samples for trace-element status and serological evidence of infectious disease. Other procedures, such as pasture larval counts, assist in forecasting gastro-intestinal parasite problems, while snail counts yield valuable information on fascioliasis. The second source of information is from records of ill-health and deaths, allied to post-mortem and laboratory findings carried out by the local veterinary practitioner and the veterinary investigation service.

Project 02008 — Cattle production

The problem of enteric disease in housed suckled calves has been a perennial one since the suckler cow studies commenced. The impact of these infections relates to a highly susceptible population with conditions favouring transmission between calves. The association of rotavirus and coronavirus infections with outbreaks of scour led to collaborative studies with the Moredun Institute in evaluating the prepartum vaccination of dams to provide protection to the calves via the colostrum.

In 1979, the spring-calving herd suffered a high morbidity associated with rotavirus and coliform infections. Contributing factors were the presence of bought-in calves and adverse climatic conditions in the shed. An outbreak of enteric disease in the autumn calving herd contrasted with the spring outbreak, in that, while morbidity was high, mortality was low and, apart from a recurrent scour, calves were bright and clinically unaffected. The organism responsible was a cryptosporidium (a member of the protozoan group, coccidia). This organism has only recently been incriminated as a potential cause of enteritis in the U.K. In this outbreak, no evidence of viral infection was found and it is postulated that the presence within the herd of a high percentage of vaccinated cows may have had a positive effect in reducing the impact of viral pathogens.

Dry cow therapy and routine spraying against flies in the dangerous months are implemented to control summer mastitis. Routine sampling of cows and calves provides information on trace-element status and endoparasite incidence.

Project 03004 — Year-round grazing systems

(1) *Lephinmore*. A strategic dosing programme against ovine fascioliasis based on the premise that by killing flukes before they reach maturity, the deposition of eggs on the pasture will be severely limited, has been extremely successful. Phase 1, from 1973 to 1976,

reduced the incidence of ewes passing fluke eggs in both the Midhill and Low end flocks from around 75% to a very low level. In phase 2, dosing was stopped in the Midhill flock in November 1976 but continued in the Low end flock until June 1980. In this phase, the incidence of ewes in both flocks passing fluke eggs has never exceeded 1%. Phase 3 commenced in June 1980 and is currently being monitored to evaluate this strategic dosing approach followed by a cessation of dosing to see if, by severely limiting fluke egg deposition on pastures, a level close to eradication can be achieved. The indications are that this approach will have economic benefits.

(2) *Glensaugh*. The significant disease encountered in the flocks was pasteurellosis. It is hoped that a new vaccine currently being tested will help to reduce such losses. In 1980, a problem of facial lesions caused by a staphylococcal infection complicated by contagious ecthyema (orf) affected a large number of lambs but the response to therapy was good.

(3) *Sourhope*. There were no significant losses attributable to any specific disease problem.

Project 03005 — In-wintering system

At Sourhope, in 1979, an outbreak of mild respiratory infection (presented clinically as coughing) occurred in lambs from the Rigg and Gairs flock. This was presumed to be related to a change in management in that year when lambing took place indoors for the first time and the causal organism was considered to be parainfluenza 3 virus.

Project 03008 — Upland sheep

The Greyface flock has endemic Jaagsiekte as a problem accounting for annual ewe losses of between 5 and 7%. There is no early diagnostic test for this disease and currently the only way of containing it is prompt removal of clinical cases and strict segregation from other flocks. Replacement animals cannot themselves be guaranteed as being free from the disease and are susceptible to that already present in the flock.

At all farms, the policy of controlling roundworm infections in sheep is based on dosing ewes twice annually. Once close to parturition and again in the autumn. The improved pastures are contaminated and lambs are at risk from overwintered larvae as well as from larvae from the peri-parturient rise in ewes. Lambs on the improved pastures are dosed with an anthelmintic at intervals of approximately 3 weeks until weaning. The commencement of dosing is based on our own nematodirus forecasts.

Pasture larvae counts give useful guides on pasture burdens and on forecasting peaks of infection. These, coupled with worm egg counts, enable appropriate measures to be taken when the incidence forecasts are high. All housed stock are dosed at entry to the house.

All lambs on reseeds are dosed with cobalt drenches in the summer and, at weaning, stock ewe lambs are given a cobalt bullet. Copper therapy is administered on the results of blood copper status estimations.

Project 05001 — Red deer

The spread of cryptosporidiosis to artificially reared red deer produced an outbreak of severe clinical disease with a high mortality and a poor response to drug therapy. This severity accords with findings in artificially reared young animals of other species.

The demonstration of low plasma copper concentrations in calves and hinds grazing improved reseeded areas at Lochhills contrasted with levels in the 'normal' range (applying criteria as for cattle and sheep) of animals with access to the indigenous hill pasture. Further studies will continue to examine possible differences between copper sufficient and copper deficient deer.

The control of endoparasites by routine dosing is complemented by faecal examinations. This is of importance particularly in dictyocaulus infection which is a serious hazard of farmed red deer.

Data handling

[ARS, EVD, JOT]

Projects 01004, 02002, 03004, 03005, 03008

Data from each of the eight Systems Development projects are processed and summarised by computer at Headquarters. The same data handling package is used for the mid-pregnancy nutrition project at Lephinmore. A total of approximately 8000 detailed individual animal records (ewes and lambs) is handled each year.

Data from a Hill Sheep Development Project run jointly with COSAC (Project 48001), some 15000 animal records, are also processed on EMAS using a simpler data handling program package.

In addition, the physical data from the Hill Sheep Development Program, representing approximately 15000 animal records, are processed on EMAS using a simpler data handling program package.

The data base of detailed individual animal records has a very wide range of uses in providing information on biological responses within defined management systems. Two examples are shown here.

The data are currently being analysed in such a way that criteria for flock management, particularly in relation to ewe live weight, can be developed. Evidence suggests that, although live weight and/or live-weight change may only account for a relatively small proportion of the variation in sheep performance, they nevertheless could serve as useful parameters on which to base management decisions, e.g. the need to feed supplements or to provide more pasture.

1. Data from 5 years of traditionally managed Blackface ewes from four hirsels on three of HFRO's farms, 3761 ewes in total, were analysed in order to quantify the effect of ewe pre-mating live weight and changes in weight after pre-mating on lambing performance. The following regression equations were derived and show the importance of achieving a higher pre-mating live weight. On this basis it becomes possible to organise the management of feed inputs (pasture or supplementary feed) to achieve such an objective and to estimate the benefit of doing so.

$$NLB = 0.29 + 0.021PM + 0.22PMC \ (p < 0.001; R^2 = 0.10) \quad (1)$$

$$LBWS = 1.51 + 0.0531PM + 0.040MWC \ (p < 0.001; R^2 = 0.17) \quad (2)$$

Where NLB is no. of lambs born per ewe

PM is ewe pre-mating live weight (kg)
PMC is ewe live-weight change, pre-mating — mid-winter (kg)
MWC is ewe live-weight change, mid-winter — pre-lambing (kg)
LBWS is lamb birth weight of singles (kg)

Equation 1 implies that each additional kg of live weight at pre-mating will result in an additional 2.1% lambs born, while each kg of live weight lost after pre-mating and before the turn of the year will provide a loss of 2.2% in lambs born.

Equation 2 implies that each additional kg of live weight at pre-mating will produce 53 g of additional weight on each single lamb born, while each kg of weight gained between mid-winter and pre-lambing will result in an additional 40 g of single lamb birth weight.

2. A study was made of 7 years data from ewes on the Birnie hirsel at Glensaugh, in order to investigate the number of newly born lambs "at risk". A total of 1731 lambs was classified into 1 kg groups based on birth weight and Table 12 shows the distribution of individuals in these groups. Table 13 shows the percentage of lamb deaths in each 1 kg birth-weight class, with emphasis on early deaths.

Table 12 shows that more than 20% of twin lambs weighed less than 3 kg at birth and Table 13 indicates that more than 25% of these lambs are at risk. These data on lamb mortality and its association with lamb birth weight, indicate the potential benefits of increasing lamb birth weight. There is good evidence to suggest that lamb birth weights can be increased by late pregnancy feeding. By examining the distribution of birth-weight classes in a flock, the potential benefits of feeding in late pregnancy, to reduce the proportion of lambs in the lowest classes, can be estimated.

Table 12

Glensaugh (Birnie) 1973-1979

No. of lambs in 1 kg birth-weight classes

	<2	<3	<4	<5	<6	<7	<8
Singles	4	60	276	373	119	14	1
Twins	14	192	520	150	8	0	0
All lambs	18	252	796	523	127	14	1

Table 13

Glensaugh (Birnie) 1973-1979

Percentages of lamb deaths in 1 kg birth-weight classes

	<2	<3	<4	<5	<6	<7	<8
Born dead	11.1	3.6	2.8	1.1	0.8	7.1	0.0
Died in 24h	27.8	7.1	2.9	1.3	6.3	0.0	0.0
Died in 48h	11.1	1.6	1.5	0.2	0.0	0.0	0.0
Died in 7 days	0.0	3.6	0.6	1.0	0.0	0.0	0.0
Died later	16.7	9.9	6.4	5.7	5.5	14.3	0.0
Total deaths	66.7	25.8	14.2	9.4	12.6	21.4	0.0

Computing services

[JAR]

Courses and tuition

Two courses for members of staff have been given. One, attended by about twenty, was devoted to teaching the use of the EMAS system.

This consisted of six lectures and associated practical demonstrations and staff were encouraged to make as much use of EMAS as possible, a number of exercises being provided to facilitate this. The other course, comprising a talk and numerous practical tutorials for small groups, was devoted to instructing staff to use the micro-computer, operating the UCSD-P system.

In addition, individual members of staff have received instruction in various aspects of computing, according to their requirements.

Software development

On EMAS, programs have been written and up-dated to cope with a variety of requirements. Larger packages include programs to process results from scintillation counters and from *in vitro* digestion analyses.

A comprehensive package of programs has been written to process the vast body of data produced by the automatic weather recording stations. These include a primary processing unit which reads the data produced by the data-loggers, detects and corrects a range of faults and anomalies and gives a summary of the data, a listing of all the faults that were detected and a file containing the corrected data and the date and time for each record. All the met. data are subsequently stored in binary sequential files, which can be read and processed much more rapidly and efficiently than 'character' or 'card-image' files. Programs available include one which gives monthly summary tables, tables of integrated temperatures, graphs of temperatures or rainfall histograms.

On the micro-computer:—

This is primarily dedicated to data preparation, in which function it replaces card punching machines. Consequently, programs have been developed to enable the micro-computer to be used in a similar manner to a card punch by reading 'format codes' and then reading in data which are then stored in a format determined by the 'format code' and in a file which may then be transmitted to a 'main frame' computer.

Glasshouses, growth rooms and microclimate

[DES]

Project 54001 — Maintenance of glasshouses and growth rooms at Bush and organisation of micro-meteorology required in field trials

Usage of the glasshouses has decreased slightly over the period of this report with more practical work being initiated in the field. The growth rooms have continued to be used to the full.

Automatic weather stations were installed to measure microclimate for various individual experiments at Lephinmore, Hartwood and Glensaugh (Hardpark, Met. Field and the Slochd). Programs now exist to extract a wide range of meteorological information from the raw data.

Analytical services

[ES, CCE, PEM, JM, DRC, ET, RES, HAS, SC]

Projects 51002, 51003, 54002

In support of the research programme, 130000 analyses were carried out on samples of plant tissues, soil extracts, biological fluids, animal feeds and animal tissues. In addition, small numbers of samples were analysed by specialised techniques (mainly X-ray fluorescence) for Animal Diseases Research Association, Grassland Research Institute, East of Scotland College of Agriculture and North of Scotland College of Agriculture and facilities were provided for Animal Breeding Research Organisation to undertake analysis of plasma samples from three projects.

Analytical methods

A comparison of preparation procedures used in the determination of faecal nitrogen showed that there was no difference between freeze-dried samples and those prepared by the conventional slurry technique. Preliminary work on the determination of plasma acetate by gas chromatography was undertaken. A method for the determination of copper in milk was developed. An evaluation into the possible use of Near Infra-red analysis to estimate digestibility, fibre and nitrogen of herbage was undertaken. Using sheep and cattle carcass components, an evaluation was made of the SOXTEC fat analyser.

PDP 11/03 Micro-computer system

[ARS, PEM]

The laboratory data capture and processing system has proved much more reliable following the resolution of an operating system problem. The addition of two fixed disks with a total of 10M bytes of on-line storage has greatly eased data storage problems.

During 1981, locally written software was developed to process data captured from Gas Liquid Chromatographs and this has been successfully tested. It is anticipated that the software will provide the basis for an Amino Acid Analyser program.

Also developed during the last year was a program to calculate and tabulate non-esterified fatty acid (NEFA) values from key-board input and a program to determine and tabulate sample concentrations of major and minor elements from paper tape output produced by a PW1212 Phillips Automatic X-ray Fluorescence Spectrometer.

The use of a communications package developed at the Edinburgh University Molecular Biology Department now allows the results from any of the preceding processes to be transferred from the PDP-11/03 to EMAS, where research workers can access the data directly.

Electronics

[ARMC, RAC]

An electronics laboratory and instrument workshop was set up at the beginning of 1980, aimed at serving the Organisation in three main areas.

(i) design and development of electronic techniques as research tools for agriculture and ecology
(ii) development of peripheral equipment for analytical services
(iii) design and development of equipment for use in the agricultural industry

As research tools, the equipment constructed tends to be of a measurement or control nature (e.g. an electronic sward biomass meter was built, which hopefully will reduce the labour intensive techniques previously used in the research programme).

Research and development is continuing on automatic data logging of physiological and environmental factors of animals in the field. This involves the development of behavioural sensors to estimate food intake and energy expenditure and meterological sensors to study environmental effects.

Many of the Organisation's analytical instruments output large amounts of data in both analog and digital forms. There are therefore requirements for interface circuitry to marry analysis with data logging and computing facilities.

It is now well recognised that a wide spectrum of applications for electronic technology exists, to allow the farmer to monitor and control his product more closely and to improve both crop and animal production more quickly and efficiently. An on-going project is the determination of foetal numbers in pregnant ewes.

Bracken

[PN, GED]

Bracken (*Pteridium aquilinum* (L) Kuhn) is primarily a woodland plant but, with the removal of trees, it has adapted to a pastoral situation so well that it now infests about 300000 ha in the UK, of which two thirds are in Scotland. Some workers (J. A. Taylor, University of Aberystwyth, private communication, 1981) believe that the plant is still spreading, so that its area is increasing at about 2%/yr. The plant tends to occur on reasonably deep mineral soils which have considerable potential for growing pasture and it reduces grass growth, harbours insects, impedes shepherding and is poisonous to some classes of stock. It is no surprise that farmers would like to rid their land of this weed. Early mechanical methods of control were expensive, labour intensive, unsatisfactory on uneven and rocky land and had to be repeated at frequent intervals. The successful use of the herbicide, asulam, by Holroyd, Parker and Rowlands (1970), led to a surge of interest and aspects of bracken control by this means were reviewed recently by Williams (1980).

Much of the early work with asulam concentrated on the technique of spraying methods and little attention was paid to the beneficial effects, if any, on the quality and quantity of the underlying pasture. Only if the latter are considerable and long-lasting can the increasing cost of the herbicide and its application be justified. Moreover, farmers who spray bracken to improve hill pasture are only eligible for grant aid (50%) if they also apply phosphate fertiliser at a minimum rate of 628 kg/ha and there is little information to justify the need for this. Experiments to investigate these aspects of bracken control were set up in 1973 and the early results have been described (Davies, Newbould and Baillie, 1979). This report briefly reviews the results from this programme of work which has now been concluded following the retirement of GED.

Bracken on two sites of differing aspect in the Cheviot Hills, one facing south and the other west, on well drained brown earth soils of the Sourhope series, were sprayed with asulam (4.5 kg active ingredient/ha) in 1973. Duplicate sets of control and treated plots were alternatively sampled and grazed in successive years. The regime of grazing was as part of the unimproved area of a two-pasture system (Armstrong *et al.*, 1978) with a grazing pressure of 10-12 ewes/ha in the post-lambing and pre-mating + mating periods. Phosphate (628 kg ground mineral phosphate/ha) (27% P_2O_5) was applied to half the area of each treatment in 1977. The growth of bracken and of the underlying pasture plants was monitored annually until 1979 and bracken alone for a further 2 years. A third site, with a south-west aspect and in the Pentland Hills, was selected to study the interaction of spraying with addition of lime and phosphate on the growth of bracken and pasture. Asulam was applied in August 1977 and lime (5 t/ha) and phosphate (628 kg ground mineral phosphate/ha) (27% P_2O_5) were added in November 1978 and March 1979, respectively.

Asulam, sprayed at the time of full frond development, reduced cover due to bracken in the following year by 98% at all sites. At sites 1 and 2, the reduction in bracken cover was still 80% some 7 years later but the fronds which were present appeared to be increasing in vigour; at site 3, 2 years later, cover was 92%, indicating a more rapid return of the bracken (Table 14). At all sites, 1 year after spraying, asulam reduced the proportion of broad-leaved grasses (*Agrostis tenuis, Agrostis canina* and *Poa pratensis*) which resulted in an increase in bare ground and the spread of the resistant fine-leaved grasses. This effect had almost disappeared 3 to 4 years after spraying on sites 1 and 2, as broad-leaved grasses re-occupied the bare ground. Recovery seemed to be slower on site 3.

Table 14

Reduction (%) in numbers (/m²) and height (cm) of bracken fronds following the application of asulam (Sites 1 and 2 sprayed 1973; Site 3 sprayed 1977)

Site	Year	Numbers	Height
1	1974	98	48
	1981	80	39
2	1974	99	51
	1981	79	29
3	1978	98	59
	1981	92	52

Production of dry matter was assessed from quadrats cut four times in the year. In the first year after spraying, production from the sprayed plots was lower than from control plots at all sites, presumably due to the decrease in broad-leaved grasses, combined with unstable top soil conditions. Thereafter, depending on aspect and site type, production was enhanced by spraying by up to 68% (Table 15). However, averaged over 3 years on the three sites, production of dry matter was increased by 24% or by 378 kg/ha/yr. The addition of phosphate had no significant effect on production, nor did the application of lime to site 3 (Table 16). There were some indications that the contents of phosphorus, calcium and nitrogen in the herbage of sites 1 and 2 were increased by application of phosphate.

Table 15

Cumulative annual herbage production (kg DM/ha) for successive years after spray treatment

Figures in brackets show % increase or decrease relative to the control (unsprayed) treatment

	Years since spray applied		
	1	2	3
Site 1	1400 (−23)	3039 (+47)	2588 (+48)
Site 2	1719 (− 5)	2069 (+18)	2510 (+55)
Site 3	717 (−24)	1923 (+68)	1473 (+29)

Table 16

The effect of lime (L1) and Phosphate (P1) on cumulative annual herbage production (kg DM/ha) (Sites 1 and 2 means for 1977, 78 and 79; Site 3 means for 1979 and 80)

		Control		*Sprayed*	
		Po	P1	Po	P1
Site 1	Lo	2279	2519	3570	3169
2	Lo	1768	1989	1961	2177
3	Lo	1165	1268	1508	1835
	L1	1064	1076	1680	1772

Conclusions

On favourable sites, i.e. those with a south-facing aspect and with about 40% of broad-leaved grasses, spraying bracken with asulam can increase annual pasture production by up to 1000 kg DM/ha. Allowing for a depression in yield in the first year after spraying, the annual average increase in dry matter production at site 1 over the 6-year period was 725 kg DM/ha when control of bracken has been shown to be greater than 80%. This extra production is accompanied by small increases in quality of herbage, as indicated by the proportion of green material and the content of nitrogen and phosphorus. Since the annual dry matter intake of a hill ewe is estimated to be about 500 kg (Eadie and Cunningham, 1971), utilisation by grazing sheep of the extra production, following use of asulam, would have to be 69%, i.e. to the highest standards achieved in lowland agriculture, for this to support a ewe. Should this be the case and should the ewe have a lamb each year which is sold at £20, the cost of the chemical and its application (£20/ha at 1980 prices) would be covered at least five times by the extra production. It appears that the addition of lime and phosphate to the pastures underlying bracken has little effect on the amount of herbage produced although it may have small effects on herbage quality. Despite the high degree of control of bracken achieved initially in these trials, it is apparent, from the number of fronds and their vigour 6 years after spraying, that bracken infestation is starting to increase again. It is evident that pasture cleared of bracken must be grazed intensively and preferably with cattle in addition to sheep, if re-infestation is to be delayed, and that re-application of herbicide is probably necessary to eliminate the weed completely.

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Dietary supplementation in the sheep

[JAM]

One of the aspects of UK sheep production which surprises those in the sheep industry visiting from countries outwith Europe, is the amount of supplementary feeding that ewes receive. The biological and economic reasons why modern sheep systems are so dependent on supplementing the diet obtained by sheep from pasture centre on the levels of individual ewe performance and total flock output required to balance rapidly increasing fixed costs. These levels of performance can only be sustained if additional inputs of energy and protein are provided as supplementary feeding to meet the shortfall created by an insufficiency from ingested herbage during pregnancy and lactation. In 1979/80, £5.20 per ewe was found to have been spent on such feeding on farms in the less favoured areas in the south-east of Scotland (E.S.C.A., 1981) and this amounted to 50% of the total variable costs of the sheep enterprise. Whilst it is likely that the present ratio of the price of cereals — the most important component of supplements — to the price of lamb which the farmer receives will remain much the same in the near future, it is clear that the efficient use of supplementary feeding can have an important bearing on the profitability of the sheep industry.

In hill and upland sheep systems, where the ewe obtains most of her nutrients from grazed herbage, it is not difficult to identify pregnancy and lactation as those periods of the productive cycle when the balance between ingested nutrients and the energy and protein requirements is such that the feeding of supplements may be of benefit. Part of the energy deficit may be met by the use of the fat tissues of the ewe and the amount and type of supplementary feeding given has to take into account the extent to which the fat tissues can be used. The lack of suitable techniques for measuring the amount and rate of change of these fat tissues has hampered our ability to exploit these energy reserves adequately and has led to a lack of precision in the predictions of the amount and type of supplement to be fed in relation to the fatness of the ewe.

The use of fat tissues of the hill ewe in mid-pregnancy, without the provision of any supplementary feeding, has been advocated by Russel (1971), with the loss of up to 5 kg in live weight, although involving some loss of fat tissue, not being considered as likely to reduce lamb birth weight and subsequent performance. However, recent experiments at the Lephinmore (A. J. F. Russel, I. R. White and D. N. McFarlane, unpublished) and Glensaugh (Lippert, Milne and Russel,

1982) research stations of the Organisation have shown an advantage in lamb birth weight to feeding supplements in mid-pregnancy to Scottish Blackface ewes grazing hills in which heather is a component of their diet and where the stocking rate on the hill is relatively high in winter, as would be the case in most improved systems of management. It is not only necessary to establish the benefits in animal production terms of feeding any supplement but also to ensure the choice of an effective supplement. This requires a knowledge of the influence that the amount and type of supplement has on the substitution rate of herbage by the supplement and on the supply of absorbed nutrients as volatile fatty acids and amino acids and how these may be modified by such factors as the frequency of feeding of the supplement. Thus, information gained from an initial period of indoor experimentation is needed before supplements can be tested under field conditions.

In relation to supplements in mid-pregnancy, indoor experiments firstly examined the effect of feeding various amounts and proportions of simple nitrogen and energy sources, such as urea, starch or sucrose, on the voluntary intake and digestibility of heather (Milne, Christie and Russel, 1978) and of mixtures of heather and *Agrostis/Festuca* (J. A. Milne, A. M. Spence and H. A. Fisher, unpublished). These experiments showed that the feeding of a supplement containing 100 g starch and 3 g N/day, as urea, increased or did not impair the voluntary intake of the roughage, demonstrating that the supplement was acting as a true supplement and not substituting for the roughage. This is a considerable advantage because of the relatively low cost of the herbage in relation to the supplement, notwithstanding the poorer nutritive value of the herbage. The levels of digestible energy obtained were estimated to be such that the high ewe live-weight losses sustained in mid-pregnancy under the conditions described above would be held at acceptable levels by feeding such a supplement. The effect of frequency of feeding on impairment of rumen digestion was also found to be least with the starch and urea supplement (Milne *et al.*, 1978) and further experiments showed that volatile fatty acid production rates were increased by 20% and that the nitrogen in the supplement was used efficiently, leading to a 39% increase in the amounts of amino acid nitrogen absorbed (Mayes and Lamb, 1981). Thus, the indoor experiments delineated the amount and composition of a supplement worth examining under field conditions.

One important factor in the efficient use of supplements, which has been ignored in the past because of the difficulty of quantifying its effects, is the method of feeding the supplement. Feeding it once daily as a pellet or cob or in a self-feeding system such as a lick or feed-block could influence the intake of supplement by individual ewes or alter their grazing behaviour to such an extent as to considerably influence the impact of the supplement on the nutrition of the ewe. Experiments, which have demonstrated the advantage of feeding supplements in mid-pregnancy to ewes grazing a hill containing 20% *Agrostis/Festuca* and 80% heather, by improving lamb birth weight by 10% and reducing ewe live-weight losses in mid-pregnancy by 4 kg (Lippert *et al.*, 1982), also showed that between-day and between-animal variation in supplement intake was greater for feed blocks than for pellets fed once daily, with coefficients of variation ranging from 20 to 60% for feed blocks and 20 to 30% for pellets. The rankings of ewes in intake of feed block remained similar over successive measurement periods, suggesting that, if the reasons why some ewes ate more than other ewes was understood, it would be possible to reduce between-animal variation in feed block intake and this approach is currently being pursued. The position of the feed block in relation to vegetation type changed the grazing behaviour of the sheep, so that they spent more time grazing on the vegetation type on which the block was placed. This influenced nutritional parameters such as ruminal ammonia concentration, which was only 1.9 mmol when the feed block was placed on heather but 3.2 mmol when placed on *Agrostis/Festuca* vegetation.

The interaction between the supplement and pasture demonstrated above is perhaps most apparent in early lactation when ewes grazed perennial ryegrass/white clover swards. Herbage masses of under 1000 kg DM/ha are known to limit herbage intake (Hodgson, 1977) and, consequently, ewe milk yield and lamb growth rate. With the dates of lambing favoured in most current sheep systems, there is a period from 2-8 weeks when herbage masses are below 1000 kg DM/ha and when the growth rate of herbage would be similar to or less than its defoliation rate. An interaction between the amount of supplement required to be fed and herbage mass would be expected, although no experimental information existed to quantify the nature of the interaction until the current series of experiments discussed below was undertaken.

In the first experiment, a conventional barley:soya bean meal supplement was given at three levels in the first 6 weeks of lactation to ewes rearing twin lambs and grazed on swards maintained at three herbage masses. Surprisingly, no responses in lamb growth rate were obtained from supplements at low herbage mass but lamb growth rate increased with increasing herbage mass, as could be expected (see Table 17). At the lowest herbage mass of 500 kg DM/ha, the ewes lost less live weight when more supplement was given, suggesting that, at higher proportions of a cereal-based supplement in the diet, there appeared to be a partition of nutrients towards the tissues of the ewe rather than milk yield. The results of the experiment indicated that the composition of the supplement needed to be improved to achieve a benefit in lamb growth rate. Robinson *et al.* (1979) have suggested that the feeding of a supplement, which would provide an increased supply of absorbed protein to the small intestine, could increase milk yield and improve lamb growth rate in early lactation at pasture. The provision of additional ruminal acetate rather than propionate may also be beneficial in removing a limitation on ewe milk fat synthesis.

Table 17

Intake of herbage by ewes and the daily live-weight changes of the ewe and her twin lambs in the first 6 weeks of lactation (means of 7 ewes)

Amount of herbage (kg OM/ha)		500			750		1500	SE of mean
Amount of supplement (g OM/day)	0	480	960	0	480	960	0	
OM intake of herbage by ewes (g/day)	**1834**	1500	1338	**2347**	1903	1582	**2388**	64.2
Lamb live-weight gain (g/day)	**251**	266	256	**313**	288	322	**332**	9.2
Ewe live-weight change (g/day)	**−280**	−235	− 82	**−88**	− 14	− 57	**+13**	46.1

(Milne, Maxwell and Souter, 1981)

In a second series of experiments, a supplement based on sugar beet pulp and white fish meal, to provide a more suitable combination of absorbed nutrients, was compared with a conventional barley:soya bean meal supplement and with a lower level of a simple sugar beet pulp supplement. Indoor experiments were conducted to confirm that the diets produced different amounts of absorbed nutrients and altered the partition of nutrients between milk fat and body fat, whilst a grazing experiment tested the effects of feeding the supplements when ewes grazed swards of a herbage mass of less than 1000 kg DM/ha in the first 8 weeks of lactation. The experiment also examined the long term effects on weaning weight of the lambs when the ewes grazed swards which were unlikely to limit their herbage intake after supplements had been withdrawn; an aspect which is often neglected. As can be seen from Table 18, the supplement based on sugar beet pulp and white fish meal gave rise to the greatest live-weight gains of lambs, so that at 8 weeks of age the lamb live weights were 2.3 and 1.6 kg greater than those achieved on the low level of supplement and the conventional supplement treatments, respectively. At weaning, because of the faster growth rates in late lactation of the lambs that had grown more slowly in early lactation, the effects of the supplements were reduced, with the weaning weights of lambs from ewes receiving the sugar beet pulp, the barley:soya bean meal and the sugar beet pulp:white fish meal supplements being 31.6, 32.1 and 32.9 kg, respectively. Thus, although the change in the composition of the supplement improved lamb growth rates when supplements were being fed, some of the benefit was lost by weaning. The importance of changes in the fat tissues of the ewe during lactation, as a consequence of the feeding of supplements in relation to the body condition of the ewe at mating and how that has affected reproductive performance, is also being studied.

Table 18

Ewe and twin lamb performance from birth to weaning when supplements were given in the first 8 weeks of lactation

	450 g/day sugar beet pulp	900 g/day 86% barley: 14% soya bean meal	900 g/day 86% sugar beet pulp: 14% herring meal	SE of mean
0-8 weeks of lactation				
Lamb live-weight gain (g/day)	278	296	337	4.5
Ewe live-weight change (g/day)	19	38	91	13.8
8-15 weeks of lactation				
Lamb live-weight gain (g/day)	233	222	204	6.1
Ewe live-weight change (g/day)	16	−1	−74	14.5

(Milne, Maxwell, Agnew and Sibbald, 1982)

These examples of the research approach to designing a supplement for use in mid-pregnancy and early lactation demonstrate the many factors that have to be taken into account. The species of herbage, its quality and amount, the fat content of the ewe's tissues, the method of feeding the supplement and the long- as well as short-term implications all have to be considered in understanding the effects that the amounts and composition of the supplement may have on the digestion and metabolism of the sheep. The relative importance of these factors and the degree to which they can be manipulated will vary depending upon circumstances, thus influencing the research approach. Against this background of what may be biologically attainable, decisions on the supplement ultimately advocated have to be made within a framework of economically viable systems of production.

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An aid to land-use decision-making for agriculture and forestry

[ARS, TJM]

In recent years, it has been argued that the UK should become less dependent upon imported timber supplies by increasing home timber production from new and existing areas of forest. The ways of achieving this and some of the consequences have been outlined and discussed elsewhere (F.C., 1977; C.A.S., 1980; Cunningham, Eadie, Maxwell and Sibbald, 1978). Increased timber from improved production levels in existing forests appears to be limited to about 10-15%. An increase from 8 to 20% self-sufficiency in timber production for the UK by the year 2030, which appears now to be a generally accepted policy, must come therefore from the planting of new forests. The land required for this, about 1.5M ha, is presently in agricultural use and consists mostly of rough grazings currently used for hill and upland farming.

Although an increase in the area of land in forest might be seen to be at the expense of agricultural output, within limits this may not be so. It has been demonstrated that considerable potential for improving agricultural output and productivity from the hill and upland areas of the UK is possible (Armstrong, Eadie and Maxwell, 1977; Thompson, 1978). The key to realising this potential is the creation of limited areas of improved pasture on hill land and using them in association with the remaining hill pasture to have the maximum improved nutritional effect on the hill ewe and therefore on her ability to produce more lambs (Eadie, 1971). Such improvement, coupled with inputs of supplementary feed, also makes it possible to increase ewe numbers to levels which substantially improve the use of summer pasture production. The consequent increase in output of lamb per unit area of hill land can be substantial.

The present study arose out of a recognition within the Organisation that it might be possible to develop a procedure which would test whether or not it was possible on a given area of land both to produce timber and at least maintain, on a reduced area of land, the existing level of agricultural production.

Forestry and agriculture both require fences and roads which can be shared. The provision of roads gives access to land which otherwise, from an agricultural point of view, might not be economically improved. Although there may also be advantages in selling land to forestry to realise capital, which is subsequently invested to improve agricultural output, this is not a consideration which was dealt with initially; rather an area of land was examined in relation to its relative potential in forestry and agricultural production, ignoring its capital value.

Crucial to an objective appraisal of how best to achieve successful land use between agriculture and forestry, was the need to find a basis by which land would be allocated to each enterprise. The method had to be adaptable and take account of the various constraints on land use that could be envisaged both from practical and logistical points of view and as a consequence of the various policy directives issued by Government. It was considered that the outcome of allocating different proportions of land to either forestry or agriculture should be first presented in economic terms and therefore the method had to take account of widely differing time production cycles and have the ability to examine solutions at different discount rates.

The method chosen, which is briefly outlined below, has been written as a computer program in Fortran and has been described in detail by Maxwell, Sibbald and Eadie (1979).

The method first describes the area, normally a farm or estate, by dividing it into a grid of square blocks (10 ha each) and classifying each block by 'walking the ground' and by the use of maps as follows:—

1. Forest yield class — this figure is used to assess potential in forest production and values are acquired from the local forest interest.

2. Vegetation type — this is a general species association classification (e.g. *Calluna/Eriophorum, Molinia/Nardus* or *Agrostis/Festuca*) and is used to determine contemporary stock-carrying capacity and level of individual ewe performance.

3. Soil type — used as a measure of potential for agricultural improvement.

4. Existing access — the position of roads and tracks will be important in allocation of land, since access to forest is essential.

5. Existing fencing — the use of existing fences may reduce capital costs in setting up land allocations.

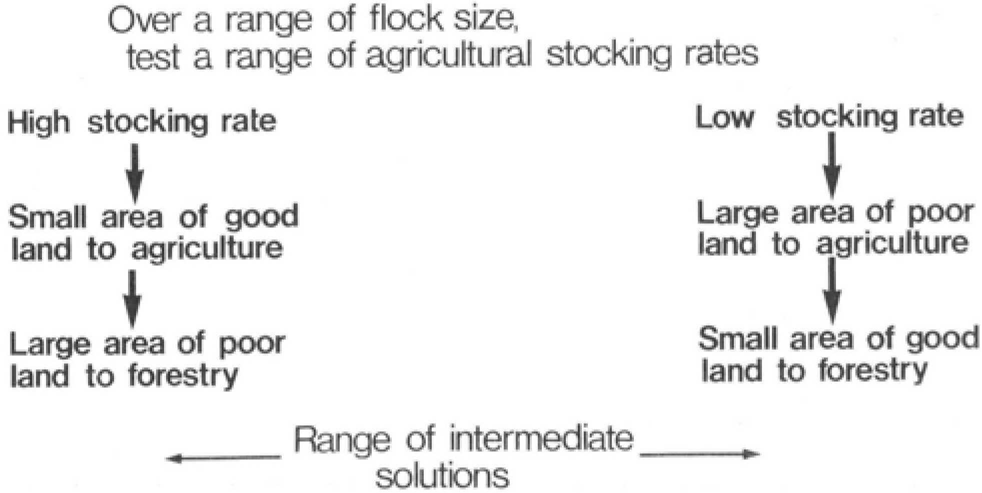
Agricultural and forestry prices and costs are also required.

These classifications are used as the basis for allocating blocks according to a number of relevant constraints. The first is that the sum of the blocks allocated to agriculture must provide an economically viable farm unit with potential for development (i.e. capacity to improve output and productivity). Secondly, taking account of existing neighbouring forest interests, enough land must be allocated to forestry to provide an economic forest enterprise.

Other constraints may be regarded as optional as far as the method is concerned. Having decided upon the need to include a constraint, however, its importance relative to other constraints must be specified. The constraints used for the two examples described below include a need to make all agricultural land contiguous, to include existing farm buildings and improved land in agriculture, to use all unplantable land and to minimise the lengths of roads and fences.

Fig. 9

The effect of required stocking rate (land quality) on the allocation of land to agriculture and forestry



Within the limits of these constraints, a range of land allocations is examined, based on a range of flock sizes carried at different stocking rates. This results, as can be seen from Figure 9, in both agriculture and forestry being allocated, in turn, to land of varying quality and of varying amount. At the completion of an allocation, fences and roads are constructed and the economic consequences of the allocations are calculated.

Each allocation is examined in terms of

a) unimproved agriculture

b) 10% of land allocated to agriculture being improved.

(Land improved is based on a least-cost calculation taking account of land quality, reseeding, haulage and fencing costs.)

Using a project length equivalent to a cycle of forestry production and an appropriate discount rate, a 'net present value' (NPV) for each enterprise is calculated, the two are summed and the capital in fences and roads deducted, except those used for agricultural development alone; this produces a 'net integrated benefit' (NIB).

To simplify the presentation of data, the NIB produced from the area wholly devoted to agriculture without further land improvement is set to 100 and all other schemes expressed in relation to this base value; this is called the 'net benefit index' (NBI).

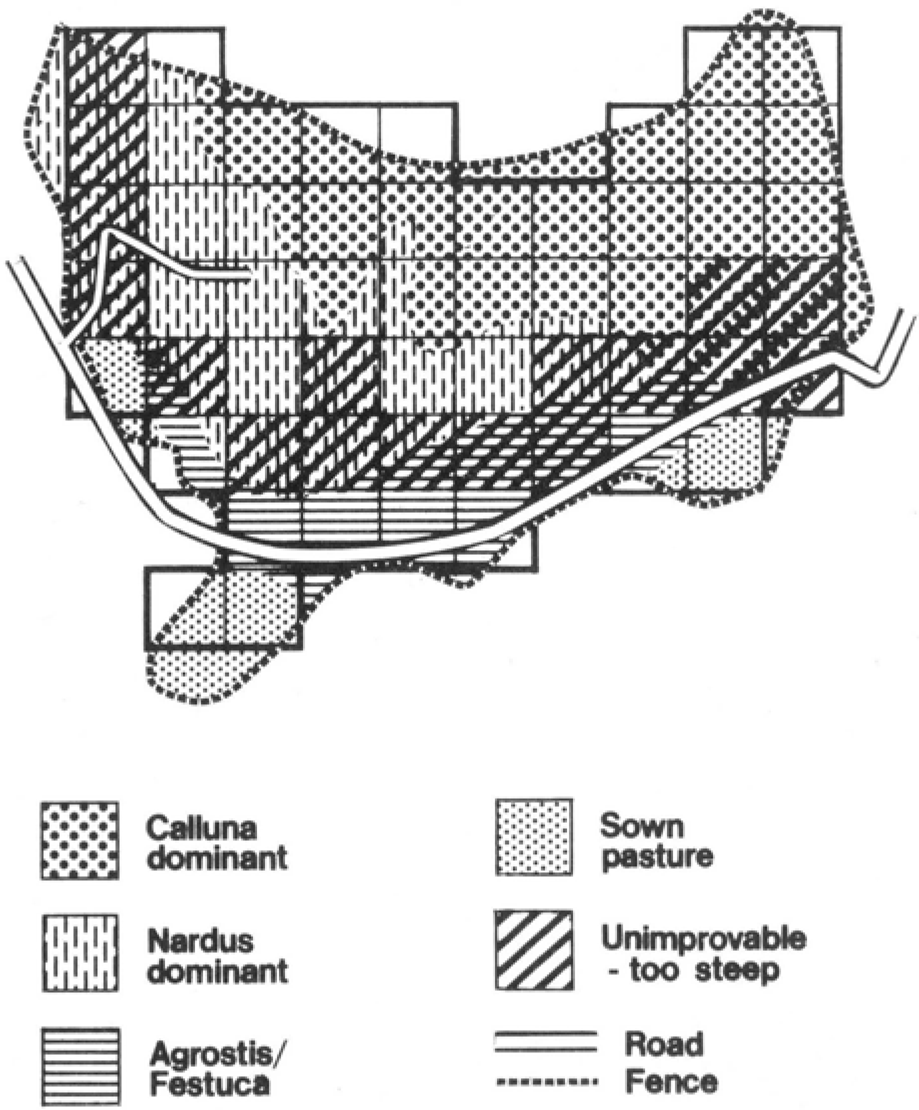
The usefulness of the results in determining the choice of a particular land allocation is best demonstrated by reference to two examples.

Example 1

This example represented a West of Scotland hill farm of 560 ha on *Calluna/Tricophorum* vegetation with *Molinia* and *Nardus* and some *Agrostis/Festuca*. There were 40 ha of inbye land. The farm area was subdivided into 56 × 10 ha blocks distributed within an 8 × 10 grid to represent its general outline (Figure 10). Four blocks were denoted as inbye land and these were located within the grid to represent their approximate locations. Seventeen blocks, which had a soil type which would indicate a high level of improvability, were coded unimprovable because of their extreme gradients.

Fig. 10

Example 1 : Vegetation classes, roads and fences within grid of 10 ha blocks



Using the whole area as a hill sheep unit, it was estimated that the unit would carry 862 ewes weaning at 103%. This relatively high level of individual performance arises because of the 40 ha of inbye land available on the unit and the use of late pregnancy feeding. (The NPV for this system was £56552, i.e. NBI = 100). The 'Management and Investment Income' (MII) was £2987 (at 1978 prices and costs). The entire area, if afforested, produced an NBI of 145.

Table 19, Example 1

Production figures for integrated and non-integrated schemes involving unimproved agriculture

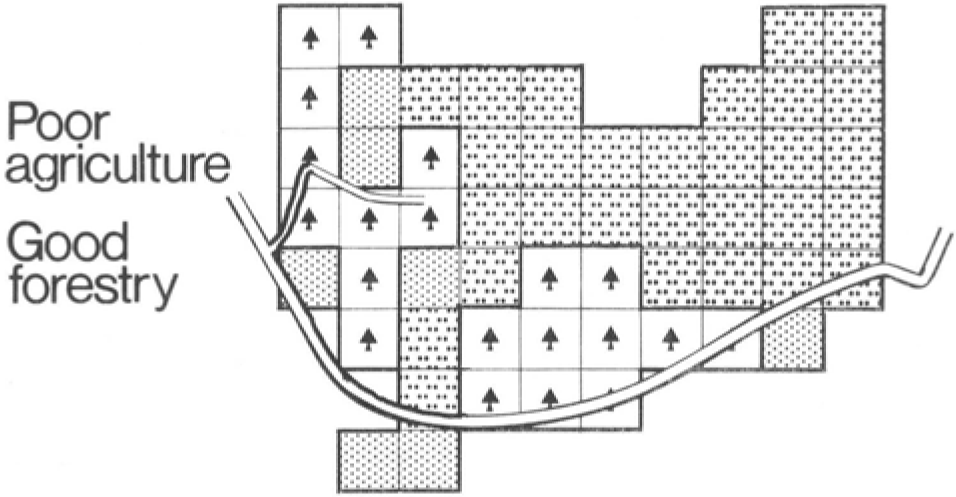
Ewe flock size	Land quality to agric.	% of area in forest	% of potential forest prodn. achieved	Stocking rate, hill* (ewes/ha)	Weaning %	Area in agric. (ha)	NBI	Agric. MII £/annum total	Agric. MII £/annum /ewe
	poor	68	75	0.75	112.9	180	137	1288	2.68
500	inter.	77	80	0.94	114.5	150	145	1348	2.70
	good	79	73	1.30	118.5	120	152	1541	3.08
	poor	38	67	0.66	111.0	350	134	1922	3.20
600	inter.	54	41	0.93	115.5	260	134	2152	3.58
	good	63	62	1.20	117.6	230	158	2268	3.78
	poor	21	39	0.75	106.8	440	117	2319	3.31
700	inter.	36	24	0.94	115.0	360	130	2818	4.03
	good	42	28	1.08	116.4	320	143	2920	4.17
862	all agric.	0	0	0.89	102.8	560	100	2987	3.46
0	all for.	100	100	—	—	0	145	0	0

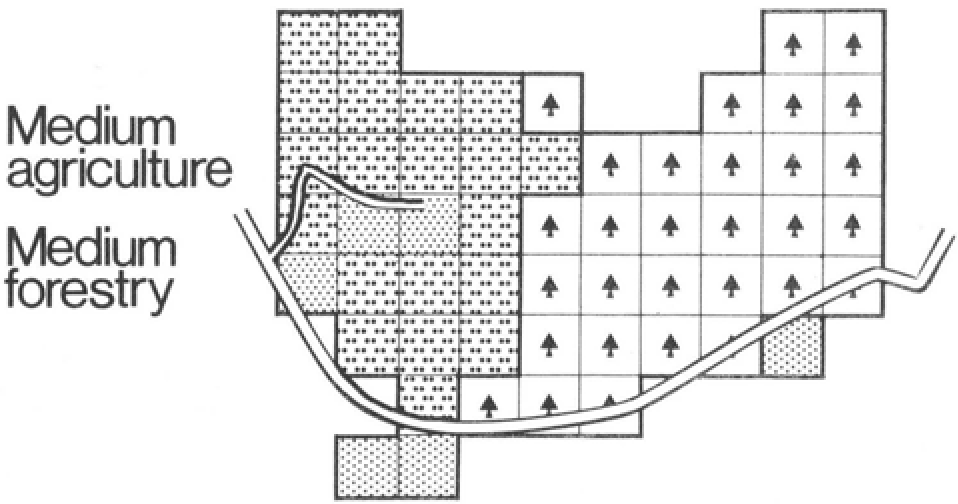
* excludes inbye land

Table 19 shows a set of results covering a range of flock sizes from 500 to 700 without further land improvement. The range of flock size shown in Table 19 was limited to 500 ewes at the lower end because smaller flocks were considered to be uneconomic and to 700 ewes at the upper end since larger flocks left insufficient land for a viable forest unit. The results for each flock size are shown where the flock was run on poor, medium or good quality ground and Figure 11 shows the land allocations for the 600 ewe flock on these varying land qualities.

Fig. 11

Example 1 : Three alternative land allocations to support a 600 ewe flock — also showing blocks subsequently improved to allow increased stock numbers





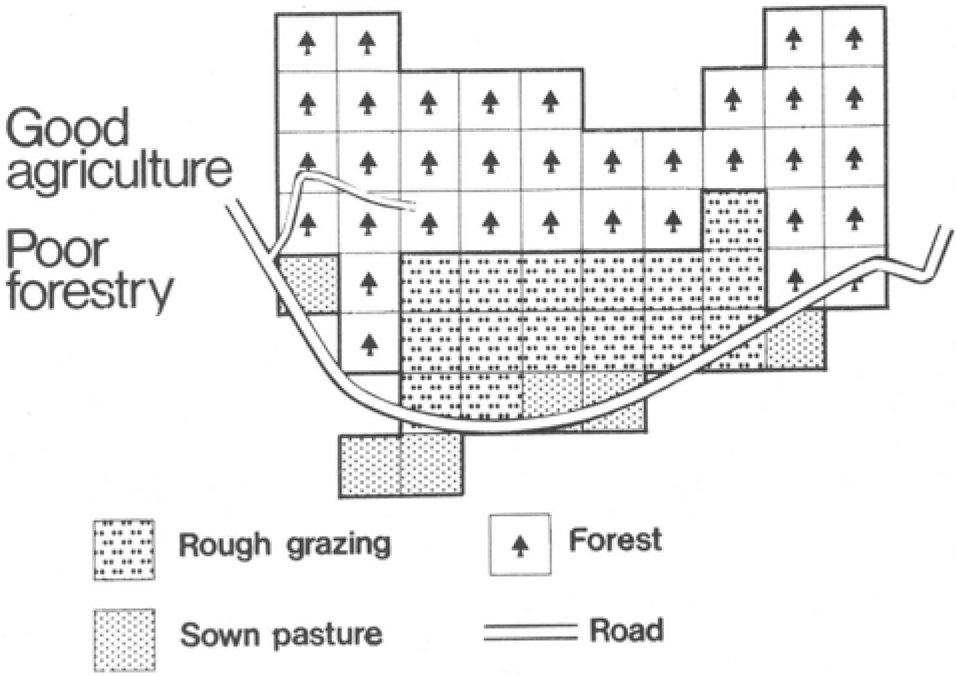


Table 20, Example 1

Production figures for integrated and non-integrated schemes involving 10% of agricultural land improved

Initial ewe flock size	Initial land quality to agric.	No. of blocks impr.	Stocking rate, hill* after impr. (ewes/ ha)	Wean % after impr.	Final ewe flock size	NBI	Agric.. MII £/annum total	Agric.. MII £/annum /ewe	1st year bal. + ve
	poor	1	1.36	112.3	591	152	1893	3.20	2
500	inter.	1	1.72	114.0	589	160	1966	3.34	2
	good	1	2.38	118.6	590	169	2209	3.74	2
	poor	3	1.55	110.7	882	174	3701	4.20	2
600	inter.	2	1.71	115.2	776	163	3356	4.32	2
	good	2	1.98	117.5	776	189	3510	4.52	1
	poor	4	1.62	112.3	1048	173	4800	4.58	1
700	inter.	3	1.74	114.8	958	169	4492	4.69	1
	good	3	2.01	116.3	962	183	4627	4.81	1
862	all agric.	5	1.71	113.8	1292	176	6295	4.87	1
0	all for.	—	—	—	0	145	0	0	—

* excludes inbye land but includes improved hill areas

It was also important to examine the consequences of further land improvement on agricultural output, since this might allow more land to be allocated to forestry and yet provide a means of generating improved productivity and increased output in agriculture. The data in Table 20 provided a means of assessing these possibilities.

Example 2

This example was a hill farm of 720 ha set in the South West of Scotland, consisting mainly of *Calluna* on deep peat and *Nardus* heath with some *Molinia* and a proportion of *Calluna/Juncus* on lower, poorly drained, slopes with shallower peat. The farm carried a stock of 400 Scottish Blackface ewes. The land rose to nearly 460 m and 70 ha of the top ground was considered to be unplantable. There was a small area of *Agrostis/Festuca* grassland and 60 ha of enclosed inbye land. The farm area was subdivided into 72 × 10 ha blocks within a 10 × 16 grid (Figure 12). A private forestry company wished to plant as much of the area as possible while creating a viable agricultural unit which they could lease to a tenant.

Fig. 12
Example 2 : Vegetation classes, roads and fences with grid of 10 ha blocks

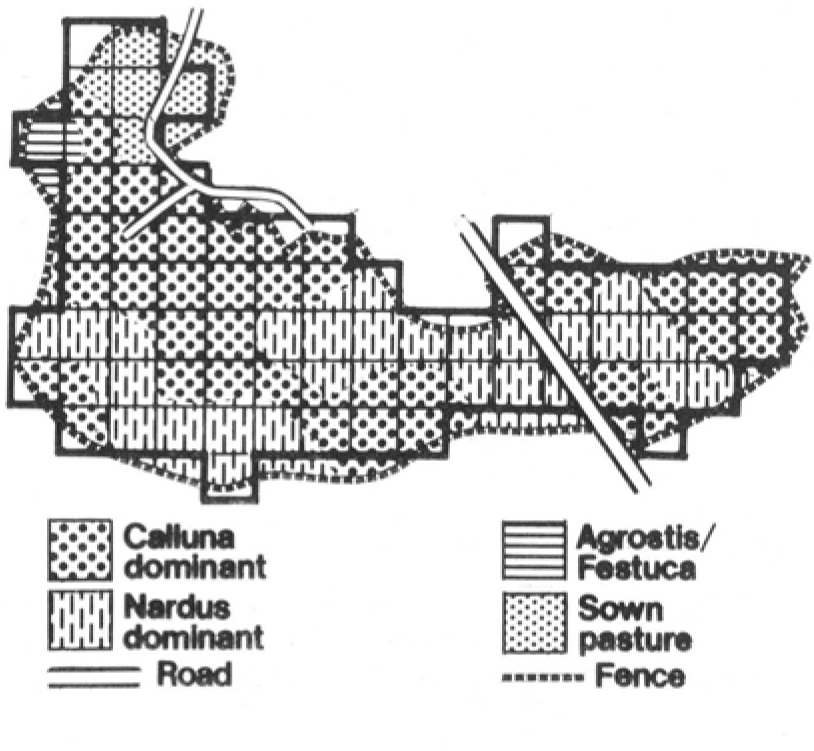
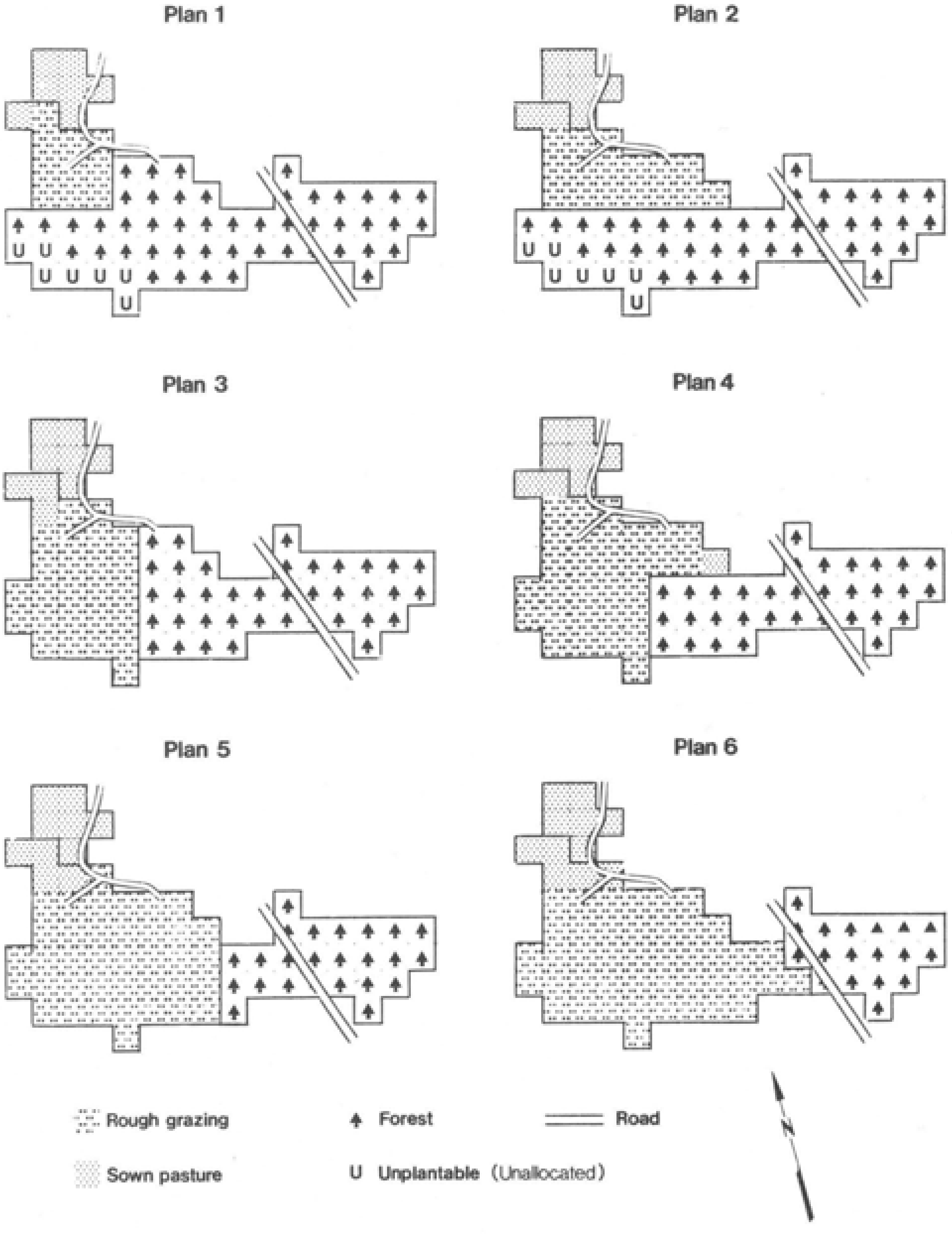


Fig. 13

Example 2 : Plans of six land allocations tested



A preliminary appraisal of the potential schemes for the area indicated that those which allocated land to agriculture at the east end of the farm were less economically viable than those with land allocated to the west. This arose because of the needs to achieve contiguity with the steading and inbye blocks, to make use of the only unplantable land on the area, which was all at the west end of the farm, and because an intersecting main road was at the east end of the area. For these reasons, a range of six plans was considered further (Figure 13). In each plan, the area of land lying to the east of the main road was afforested and the range covered increasing afforestation towards the west.

The forest production levels for each of the six plans are shown in Table 21.

Table 21, Example 2

Unimproved agriculture

	% Area in forest	% Forest potential	Stock no. N	Stocking rate (ewes/ha)	Wean % age	NBI	Final agric. MII (£/annum)	Final agric. MII (£/ewe)
Plan 1	73.4	63.3	526	3.09	129	318	2679	5.09
Plan 2	62.5	46.5	601	2.50	132	269	3722	6.19
Plan 3	57.8	56.4	656	1.93	131	349	4346	6.63
Plan 4	50.0	44.0	706	1.81	126	298	4132	5.85
Plan 5	37.5	37.2	762	1.59	119	275	3593	4.72
Plan 6	28.1	27.5	800	1.48	112	218	2940	3.68
Base	0	0	912	1.27	106	100	2441	2.67
All for.	100.0	100.0	0	—	—	424	—	—

Three possible farming schemes were examined.

a) *Hill sheep system with no further land improvement*

The inbye, which was always allocated to agriculture, became a much higher proportion of the whole farm area as less of the hill was allocated to agricultural use and consequently higher levels of individual animal performance were obtained. The smaller agricultural land allocations (Plans 1, 2 and 3) represented increasingly intensive systems.

It can be seen from Table 21 that the NBI (at 1980 prices and costs and a 7% discount rate) for a wholly afforested scheme was higher than all agriculture or any of the integrated schemes. This was partly due to the need to build up stock numbers from 400 to the final numbers that it was possible to carry even without further land improvement. Even so, the MII for agriculture, in some cases, was considered rather less than necessary for a one-man unit.

b) *Intensified hill sheep systems*

This involved further land improvement, investments being made in relation to flock build-up and improved lamb weaning percentages. The data in Table 22 show that the MII's from agriculture were higher although no integrated scheme appeared to be able to generate a higher level of NBI than forestry alone, again partly because of the need to substantially increase ewe numbers.

Table 22, Example 2

Improved agriculture

	Start stock no.	Final stock no. No.	Final stock no. Yr	Final stocking rate (ewes/ ha)	Final wean % age	NBI	Final agric. MII (£/ annum)	Final agric. MII (£/ewe)	Max. O/D	First year + ve
Plan 1	526	601	4	3.53	129	322	3440	5.72	2792	6
Plan 2	601	770	5	3.21	132	290	5440	7.06	4034	6
Plan 3	656	920	7	2.71	132	377	6951	7.56	3250	7
Plan 4	706	956	7	2.47	132	337	7181	7.44	2455	6
Plan 5	762	1121	9	2.34	131	339	8594	7.67	1669	4
Plan 6	800	1253	8	2.61	131	315	9433	7.53	1726	7
All agric.	912	1556	9	2.16	130	259	11692	7.51	300	2
Base	912	912	1	1.27	106	100	2441	2.67	0	1
All for.	0	0	—	—	—	424	—	—	—	—

c) *Cross-bred flock using 40 ha inbye in addition to a hill sheep system*

The 40 ha were used to run a 400 Greyface ewe flock, with a weaning percentage of 140. The Gross Margin was calculated as £27 per ewe and total MII as £3740 per annum.

For this scheme, it was assumed that the total fixed costs, except for appropriate increases in labour costs in relation to ewe number, would be covered by the cross-bred flock. Capital for the cross-bred ewes would be provided by the tenant.

The results of this scheme are outlined in Table 23 and show MII values from agriculture which were considered to be highly satisfactory and also show an integrated scheme (Plan 3) with a higher NBI than forestry alone.

Table 23, Example 2

Improved hill agriculture with crossbred flock

	Hill only					Hill + cross-bred	
	Start stock no.	Final stock no. No.	Final stock no. Yr	Final stocking rate (ewes/ha)	Final wean % age	NBI	Final agric. MII (£/annum)
Plan 1	226	301	1	2.37	128	397	5625
Plan 2	301	470	6	2.37	131	388	8627
Plan 3	356	620	7	2.07	126	495	10091
Plan 4	406	665	7	1.90	120	445	10048
Plan 5	462	821	9	1.87	119	436	12106
Plan 6	500	953	10	1.91	119	400	13413
All agric.	612	1161	11	1.71	112	228	14067
Base	612	612	1	0.90	83	100	5302
All for.	0	0	—	—	—	461*	3740

* NBI includes an estimated value from the cross-bred flock

Conclusions

The method described produces results for a range of potential solutions, as shown in the two examples, which allow land-use decisions to be made on a more objective basis.

The results allow an examination in overall economic terms (the NBI) of the criteria used in decisions concerning the use of areas of land by both agriculture and forestry; the scheme with the highest NBI can easily be determined. However, the ultimate choice of scheme may be influenced by other factors, for example, the level of MII achieved by agriculture or the proportion of land allocated to forestry. Additionally, it may be necessary to take account of other factors, such as Government policy with regard to conservation, water supply aesthetics or regional planning policies. The results produced by the method provide a means of assessing the consequences of any of these influences in economic terms.

The appraisal of the range of solutions can include variations in discount rate, prices and costs to test sensitivity to changes in these parameters.

Finally, it is pertinent to note that it is not simply the relative geographic positions of various site types with regard to soil, vegetation or yield class that will determine the "best" scheme in economic terms. The influence of the siting of existing roads and tracks for access will have a major effect.

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Soil acidity

[MJSF, KL]

It is generally appreciated that soil acidity is worse in soils on acidic rock, like granite, than on basic rocks like limestone and that it gets progressively worse under increasing rainfall conditions. Perhaps it is less well understood why this should be so, what factors are important in controlling these processes and what determines the amount of lime required to correct soil acidity. The purpose of this report is to briefly review these processes and to describe the progress made towards both a better understanding of the chemistry of acidity in hill soils and the improved prediction of the lime needs of such acid soils. The reason for our interest in acidity is, of course, that it is one of the major limitations to pasture production and, although it arises from natural causes, it can be corrected by farm practices. While the ways in which acidity affects plant growth, including the toxic effects of aluminium and manganese under acid conditions, are undoubtedly important questions, they are considered beyond the scope of this review.

When soil formation starts, the raw materials are more or less neutral and soils only become acid because, in temperate climates, the effects of leaching usually exceed those of weathering. The primary cause is carbonic acid (CO_2 dissolved in rain) which provides a more or less continuous supply of H^+ proportional to the amount of rain. Additional sources of acidity include (i) carbonic acid due to dissolution of CO_2 produced by respiration of soil flora and fauna, (ii) organic acids produced during residue decomposition, (iii) mineral acid produced during microbial nitrification and, less commonly, from oxidation of iron pyrites when previously anaerobic soils are aerated and (iv) the extra addition of anthropogenic substances via the atmosphere in "acid rain". If soils are to remain neutral (or even near neutral), these sources of acidity must be neutralised (or partially neutralised) by bases. Under natural conditions, the main source of bases is from the weathering of rock minerals and the more basic rocks yield more than do acidic rocks. This process does tend, however, to slow down with decreasing temperatures in the hills where it is most needed to counteract the effects of increasing rainfall. Because of exchange processes in soil, H^+ tends to displace the basic cations (Ca, Mg) which may be lost by leaching but the active re-cycling of these cations by deep rooting plants tends to minimise this process. The balance of these processes is one of the most important factors controlling the distribution of hill soil types, which range from acidic brown soils on lower slopes (pH 5.5-4.5), through podsols and peaty podsols (pH 4.5-4.0), to peat (pH < 4) on the higher ground. The alternative source of base is lime, which is applied in farm practice to correct acidity.

Increasing organic matter (OM) content is also usually associated with increasing elevation and acidity in hill soils. This constitutes both cause and effect because increasing acidity retards the decomposition of OM and hence favours its accumulation by tipping the production-decomposition balance. With increasing OM content, the number of exchange sites also increases and if these are not satisfied by basic cations (from weathering) they will be filled by H^+ and the soil will become progressively more acid. Organic matter plays a very important part in the chemistry of soil acidity in hill soils: it is mainly the "weak acid" nature of organic exchange sites which prevents soil acidity falling below about pH 3.8 unless mineral acids (like sulphuric) are also present.

It has long been known that acidity in soils is not simply due to H^+ in soil solution but is also related to the hydrolysis of aluminium derived from soil minerals:

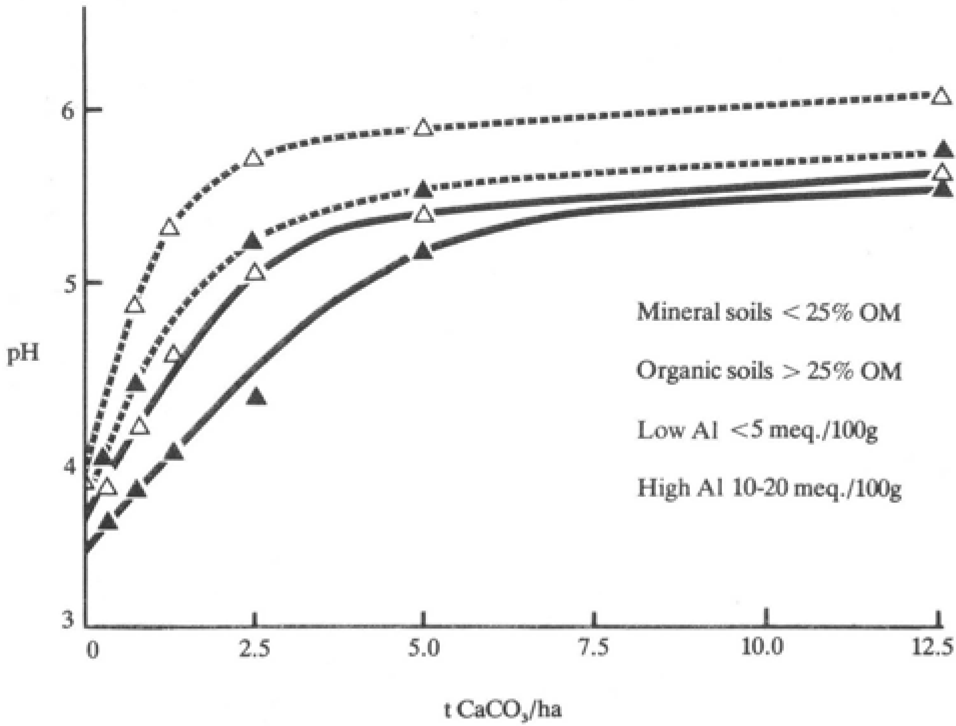
$$Al^{3+} + H_2O \rightleftharpoons Al(OH)_3 + 3H^+$$

If this were a simple chemical reaction, with a fixed equilibrium constant, it would be possible to define the amount of Al^{3+} in solutions at a given pH or vice versa. (It should be noted that it is just as important to know the amount of potentially toxic aluminium in solution at a given pH, as it is to know the pH which would result from a given amount of aluminium.) However, this is not possible because the chemistry of aluminium is far from simple, involving exchange reactions as well as solution chemistry and the occurrence of polyhydroxy aluminium complexes which may lead to the presence of more aluminium in solution than might otherwise be calculated.

Some of the relationships between OM, aluminium and acidity in hill soils were described by Floate (1978). Using soils from hill land in southern Scotland, it was shown that, when the OM content was less than 5%, Al^{3+} constituted almost 100% of total exchangeable acidity, when the OM was between 5 and 25%, Al^{3+} accounted for a declining proportion of the exchangeable acidity and when the OM was above 25%, Al^{3+} acidity was less than 30% of the total while the remainder

Fig. 14

Effects of organic matter and exchangeable aluminium content of hill soils on pH response to lime



was due to H^+. Although exchangeable Al^{3+} as a component of acidity decreased, the total exchangeable acidity and the cation exchange capacity (CEC) increased with increasing OM content. Evidence was presented to show that both OM and exchangeable Al^{3+} influenced the pH response of soils to increasing amounts of added lime (Figure 14) but it was also observed that the CEC of the four soils increased in order of increasing amount of lime required to attain a given soil pH.

The effect of exchangeable Al^{3+} on the responsiveness of a soil to lime was also indicated by samples obtained (with assistance from ADAS, Bangor) from a site in N. Wales (Llansannan) which had been limed in 1952 and then left untreated until it was sampled in 1974. There was an initial rise in soil pH following applications of 1.5 t Ca0/ac (3.77 t/ha) but by 1974 the pH values of control and limed plots both averaged 4.0 on a peaty podsol of the Hiraethog series. It was found, however, that the control soil required 0.5 t lime/ac (1.26 t/ha) compared with 0.3 t/ac (0.75 t/ha) on the formerly limed soil to raise the pH to 5.0 in laboratory tests. This was attributed to the significantly higher exchangeable Al^{3+} (6 meq./100 g) in the control compared with that (only 1 meq./100 g) in the formerly limed soil. It is interesting to note that the residual effects of lime on exchangeable Al^{3+} have persisted for more than 20 years, while the soil pH reverted to the same level as the control in a shorter but unknown length of time. ADAS records show that a significant pH difference persisted at least until 1962.

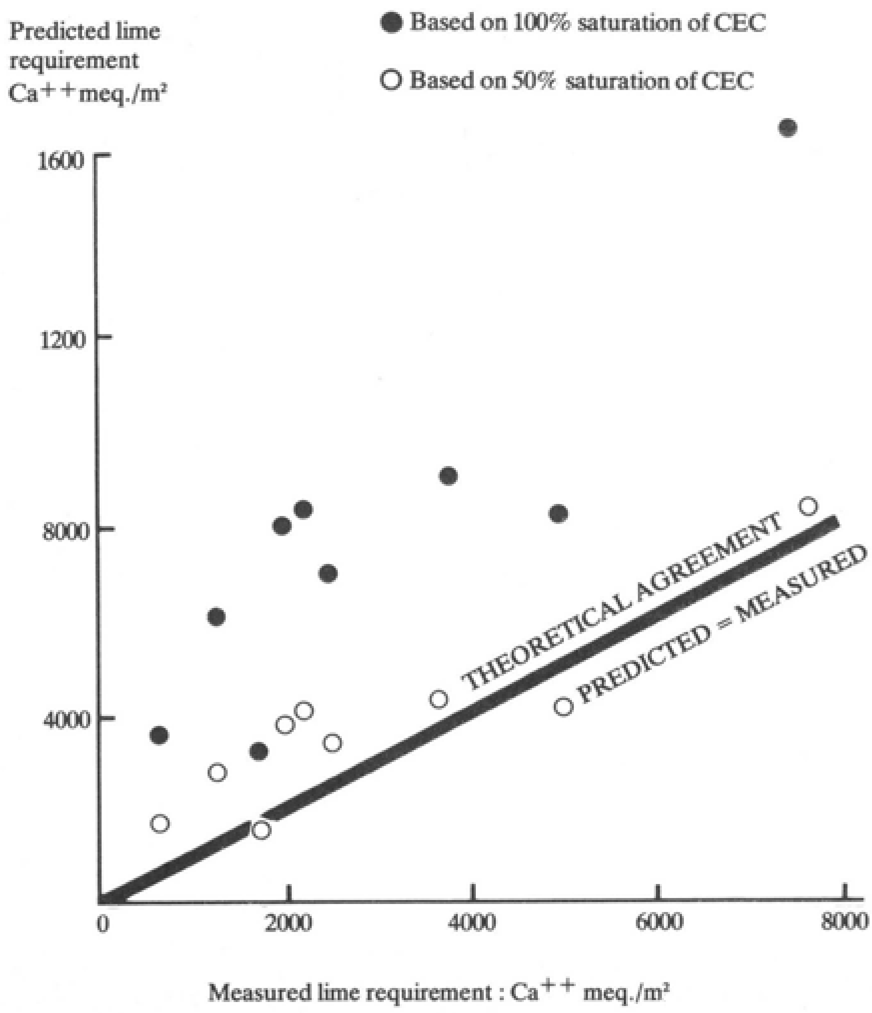
Further evidence for the influence of aluminium in lowering the response of soils to lime had been obtained when Lowe (1975) showed that, with increasing additions of aluminium sulphate to soils from Sourhope, more lime was required to attain a given pH.

Because of the limitations on herbage production imposed by acidity, it is important to be able to raise the pH of hill soils, especially for improved pasture species. Lime is the most widely used material for this purpose although marl, calcareous shell sand and basic slag have been used in the past. Whichever material is chosen, we need to know how much to apply: this is not just a simple function of the natural pH of the soil but also appears to be related to OM and aluminium content and may also be a function of CEC. Many methods have been used by soil testing services but the one currently employed by ADAS is a buffer titration procedure using para-nitro phenol.

In the work reported by Floate (1978), the measured amount of lime needed to raise the pH of 9 test soils to pH 5.5 was compared with the amounts predicted by several methods used for the determination

Fig. 15

Relationships between lime requirement predicted from 50% and 100% saturation of CEC at pH 7.0, and measured lime response



of "Lime Requirement". Predictions based on the standard ADAS method gave values for most soils which were much higher than the measured amounts, while calculations based on exchangeable Al^{3+} gave values which were too small except in two cases where the agreement was very good. Prediction of lime requirement from CEC measured at pH 7, gave values which were still too high but were significantly correlated with the measured response to lime. When the calculation was based on the amount of lime needed to satisfy 50% of the CEC, the prediction was much improved and the correlation between predicted and measured values was highly significant (Figure 15). It was concluded that prediction of lime requirement from 50% saturation of CEC might provide an improved method applicable to hill soils and that its applicability should be tested in the field.

Field experiments to test the responsiveness of two soils had been established in 1974 and 1975. These experiments, on deep peat at Lephinmore and on an acid brown soil at Stanhope (see Project 04011), also had as part of their objectives an evaluation of the persistence of sown pasture species. On the ryegrass/clover reseeded areas on deep peat, the response to lime was patchy and this resulted in appreciable differences in pH between replicates of the same treatment. This prevented a proper interpretation of the relationship between lime response and predicted lime requirement. With lime treatments ranging from 0 to 5 t/ha in 1974, the resultant pH ranged between 4.0 and 5.1 in 1977. Relationships between herbage yield and soil pH for 24 individual plots indicated a sigmoidal response with a point of inflection (m) which may be regarded as giving critical pH values for the reseeded species. Data for ryegrass and clover responses in 1975 and 1976 were related statistically by a double exponential response equation to soil pH measured at the appropriate time. This technique indicated critical values (m) of about pH 4.0 and 4.5 for ryegrass and clover, respectively.

Progress on the Stanhope site is reported under Project 04011, where it is noted that field evidence has been obtained for the usefulness of the proposed method of predicting lime requirement based on partial saturation of CEC.

Measurements of CEC in adjacent limed and control soils from Lephinmore and Stanhope, indicate that CEC at pH 7 is independent of both natural soil pH and past lime treatment, so that the proposed method may only be applicable to virgin soils.

Data on the relationship between the pH-dependence of CEC and both OM and exchangeable aluminium content and on the responsiveness of soils to lime in relation to CEC, OM and exchangeable aluminium content, were re-examined to seek a more generally applicable prediction for lime requirement. This showed that, for a group of 10 soils varying in OM from 15 to 90%, there was a highly significant correlation between OM content and the increase in CEC between pH 3.5 and 8.0. This was probably the basis of the previously reported relationship between OM and soil response to lime. Although evidence reported above indicated the importance of exchangeable aluminium in determining soil response to lime, the present evidence suggests that OM (and hence pH-dependent CEC) may be more important than aluminium. It has recently been shown that the laboratory response to lime was highly significantly correlated ($r = 0.92$, $P < 0.001$) with Δ CEC, where Δ CEC is the pH-dependent increase in CEC between the existing and the target soil pH. Δ CEC is defined as the difference between CEC measured under unbuffered and buffered (pH 5.5) conditions. Favourable agreement was obtained between lime requirement calculated from Δ CEC and measured field soil pH response on the acid brown soil at Stanhope.

Some work has also been done in association with the Soil Science Department at ADAS Northern Region (Newcastle-upon-Tyne) and samples were obtained from peat at Redesdale EHF. Δ CEC has been measured on these samples and calculations indicate a lime requirement in the range 3.5-4.0 t lime/ha. This coincides with observations on the relative effectiveness of 2.5, 5.0 and 7.5 t/ha applied on reseeded peat at Redesdale in 1969. Obvious differences between treatments at this site have never been observed and this suggests that the lower rates were adequate although the standard ADAS laboratory procedure indicated a much larger lime requirement. It is concluded that, at the present time, the calculation based on Δ CEC seems to offer the basis for a more generally applicable and reliable prediction of lime requirement than has hitherto been available for hill soils. A lime response experiment on the peat at Redesdale EHF is currently being conducted and it will be very interesting to see how the field results compare with the calculations.

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Beef Cattle Research

A. J. F. Russel

INTRODUCTION

The Organisation's research stations have always carried a small complement of suckler cows but these, like their counterparts in many commercial hill farming enterprises, played a subsidiary role to the hill ewe stocks. The decision to devote specific resources and research effort to beef cattle was made in 1972, following the widening of the Organisation's remit to include the upland sector of the industry as well as that of the true hill farm. The overall objective of the beef cattle programme, which has been pursued unchanged since that date, is to obtain an understanding of the biological factors influencing production from suckler cows, with the ultimate aim of improving the efficiency with which hill and upland resources are used for beef production.

The programme began in 1973, following the completion of a purpose-built cattle house at Glensaugh designed to accommodate 128 individually-fed cows or 64 cow-calf pairs. A herd of some 80 cows was established, made up of approximately equal numbers of Blue Grey (Whitebred Shorthorn × Galloway) and Hereford × Friesian cows. Initially, these were crossed with Hereford bulls but after 2 years a change was made to the Charolais.

The winter feeding of suckler cows represents the largest single cost in the production of weaned beef calves and, with this in mind, the initial stages of the programme were devoted to studies of the effects of nutrition during late pregnancy and in lactation on production assessed in terms of calf birth weight, cow milk production and calf growth rate in autumn-calving cows. These were housed from some 3 months before calving until weaning when the calves were approximately 5 months old. This provided ample opportunity to examine the effects of extended periods of a wide range of nutritional regimes on the components of production.

The need to initiate studies with grazing cows and calves was accommodated by changing from autumn to spring calving in 1976. For 3 years after that, each experiment comprised late pregnancy and early lactation treatments indoors, followed by further nutritional treatments at pasture in the later stages of lactation. To meet the demands of the expanding programme, cow numbers were increased and the single herd divided into two herds, each of about 60 cows, in 1978. Since that time, one herd, calving in the spring, has been used principally for studies on aspects of grazing management and herbage utilisation. The other herd, which, to make fullest use of the facilities, calves in the autumn, has been used for nutritional studies with pregnant and lactating animals. The change in calving date of the nutrition herd provided an opportunity to undertake studies which required the use of non-pregnant, non-lactating, cows.

Following the acquisition of the new Hartwood Research Station in 1980, the major part of the beef cattle programme was moved to that station. The first cattle experiment was conducted there with the grazing herd during the summer of 1980 and the cows of the nutrition herd were moved in the autumn of the following year. The present beef cattle facilities at Hartwood comprise one house which can accommodate 120 individually-fed cows or 60 cow-calf pairs and another in which some 120 cows can be loose-housed. It is intended to increase the beef cow complement at Hartwood to 250. The original cattle house at Glensaugh has been modified to accommodate the first nutritional studies on weaned calves, an area which has long been recognised as meriting attention but for which there were previously no facilities.

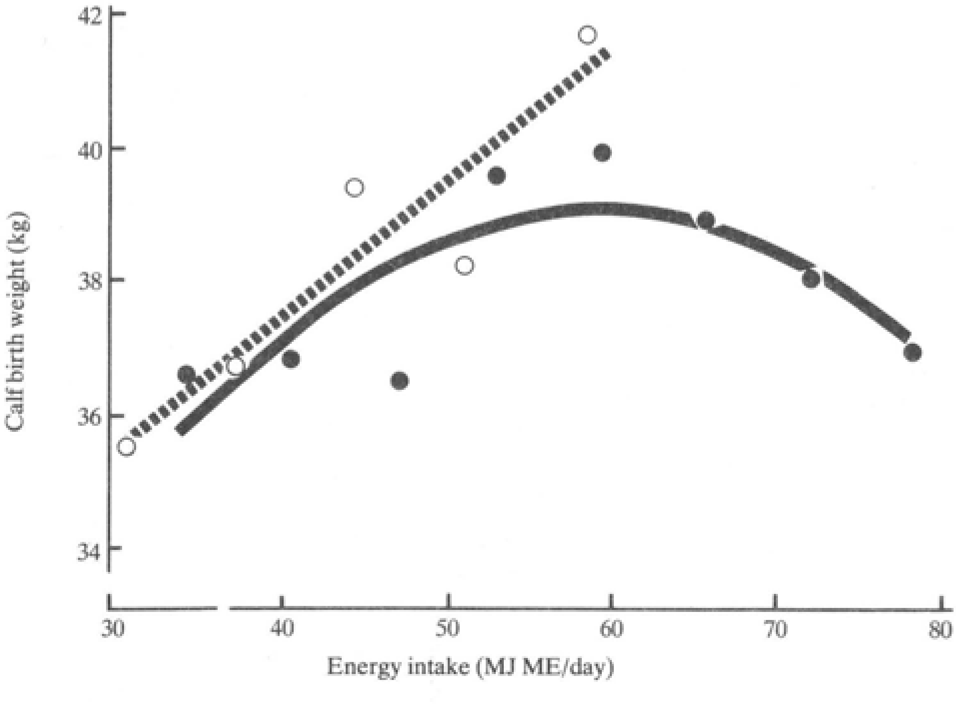
THE EFFECTS OF NUTRITION ON PRODUCTION

In Late Pregnancy

The first experiments with suckler cows examined the effects of nutrition during the final 12 weeks of pregnancy on calf birth weight and, against a background of high levels of *post-partum* nutrition, on subsequent milk production and calf growth rate. The cows were all in good body condition (condition score 3 or greater) at the beginning of late pregnancy. A range of energy intakes of approximately 30-78 MJ ME/day, corresponding to some 65-170% of the maintenance energy requirements of non-pregnant cows, produced significant effects on calf birth weight, as illustrated in Figure 16. Maximum birth weights resulted from energy intakes of about 120% of non-pregnant maintenance and it appeared that reductions were caused by either very low or high levels of feeding. The largest difference in birth weights between treatments was 15% and, in general, the lower levels of energy intake resulted in reductions of some 10-12%. This order of reduction in birth weight is considered to be acceptable and, in these experiments, did not have any adverse effects on subsequent performance. Indeed, since neonatal mortality increases with above-average birth weights, a case can be made for nutritional regimes which will result in a moderate depression in birth weight and in the loss of body condition of cows

Fig. 16

The relationship between calf birth weight and the energy intake of cows during late pregnancy (● 1st year, ○ 2nd year)



to reduce the incidence of calving difficulties. The nutritional treatments imposed prior to calving had no significant effects on milk production or on calf growth rate when all cows were unequivocally well fed during lactation.

In a subsequent study, the interactions between body condition at 12 weeks *pre-partum* and nutrition from that time until calving were examined. The results confirmed the earlier finding that severe undernourishment in late pregnancy did not prejudice the subsequent performance of cows which were in good condition at the beginning of late pregnancy. The majority of cows in poorer condition (condition score 2) and subjected to a similar severity of undernourishment gave an acceptable level of performance but, although there were no effects on birth weights, their calves grew less well, irrespective of the level of *post-partum* nutrition. Some undernourished Hereford × Friesian cows were removed shortly before or immediately after calving, as it was considered that persistence with the treatment could have affected them adversely. In this particular experiment, levels of feeding were regulated according to plasma 3-hydroxybutyrate concentrations to produce distinctly different nutritional states. Although this technique was not as successful as in earlier work with pregnant ewes, it was clear that the cows in good body condition did not require any greater quantities of food than did those in poor condition to maintain the same prescribed nutritional state, despite their considerably heavier body weights. The results, in general, show that there are considerable opportunities for using the cow's body reserves to effect economies in the use of expensive winter feeding stuffs, provided that the cows are in good body condition at the beginning of the late pregnancy period.

The work on late pregnancy nutrition also included an examination, in collaboration with workers from the Animal Breeding Research Organisation, of factors affecting immunoglobulin production by the cow and absorption by the calf. Very severe levels of undernourishment reduced immunoglobulin transfer but not to an extent where concentrations were considered unduly low. Concentrations of immunoglobulins in the colostrum of Blue Grey cows and in the serum of their calves were higher than in the Hereford × Friesian cows and calves. There was evidence of a more rapid uptake of colostrum by calves from Blue Grey cows and it was noted that cows of both genotypes which transferred high immunoglobulin concentrations in one year tended to do so subsequently.

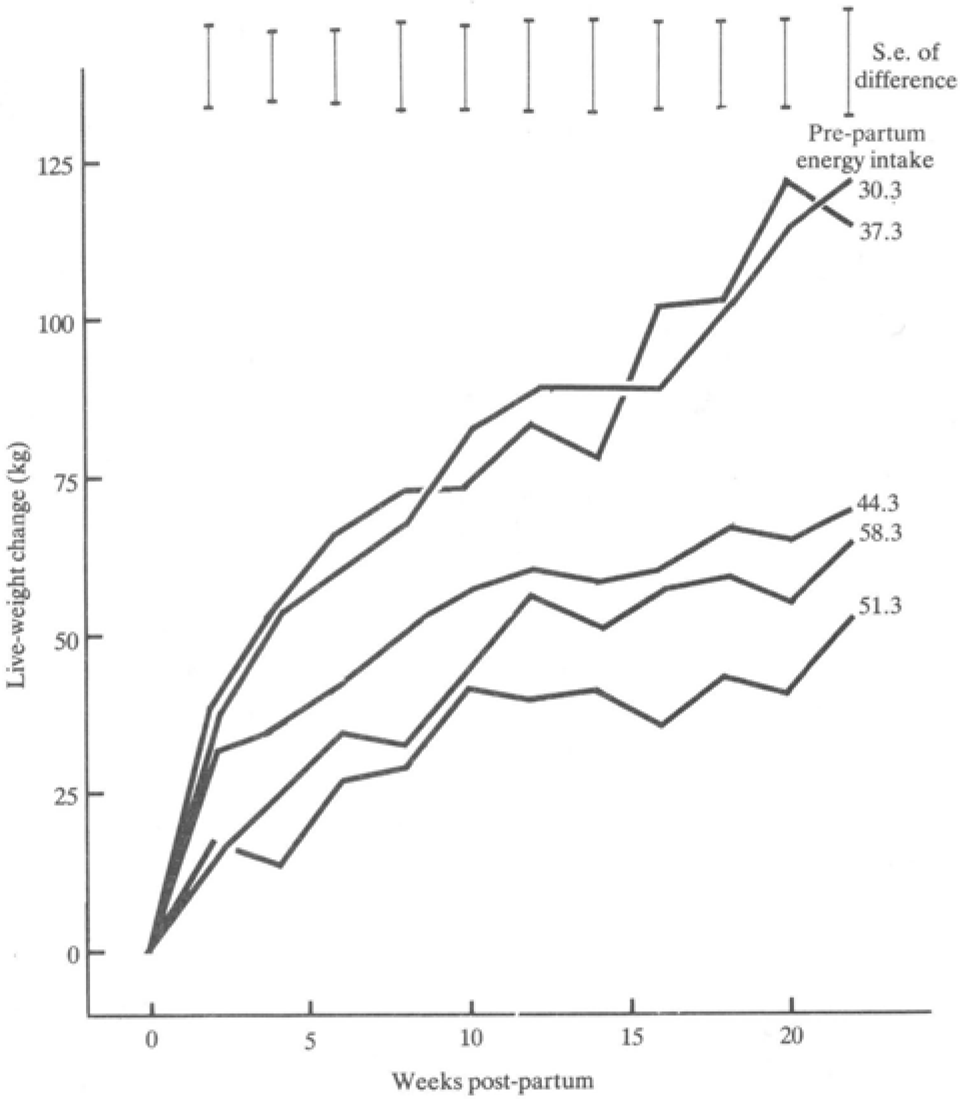
In Lactation

The early work with cows unequivocally well fed throughout lactation (i.e. energy intakes rising rapidly from about 100 MJ ME/day to around 150 MJ at 3 weeks *post-partum* and, exceptionally, to near 200 MJ at 10-12 weeks) indicated that Blue Grey and Hereford × Friesian suckler cows were capable of high levels of milk production for considerable periods. Under the conditions of these experiments, which were conducted on cows in good body condition at 12 weeks *pre-partum*, level of milk production was not affected by severe undernourishment in late pregnancy. Mean levels of milk production averaged 10 kg/day over 22 weeks. The only important demonstrable effect of a wide range of *pre-partum* nutritional treatments was an inverse relationship between *pre-partum* food intake and rate of recovery of cow live weight during lactation (Figure 17).

The results of a number of experiments in which nutrition was deliberately restricted in early lactation illustrate the suckler cow's considerable ability to utilise body reserves for milk production. There is now a substantial body of evidence to show that levels of feeding calculated to provide sufficient nutrients for, say, 2 and 9 kg milk/day result in comparatively small differences in the actual quantities of milk produced in early lactation. Typical production figures for these two levels of feeding are of the order of 8 and 9.5 kg/day for the first 6 weeks of lactation, corresponding to calf growth rates of 770 and 930 g/day, respectively. However, the magnitude of these differences increases with time. One of the consequences of this comparatively small difference in milk production, despite the substantial difference in energy intake, is that the more poorly fed cows lose weight at a rate of up to 1.0-1.5 kg/day. If milk production from body reserves is to be sustained for any appreciable period — and other work has shown that it can be continued for some 3 to 4 months — it is clearly important to ensure that the cows have adequate reserves remaining at parturition.

Fig. 17

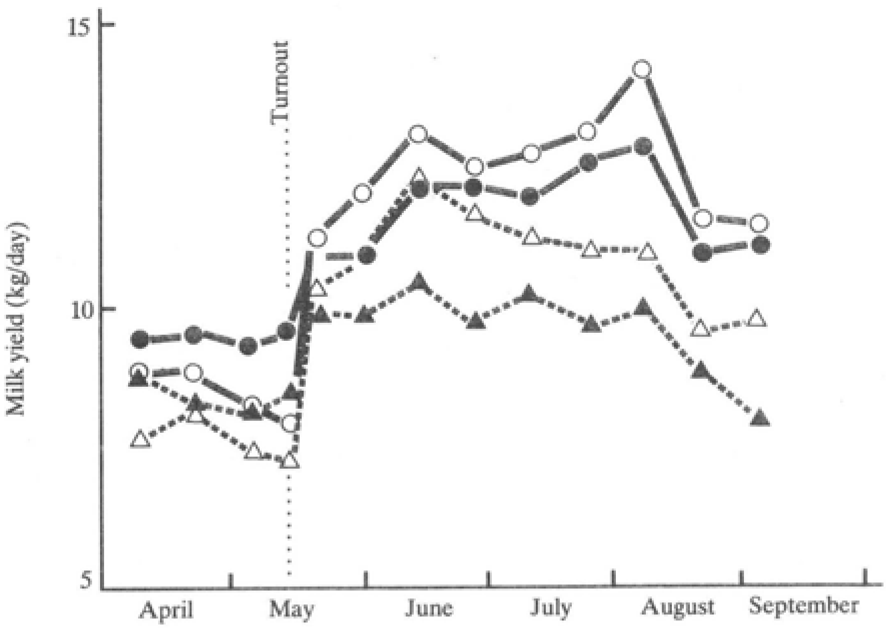
Changes in the mean live weight (with s.e. of difference) during lactation of cows on five levels of energy intake in late pregnancy and fed ad libitum *in lactation*



An important feature of the lactation studies has been the response in milk production to substantial improvements in the level of nutrition, such as occurs following the turnout of cows and calves to pasture. This has been characterised in every case by a very rapid increase in milk production. The response has been observed in cows varying in stage of lactation from about 6 to 16 weeks and illustrates the responsiveness of the milk production of such cows to improved nutrition. The other interesting feature of this response is that it has been consistently greater in cows which have been relatively poorly fed in early lactation. The example illustrated in Figure 18 is from an experiment in which cows in early lactation were fed sufficient nutrients to supply the needs of either 2.25 (Treatment L) or 9.0 (Treatment H) kg milk/day. At pasture, the previously poorly fed cows produced more milk than those previously well fed and this ranking was maintained throughout the grazing season. The effect appears to be largely independent of sward conditions.

Fig. 18

Mean daily milk yield estimated at 2-week intervals for Hereford × Friesian cows, Treatments L (○) and H (●); and Blue Grey cows, Treatments L (△) and H (▲)



Subsequent studies have shown that these responses in milk production can be largely explained by increased herbage intakes following turnout. It is currently assumed that these enhanced voluntary intakes at pasture are attributable to differences in body composition arising from the nutritional treatments imposed prior to turnout, rather than to the actual levels of feeding *per se*, and it is proposed to test this hypothesis and attempt to quantify such effects in a forthcoming experiment.

At Pasture

Most of the grazing work with suckler cows has been confined to studies on sown swards under relatively intensive management. In the initial studies, attention was concentrated on the evaluation of the effects of treatments imposed indoors during pregnancy and early lactation on performance during the grazing season. These provided basic information regarding changes in cow live weight and condition, levels of milk production and rates of calf live-weight gain which could be achieved from grazing animals in mid- and late lactation and related these measurements of performance to estimates of herbage intake.

The responses in milk yield following turnout to graze were reflected in calf growth rates, so that the earlier weight disadvantages of the calves of cows poorly fed in early lactation were overcome by weaning. The effects of early lactation nutrition on cow live weight and condition also disappeared by the end of the grazing season. Under relatively generous rotational grazing management with a herbage allowance of 40-50g DM/kg LW/day, giving the opportunity to consume herbage with an organic matter digestibility in excess of 0.7 throughout the grazing season, cows were capable of sustaining levels of milk production averaging 10-13 kg/day to weaning at about 180 days *post-partum* and calf growth rates of 1.1-1.2 kg/day.

Levels of cow and calf performance were consistent from year to year, despite substantial variations in the preceding winter treatments. In one trial, a leader/follower system of management was used to introduce contrasts in the quantity and quality of the herbage grazed. There were substantial differences between leaders and followers in the herbage intakes of the cows (12.8 v. 11.1 $\pm$ 0.42 kg DM/day) and in the weight gains of the cows (1.0 v. 0.6 $\pm$ 0.07 kg/day) and their calves (1.3 v. 1.0 $\pm$ 0.04 kg/day). The effects of the grazing treatments on cow and calf live weights at weaning were substantially greater than the effects of the preceding winter treatments.

Continuous stocking managements have been used in more recent studies, partly as a means of achieving greater uniformity of sward conditions and more consistent control of nutrition, and partly in recognition of the greater relevance of this procedure to beef cow management. Contrasting sward conditions have been employed to study further the interrelationships between the effects of winter and summer nutrition on cow and calf performance and to extend the earlier observations on changes in milk yield at turnout to studies on the responses in milk yield and calf growth to changes in nutrition at different stages in the grazing season. The effects of small changes in sward conditions on animal performance can be substantial; for example, in one study with swards maintained at either 5-6 cm or 3-4 cm surface height, cow live-weight losses over a 4-week period averaged 1.2 and 2.1 kg/day, respectively, with associated calf growth rates of 1.2 and 0.7 kg/day, respectively.

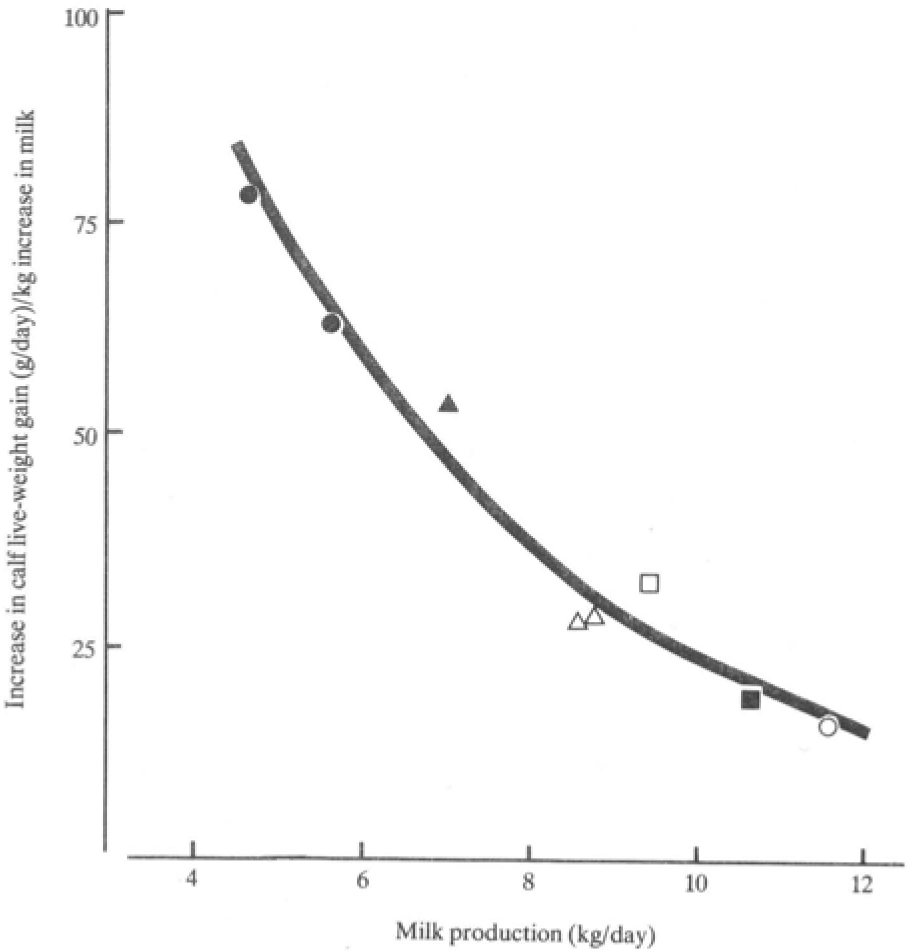
Calf Nutrition and Growth

During the first 6 to 8 weeks after parturition, the suckling calf does not eat appreciable quantities of solid food and its growth rate is thus almost wholly dependent on its milk intake. Although the effects of maternal nutrition on milk production in early lactation are comparatively small, they are, at that stage, consistently reflected in the rate of calf live-weight gain. Beyond this age, calves appear to be able to compensate, to some degree, for a reduced availability of milk, by increasing their intake of solid food, provided that sufficient quantities of high quality creep feed or grass are made available. While examination of the relationship between milk production and calf growth rate shows the diminishing importance of milk intake as a factor determining rate of calf live-weight gain with advancing age, the level of milk production can, nonetheless, still account for a significant proportion of the variance in calf daily gain at 5 months of age.

The response in calf live-weight gain to level of milk production has also been shown to decrease as milk production increases. This particular relationship (illustrated in Figure 19) is, in fact, dealing with the marginal increase in calf performance which may be expected per unit increase in milk intake at various levels of milk production. For example, at relatively low levels of milk production of about 5 kg/day, an increase of 1 kg/day would be expected to produce a marginal increase in calf growth rate of some 75 g/day, whereas at levels of milk production of around 10 kg/day, the calf's response to an additional 1 kg/day would have fallen to only 25 g/day. This relationship is interpreted as indicating that, at levels of milk production of the order of 10-12 kg/day, the opportunities for increasing calf growth rates through further increases in milk production are strictly limited and presumably costly, at least in energetic terms.

Fig. 19

The relationship between the increase in calf daily live-weight gain per unit increase in milk and the level of milk production. Data from HFRO Blue Grey (□) and Hereford × Friesian (■) cows. Other symbols refer to reports in the literature



Both Blue Grey and Hereford × Friesian cows are clearly capable of maintaining levels of milk production of this order for substantial parts of a lactation and this prompts the question as to whether, at such levels of production, a system of double or multiple suckling, which would give a greater marginal response in calf growth rate, should be considered. Multiple suckling systems create a high labour demand and are probably unrealistic for many livestock rearing areas. Recent progress in procedures for inducing twinning in cattle, however, indicates the potential for improving the efficiency of calf production, provided that the extra nutritional demands of the cows can be met.

An initial study of the nutritional requirements of twin-suckling cows, using a calf-fostering procedure, proved to be somewhat disappointing because many of the calves were affected by digestive tract infection. In the indoor phase of the trial, cows were fed for levels of milk yield ranging from 2.5 to 17.5 kg/day and the milk yield of the cows was more strongly influenced by plane of nutrition than by the number of calves suckled. Milk yield was 10-15% higher in twin-suckling than in single-suckling cows and the growth rate of twin calves was only 55-60% of that of single calves. During the grazing season, the growth disadvantage of the twin calves was reduced but they were still only 80% of the live weight of single calves at weaning. Clearly, more work is required to put the nutrition and management of twin-reared calves on a sounder footing.

REPRODUCTIVE EFFICIENCY

The achievement of timely and successful rebreeding is a major factor determining the profitability of suckler cow enterprises. Because of the need for relatively large numbers of animals to demonstrate significant effects, the investigation of factors affecting reproductive efficiency is one of the more difficult areas to study in detail. Opportunities have, however, been taken to examine, in the experiments on pregnancy and lactation, the effects on reproductive performance of the various treatments applied. In general, these have failed to show statistically significant effects, although there have been indications that the more severe nutritional treatments in early lactation have lengthened the calving interval, particularly in Hereford × Friesian cows.

For a number of years, milk samples from both the nutrition and grazing herd cows have been made available to the University of Nottingham School of Agriculture for milk progesterone determinations. This has been part of a wider study to examine the importance of some of the factors affecting ovarian activity in *post-partum* beef cows. The results have shown a significantly longer acyclic period in the cows of the spring-calving grazing herd (87.8 days) than in those of the autumn-calving nutrition herd (66.7 days). However, the shorter acyclic period in the latter does not necessarily indicate a better reproductive efficiency and the experience of recent years has been of greater difficulty in achieving a satisfactory calving interval in the nutrition herd. The grazing herd cows, on the other hand, while taking longer to commence ovarian activity after calving, have consistently rebred very quickly and successfully when mated at pasture immediately following turnout. In this herd, it was also observed that Blue Grey cows resumed cyclical activity significantly earlier (81.1 days) than did Hereford × Friesians (91.5 days). There was no significant difference between genotypes in the nutrition herd (63.6 and 67.8 days, respectively). Although it was possible to demonstrate a significant negative correlation between *post-partum* live weight and the length of the acyclic period, this accounted for only some 14% of the variance in the latter and there are clearly other important but as yet unquantified factors affecting reproductive efficiency.

In experimental situations where cows are kept in individual standings, the detection of oestrus poses special problems not encountered with group-housed or grazing animals. Two techniques for the objective detection of oestrus have been employed in recent years. These are the use of a vaginal probe to measure the electrical resistance of vaginal mucus and the examination of fenestration patterns of cervical mucus. Both techniques have proved effective and experience has shown that best results are achieved by the simultaneous use of the two approaches.

THE EFFECTS OF GENOTYPE ON PRODUCTION

The work referred to above has all been embodied in experiments in which the two genotypes (Blue Grey and Hereford × Friesian) have been represented, as far as possible, in a balanced manner designed to permit the ready identification of production differences between these two main types of suckler cow. The results have shown a considerable number of differences in important components of production and these have generally been in favour of the Hereford × Friesian. In comparison with the Blue Grey, and after making due allowances for differences in live weight, the Hereford × Friesian has generally produced calves of heavier birth weight. Their milk production measured in a number of experiments with housed and grazing cows has consistently been some 1-2 kg/day greater than that from Blue Greys and, at least partly as a result of this, the rate of live-weight gain of their calves has generally been some 100-120 g/day greater than that of Blue Grey cross calves.

Despite this evidence, there remains a hesitancy to conclude that the Hereford × Friesian is the more productive cow and that no further research effort should be devoted to the Blue Grey. What might appear to be equivocation on the point is justified on at least two counts.

First, factors such as calf birth weight, level of milk production and calf live-weight gain to weaning are undeniably very important components of production but, in terms of herd production, other considerations such as reproductive efficiency and longevity must also be taken into account. Limited information on the rebreeding performance of cows from both herds (see above) indicates that the Blue Grey may have some small advantage over the Hereford × Friesian in this respect. Detailed analyses of reasons for culling cows from the experimental herds have not been attempted but it is clear that the rate of culling of the Hereford × Friesians has been higher than that of the Blue Greys. Evidence from other sources also indicates that, when the output of weaned calves per hundred cows mated is considered, there is little to choose between the two genotypes.

A second consideration concerns effects on production of differences in body composition. A number of experiments have shown that, during early lactation, Hereford × Friesian cows lost more weight than did Blue Greys. It was also observed that, following turnout, the Hereford × Friesians had higher voluntary intakes than did the Blue Greys and this difference was reflected in their higher levels of milk production at pasture. There is now reason to believe that these higher herbage intakes may be due, at least in part, to their greater weight loss in early lactation and consequent lower levels of body fat at turnout. Recent evidence also indicates that, at equal body condition scores, the Hereford × Friesian cows have less total body fat than do Blue Greys. This has important implications regarding the interpretation of live-weight losses during early lactation in cows of similar body condition; it could also conceivably confound any effect of level of fatness at turnout on voluntary intake and, hence, on level of milk production at pasture. Much of this is, at present, conjecture but such uncertainties make imprudent any categorical statements about the "superiority" of either genotype.

BODY COMPOSITION STUDIES

In much of the work described above, the question of the utilisation and replenishment of the suckler cow's body reserves has been recognised as of central importance. Despite this, the inability to estimate the extent of, or changes in, these reserves in other than qualitative terms constrained the type of work which could be undertaken to provide information in this key area. Attention had been paid to the assessment of body condition but the means to relate this quantitatively to body fat did not exist. To meet this need, an evaluation was made of a wide range of techniques for estimating body composition in the live suckler cow. The objectives of this work were to assess the usefulness in practice of a number of existing techniques and to quantify the relationships between the *in vivo* measurements and direct measurements of body composition made following slaughter. This major study was conducted on 73 non-pregnant, non-lactating, cows of five genotypes (Blue Grey, Hereford × Friesian, Luing, Galloway and Friesian) ranging in body condition score from 1 to 4½.

Live weight, body condition score, deuterium oxide space and ultrasonic measurements of eye-muscle area and subcutaneous fat depth (between the 12th and 13th ribs or over the transverse processes of the third lumbar vertebrae) were all considered to be potentially useful in the prediction of body composition in the live animal. Combinations of techniques afforded better predictions than did any single estimate and several prediction equations incorporating different combinations of indices have been developed. The residual standard deviations of the equations used to predict body fat and protein are of the order of 13 and 3 kg, respectively. Because of differences noted in fat partition between genotypes, it is important that the equations are used only for the particular genotype from which they were derived.

The between-genotype differences in partition of body fat were such that the Friesian cows had significantly higher proportions of fat in the internal depots (omental, mesenteric and perirenal) and lower proportions in the subcutaneous depot than did the other genotypes. The highest proportions of subcutaneous fat were observed in the Hereford × Friesian cows. The results, in general, confirm the potential usefulness of body condition scoring but the between-genotype differences in fat partition indicate that it is not possible to use a single, simple, conversion factor which would apply to all breeds and crosses to translate condition score to a weight or percentage of body fat.

The work on body composition also provided useful and valuable information on the composition and energy value of changes in body weight. There is little published information to support the widely used values of 26 MJ and 150g protein/kg change in empty body weight. The results of this study indicate, however, that the value for energy increases and that for protein decreases with increasing empty body weight. For example, the energy and protein contents of 1 kg empty body-weight change at 300 kg empty body weight were calculated as 22.5 MJ and 124g protein, respectively, compared with values of 29.2 MJ and 53g protein at 600 kg empty body weight.

MAINTENANCE ENERGY REQUIREMENTS OF SUCKLER COWS

In a study of the use of blood metabolites as indices of nutritional state, it was necessary to determine the maintenance energy requirements of suckler cows and to examine how these requirements were affected by body condition and genotype as well as by live weight. The work was carried out on mature, non-pregnant, non-lactating, Blue Grey and Hereford × Friesian cows which had been fed to create a relatively wide range in body condition. The approach adopted was that of assigning animals to fixed levels of energy intake ranging from about 50 to 120% of likely maintenance requirements and of estimating individual daily changes in live weight and condition score from regressions of those variables on time. Rates of live-weight change estimated in this manner were then related to energy intake and the maintenance energy requirement was calculated as that associated with zero live-weight change.

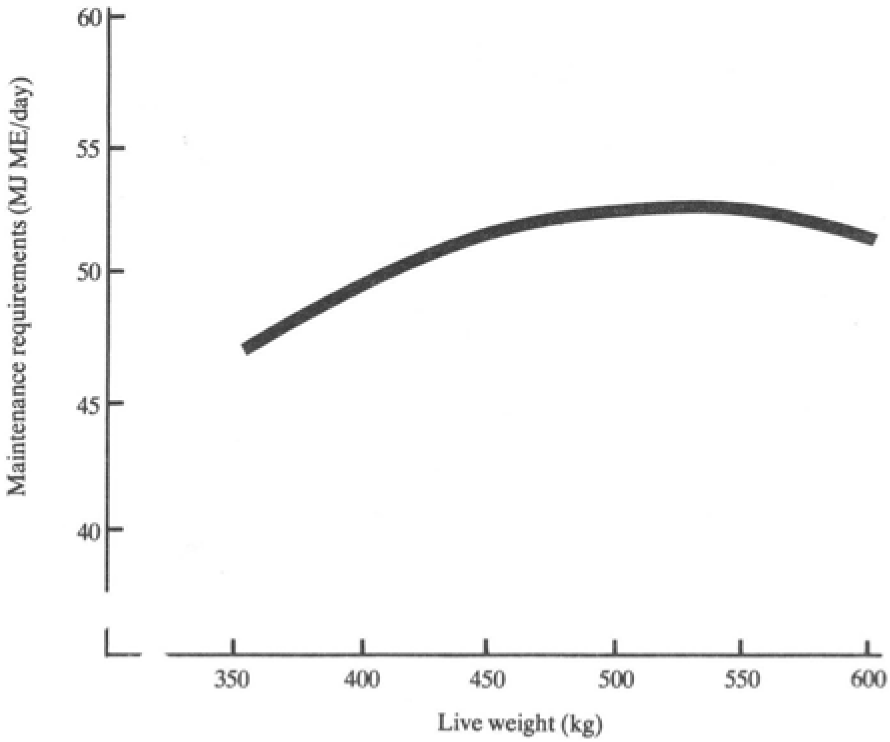
Estimates of maintenance energy requirements (M) (MJ ME/day) did not differ between the two genotypes but were shown to be determined by both live weight (LW) (kg) and condition score (CS) according to the equation:

$$M = 0.147LW - 0.016\,CS.LW$$

When account is taken of the relationship between live weight and condition score, it can be shown that, as a mature animal increases in weight and therefore in level of fatness, the rate of increase in maintenance energy requirements diminishes, as illustrated in Figure 20. The nature of the relationship between maintenance requirements and live weight (taking account of consequent changes in condition) is similar to that between body protein and empty body weight and it is considered that, because the energy cost of protein turnover is higher than that of fat, maintenance requirements are determined to a major extent by body protein mass.

Published estimates of maintenance energy requirements take account of sex, which presumably reflects different live weight:body composition relationships, but do not take into account the effect of change in body composition with change in weight. While recognising that a single relationship estimating maintenance requirements from live weight and condition score could not be expected to cover all genotypes and sexes, the results discussed above indicate that the effects of changing body composition could readily be taken into account by incorporating a live weight:body fat (or preferably, but perhaps less realistically, a live weight:body protein) relationship in the model.

Fig. 20
Maintenance requirements in relation to changes in live weight



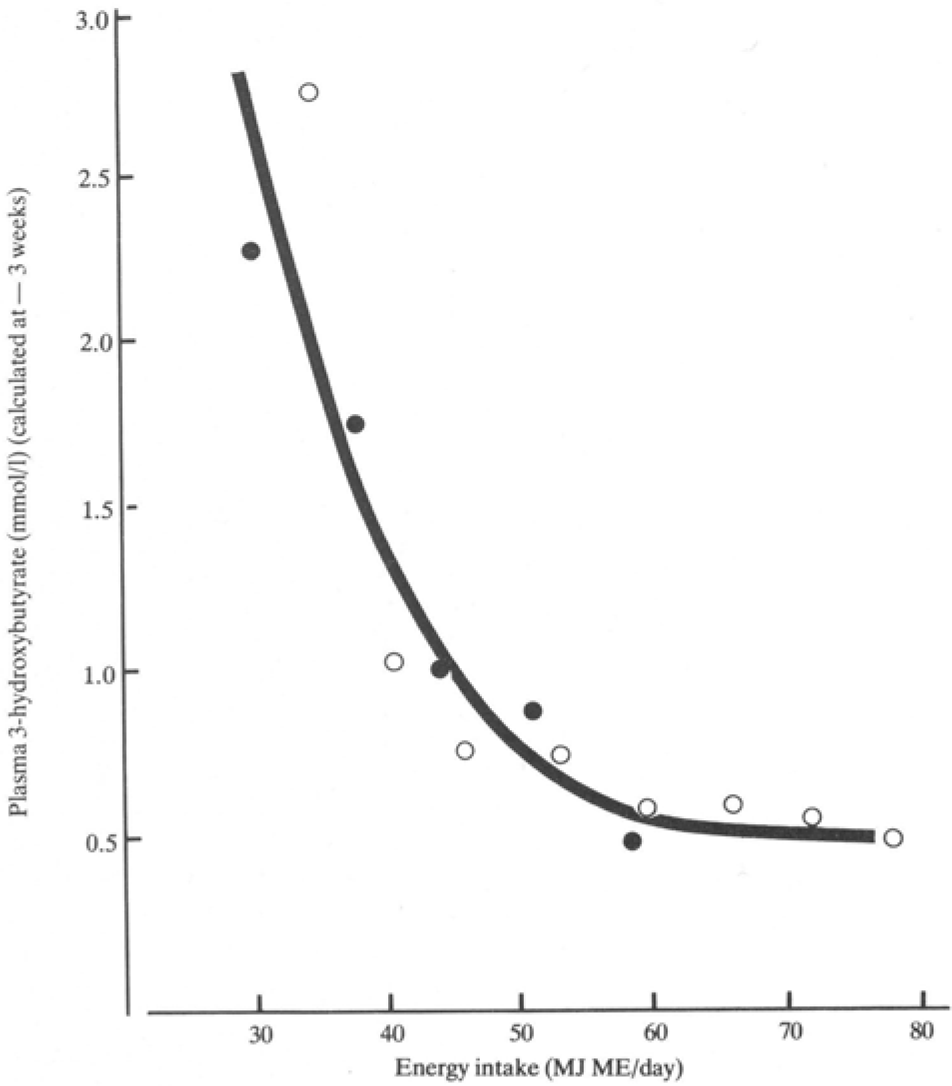
The results of this particular work also provided an estimate of the efficiency of utilisation of body tissue energy for maintenance of 0.79, as compared with the generally accepted value of about 0.70 for dietary energy.

BLOOD METABOLITES AS INDICES OF ENERGY STATUS

From the earlier review of nutrition and its effects on production, it is clear that, at certain stages of the year and of the cow's production cycle, it is likely that economic and biological considerations will dictate that cows be fed less than their requirements, while, at other stages, the nutrient intake must be greater than that needed to support the contemporary level of production. Thus, the desired level of nutrient intake at any time is likely to be greater or less than the strictly defined requirements by any amount determined by factors such as physiological state, body condition and cost and availability of nutrients. The simultaneous estimation of both nutrient intake and requirements can pose problems of measurement in most situations and, thus, a means of estimating the extent to which nutrient intake meets requirements is likely to be of considerable value in the objective regulation of nutrient intake.

Fig. 21

The relationship between calculated plasma 3-hydroxybutyrate concentration at 3 weeks pre-partum *and energy intake (○ 1st year, ● 2nd year)*



In the studies of the effects on production of nutrition in late pregnancy, plasma 3-hydroxybutyrate (3-OHB) concentrations in undernourished cows were shown to increase with advancing pregnancy up to about 3 weeks *pre-partum*, after which time they decreased. A close relationship was also evident between energy intake and plasma 3-OHB concentration at 3 weeks *pre-partum* (Figure 21). Although this relationship would permit the estimation of energy intake with reasonable confidence, there was no means of determining the level of intake which represented energy balance. This, in turn, meant that it was not possible to estimate energy deficit in other than relative terms.

Similar relationships were later established between plasma free fatty acid (FFA) concentrations and energy intake. Plasma FFA showed similar patterns of increase with advancing pregnancy up to about 3 weeks *pre-partum* and, like 3-OHB concentrations, decreased thereafter. As with the 3-OHB concentrations, the lack of knowledge of the concentration corresponding to zero energy balance precluded the estimation of energy status in absolute terms.

The experiment in which maintenance energy requirements were estimated was also designed to examine the relationships between concentrations of circulating metabolites and energy intake and, in particular, to determine those concentrations corresponding to zero energy balance. This was estimated as the concentration at the maintenance level of energy intake calculated as described above. The range of plasma 3-OHB concentrations observed in the non-pregnant, non-lactating, cows used in this experiment was very small and, although values were significantly related to levels of energy intake, it was concluded that circulating concentrations of this metabolite were likely to be of little value in characterising energy status in non-pregnant, non-lactating, cows.

Plasma FFA concentrations, on the other hand, showed considerable variation, which was closely related to energy intake. Maintenance was characterised by a plasma FFA concentration of about 450 μ eq./l, a value very similar to that determined in earlier work with sheep, and the relationship between FFA concentration and energy status fitted that found in the earlier work with pregnant cows. It thus appears that, while the use of plasma 3-OHB concentrations may be restricted to undernourished pregnant or lactating cows, plasma FFA concentrations may prove to be of value as an index of energy status of cows in a variety of physiological states.

CURRENT AND FUTURE STUDIES

Weaned Calves

The end-product of most suckler cow herds is weaned calves which are sold for growing-on and finishing in other enterprises. Producers of suckled calves generally consider returns from this form of production to be poor and the problem is particularly acute on hill farms with spring-calving suckler cows. These calves are traditionally sold at about 6 months of age and can be doubly disadvantaged because of low live weights *per se* and low prices per unit weight for this class of animal. Arguments can be advanced for an alternative strategy of overwintering such calves on a moderate level of nutrition and selling them during, or at the end of, the following grazing season, even where this would require a reduction in cow numbers (with a consequent loss of subsidy) to release winter fodder for the calves. Similar considerations also apply, albeit to a lesser extent, to calves from other than spring-calving hill cows.

The success or otherwise of a system of retaining calves beyond the traditional age of sale will depend to a large extent on costs of winter feeding and on the level of performance of the calves during a second grazing season. There is evidence of an inverse relationship between rates of live-weight gain during winter and the following summer, i.e. calves wintered relatively inexpensively and with low rates of gain, subsequently perform better at grass. This generalisation must, however, be subject to qualification as to minimum rates of winter gain and constrained by factors such as weight at the beginning of the winter period.

The need to continue studies on calves beyond the weaning stage has been recognised in the beef cattle research programme from the outset but it is only recently that facilities to pursue such work have become available. Following the move of the experimental suckler cow herds to Hartwood, the cattle house at Glensaugh has been partially converted to accommodate individually-fed weaned calves. Investigations have been initiated to examine relationships between rates of live-weight gain during winter housing and during summer grazing and how these are affected by factors such as sex, genotype, age and live weight at housing. The work is being conducted with Charolais-cross calves of known history from the Blue Grey and Hereford × Friesian cows from both the nutrition and grazing herds.

Cows and Calves

The results of the studies of the effects of nutrition on production from suckler cows indicate that low levels of feeding, even for prolonged periods, are not incompatible with high levels of production, provided that the cow has adequate body reserves prior to the imposition of the undernourishment and that sufficient quantities of high quality feed are made available at some later stage. Very low levels of energy input during late pregnancy are unlikely to have any adverse effects on subsequent production if cows are in good body condition at the beginning of late pregnancy. If this latter proviso is met, the cow will still have adequate reserves remaining at parturition to withstand a further period of undernourishment while maintaining a relatively high level of milk production in early lactation. Although this will depress calf growth rate to a small extent for the first 6 to 8 weeks, this initial disadvantage will be more than discounted if cows and calves are turned out to an adequate supply of high quality pasture. Not only will this result in higher levels of milk production and, hence, higher calf growth rates than if the cows had been fed according to their level of production in early lactation but it will also allow the cows to recover fully the live weight and body condition lost during the late pregnancy and early lactation periods.

It is thus apparent that there is considerable scope for manipulating the nutrition of suckler cows and of achieving economies in the use of expensive conserved fodder and concentrates. In general, these economies are likely to be greatest in situations where the highest standards of management are applied to grassland and its utilisation by the grazing animal throughout the growing season. There is less certainty of the scope for drawing heavily on the body reserves of spring-calving cows due to be turned out to graze on relatively poor quality hill vegetation and there is therefore a need for more work on cows grazing swards which exert a substantial limit to nutrient intake. Comparative studies with non-productive ewes and cows in other grazing projects have already demonstrated the limits to herbage intake to be expected from a range of indigenous hill plant communities. Work is also needed on autumn-calving cows subjected to longer periods of undernourishment than has normally been the case with the spring calvers.

As already indicated, the feeding during the last 3 months of pregnancy of suckler cows in good body condition at the beginning of this period should pose few problems. With cows in poorer condition, however, the strategies to be adopted in terms of food inputs and the pattern of distribution of these inputs are less clear. Plans for work with pregnant cows in a variety of body conditions have been advanced and this work will be undertaken using the techniques of estimation of *in vivo* body composition, including condition scoring, to evaluate initial and changing levels of body reserves. A preliminary study to examine and quantify changes in nutritional state with advancing pregnancy is currently in progress.

Much is now known about the impact of variations in body condition and nutrient intake upon cow and calf performance at different stages of pregnancy and lactation. However, further quantitative information is required on the extent to which nutrition and body reserves can be manipulated through the annual production cycle without adverse effects on calf performance and it is also required on the implications of interactions between the rate and duration of the depletion and repletion of body reserves. Information of this kind is best examined within the context of definable systems of calf production which provide a basis for the rigorous testing of the conclusions drawn from research on components of the complete production cycle. Work of this kind, similar to existing work on systems of lamb production, is likely to form the next major development in the cattle research programme.

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Grazing Research and Grazing Management

J. Hodgson and T. J. Maxwell

INTRODUCTION

Grazing management has been the subject of investigation and a topic for argument for many years. This is due, in large measure, to the nature of the grazing process, in which cyclic interactions occur between the animal and its food supply in a way which is not possible with other systems of animal production. In this review, it is our purpose to discuss the principles which determine the sward and animal responses to variations in grazing management and to illustrate the ways in which the principles can be introduced into grazing systems. Management in this sense is defined as the manipulation of existing plant and animal populations in order to make the most effective use of a given set of farm resources (land, buildings, labour) and variable costs (of which the most important is fertiliser). Examples will be drawn largely from grazing experiments and from studies on systems of sheep production at HFRO.

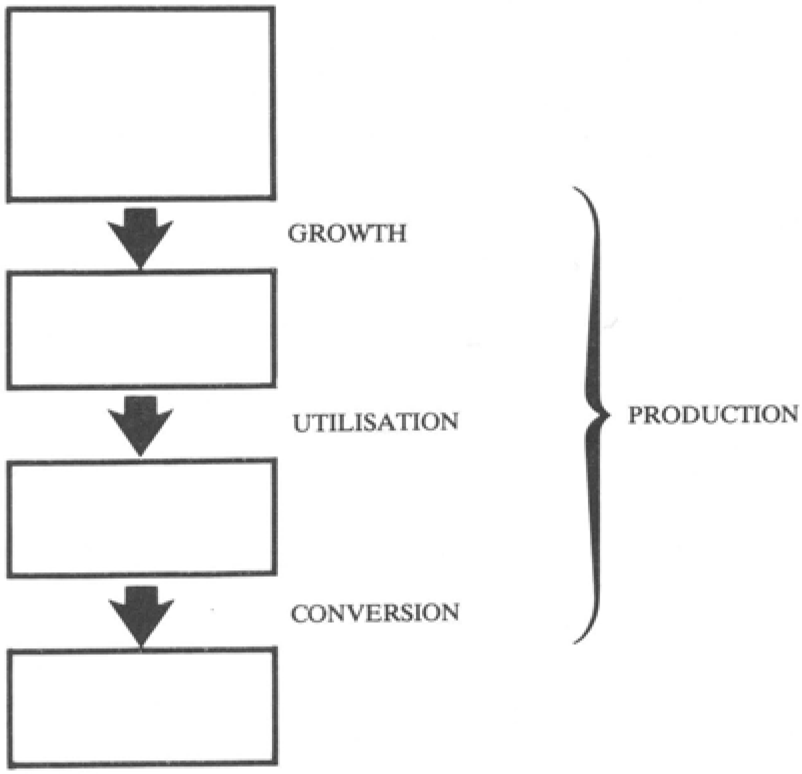
THE GRAZING SYSTEM

Any grazing system can be illustrated simply as a flow of material into the sward, from sward to animal, and ultimately into animal product (Figure 22). The output of animal product is determined by the collective efficiency of the various steps in the chain shown in Figure 22. This is not a simple additive effect because manipulations designed to improve efficiency at any one step may tend to depress it at others. Consequently, management decisions involve the choice of solutions which optimise the balance between the efficiencies in the three main stages of production.

If we are to understand properly the way in which grazing systems work, it is important to think not only in terms of the flow of quantities

Fig. 22

The sequence of herbage growth, consumption and conversion to animal product in a grazing system



of amorphous "tissue" within a system but also in terms of the populations of plants and animals and the ways in which they interact. In this sense, the effective unit of plant growth and defoliation is probably the tiller (in the case of grasses) and the stolon (the equivalent unit in stoloniferous legumes like white clover). Each of these units develops its own leaf and root system and a substantial measure of dependent existence but may be supported or adversely affected by its neighbours in specific circumstances.

HERBAGE PRODUCTION AND UTILISATION

The grasses and forage legumes evolved in parallel with grazing animals and are well adapted to withstand the adverse affects of grazing. Their growing points are hidden at the base of the sward close to ground level where they are protected from decapitation. Each grass tiller produces a continuous series of leaves during its lifetime, new leaves appearing at intervals of 7 to 60 days depending upon the time of year, and has the capacity to produce large numbers of daughter tillers. Most tillers are likely to have a life span of less than 12 months and the maintenance of an effective plant cover is a consequence of the steady replacement of tillers in the population. The pattern of leaf production and the steady turnover of growth sites are similar in white clover.

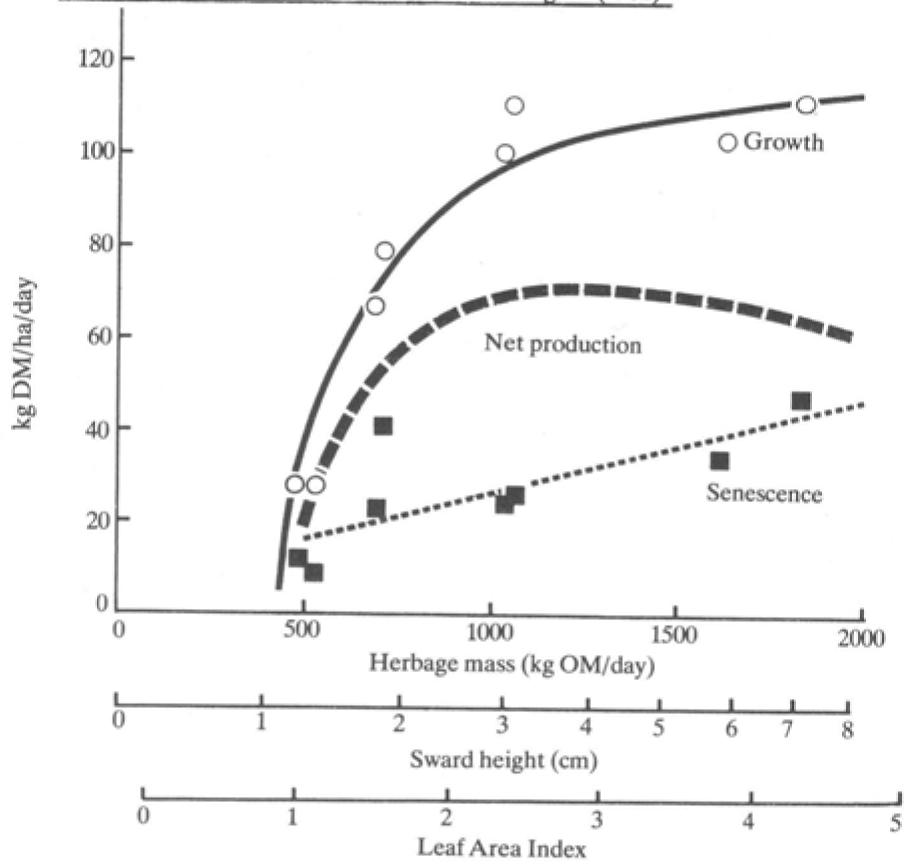
Death and replacement of tillers can occur at any time of the year and can be strongly influenced by management. The major interruption to vegetative growth, however, occurs when substantial numbers of tillers pass to a reproductive phase of growth in the spring. The elongation of the main stem and the development of a flowering head lead to an acceleration in the rate of dry matter accumulation in the aerial part of a tiller but they also mean the end of leaf production from the tiller. Further growth can then only be sustained by the development of new tiller buds at the base of the old tiller or, in some cases, by germination of shed seed.

Because growth occurs principally from the base of the sward, new leaves and tillers must grow upwards through the sward canopy in order to reach the light, eventually over-topping older leaves and sheaths. This results in a typical distribution of plant material within a well utilised vegetative canopy. In this, most of the young leaf is borne in the surface layers of the sward, with a progressive increase in the proportion of stem and senescent material in the lower layers and a progressive increase in the total bulk density of plant tissue from the top to the bottom of the sward canopy (Figure 23). In reproductive swards, or badly utilised vegetative swards, there is a much more heterogeneous admixture of leaf and stem, or of immature and mature leaf, in all layers of the sward. In these cases, too, the sward canopy will tend to be taller and to have a lower bulk density.

The characteristic patterns of leaf and tiller development mean that the processes of tissue growth and loss are continuous whenever

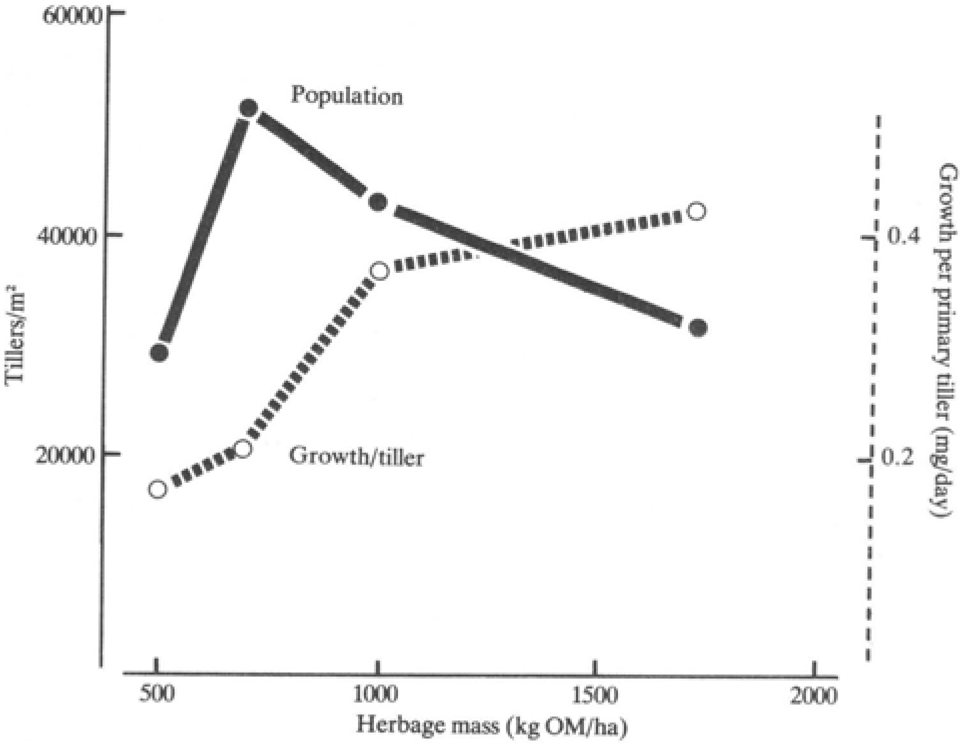
Fig. 24

The influence of variations in herbage mass (kg OM/ha) on rates of herbage growth, senescence and net production (kg DM/ha/day) in continuously stocked swards grazed by sheep. The associations between herbage mass, sward surface height (cm) and leaf area index on these swards are also shown. From Bircham and Hodgson (1982)



The practical significance of this evidence is that herbage consumption per unit area is likely to be maximised when the sward is maintained at levels of LAI and herbage mass substantially lower than those which would be expected to maximise herbage growth rates. The implication is that managements designed to keep the sward closely grazed and to encourage vigorous tillering activity are likely to encourage greater sward flexibility and greater levels of net herbage production than are managements designed to maintain high levels of LAI. The fact that variations in net herbage production are relatively small over a wide range of sward conditions about the optimum value defined in Figure 24, means that it should be possible to concentrate attention on the provision of conditions which encourage high

Fig. 25
The influence of herbage mass maintained under continuous stocking management upon tiller population density and growth per tiller in a mixed grass/clover sward grazed by sheep (from Bircham, 1981)



efficiency of conversion of ingested herbage into animal product (the final phase of Figure 22), without having to worry too much about possible adverse effects upon the efficiency of herbage production and utilisation (phases 1 and 2 in Figure 22).

HERBAGE CONSUMPTION AND ANIMAL PRODUCTION

The output of animal product from a grazing system is the product of output per animal and the number of animals kept per ha (the stocking rate). Performance per animal may be limited by the genetic potential of the animals concerned, by the relative proportions of productive and non-productive animals and, in some cases, by worm parasite infestation. It is also very much a function of nutrient intake per animal, which can be markedly influenced by the characteristics of the sward upon which the animals are grazing.

Herbage intake has been shown to be linearly related to the digestibility of the herbage eaten under both grazing and indoor feeding conditions (Figure 26) and the indications are that intake will continue to increase at a constant rate up to the highest levels of herbage digestibility which can be achieved in practice. The digestibility of the herbage eaten by grazing animals is a direct reflection of its morphological composition. The digestibility of new and expanding leaf lamina is likely to be of the order of 0.80-0.90 at all times of the year, falling steadily to 0.70 in senescent leaves, while changes in the digestibility of leaf sheaths are similar. The flowering stem also has an initially high digestibility but this falls rapidly to about 0.50 at maturity, as a consequence of the rapid development and lignification of structural tissue. Variations in the digestibility of herbage down the sward canopy (Figure 27) and throughout the year reflect changes in the relative proportions of these morphological components. Although animals usually select herbage with a higher digestibility than that of the whole sward, the digestibility of the diet and, hence, the potential level of intake, will clearly be influenced by the maturity of the sward and the distribution of components of different digestibility within it.

Fig. 26

The relationship between the digestibility of ingested herbage and herbage intake in grazing cattle for (1) primary growth and (2) regrowth (from Hodgson, Rodriguez Capriles and Fenlon, 1977)

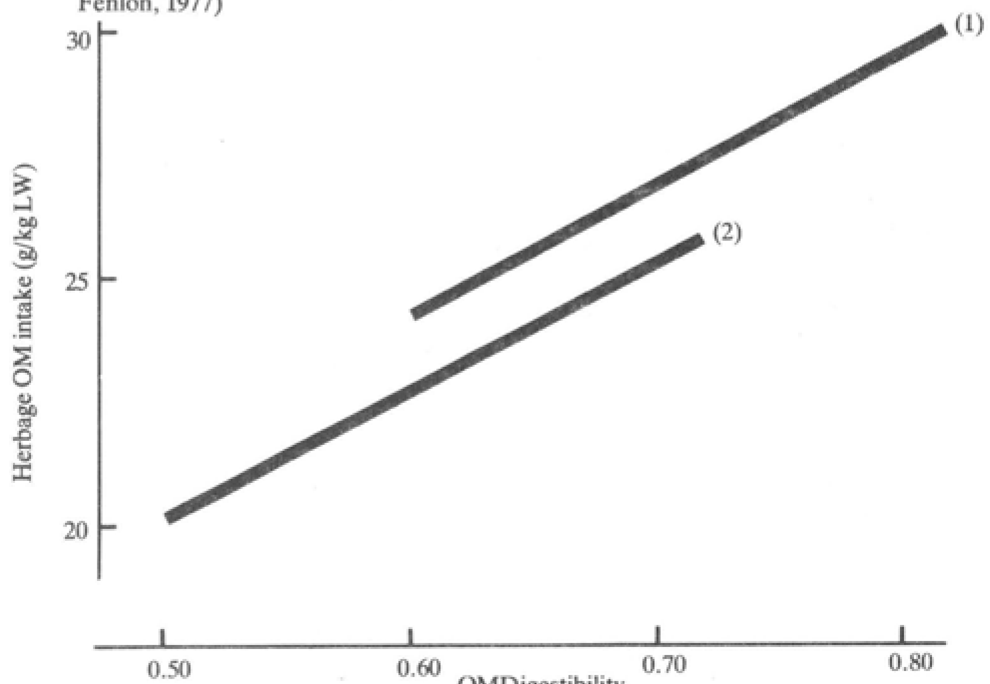
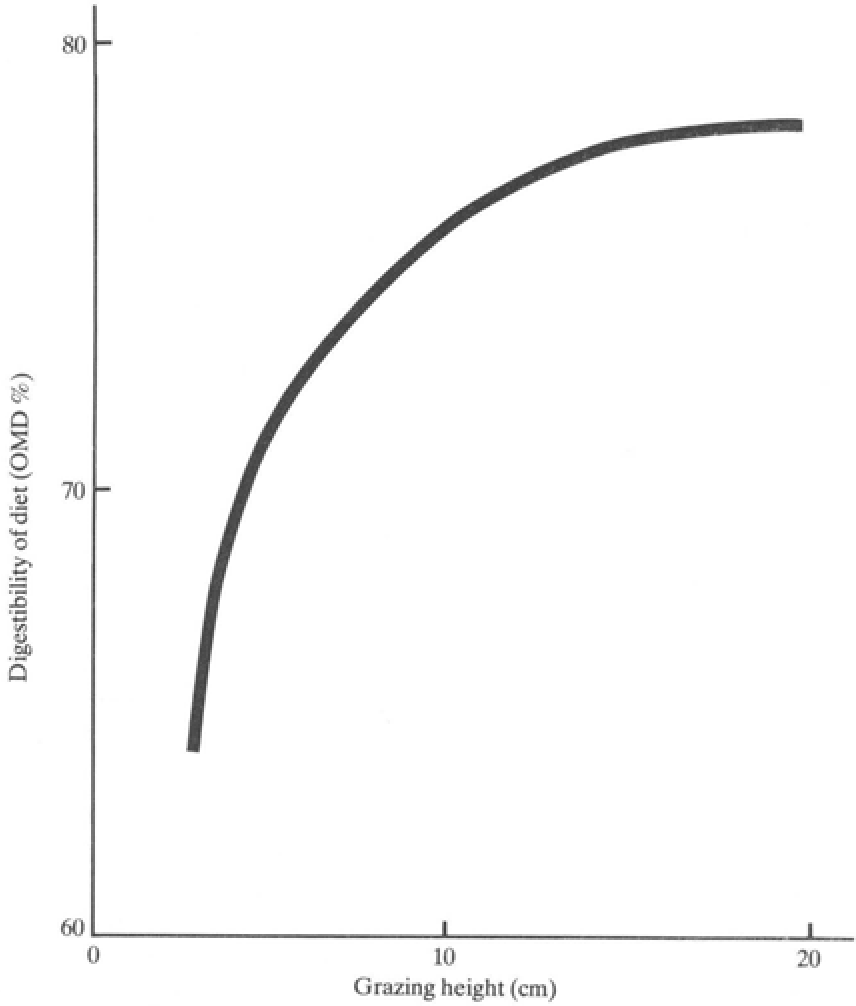


Fig. 27

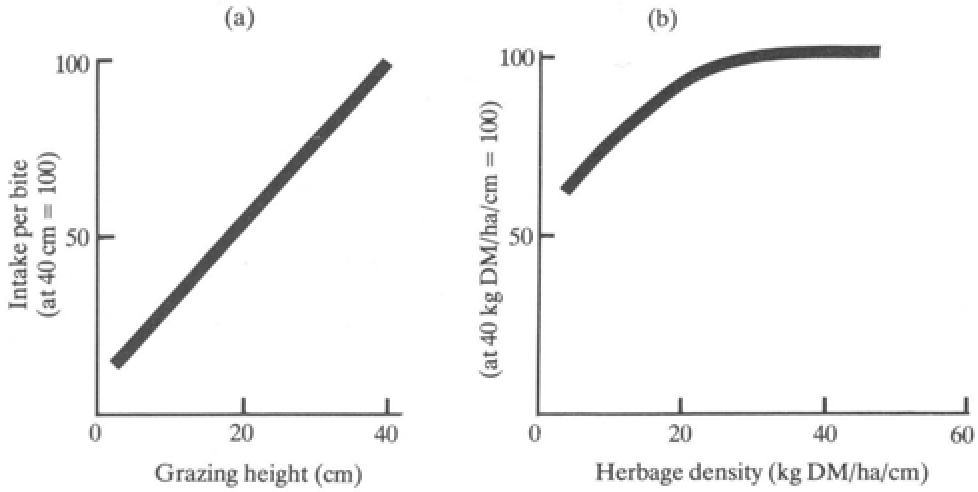
The variation in the digestibility of herbage in the horizons of a sward canopy (from Hodgson, 1981)



Intake may also be affected directly by the physical characteristics of the sward canopy. This is because the characteristics of the sward and the structure of the animal's mouth dictate that the quantity of herbage consumed per bite by grazing animals is small relative to the total daily requirement, so that animals may spend up to 12 hours grazing per day and in that time may take more than 30000 grazing bites. Intake per bite decreases, other things being equal, with declining sward height (Figure 28). This is because grazing animals will usually penetrate only with reluctance into the lower horizon of the sward which contains stem or sheath material and, generally, the depth of the leafy horizons is greater in taller swards (Barthram, 1981). Animals will also tend, generally, to select leaf from stem in all horizons of reproductive sward. Intake per bite also tends to decline as the density of leaf material in the grazed horizons of the sward falls (Figure 28).

Fig. 28

The influence of variations in (a) sward surface height and (b) herbage bulk density in the surface horizon upon intake per bite in grazing cattle (from Hodgson, 1982)

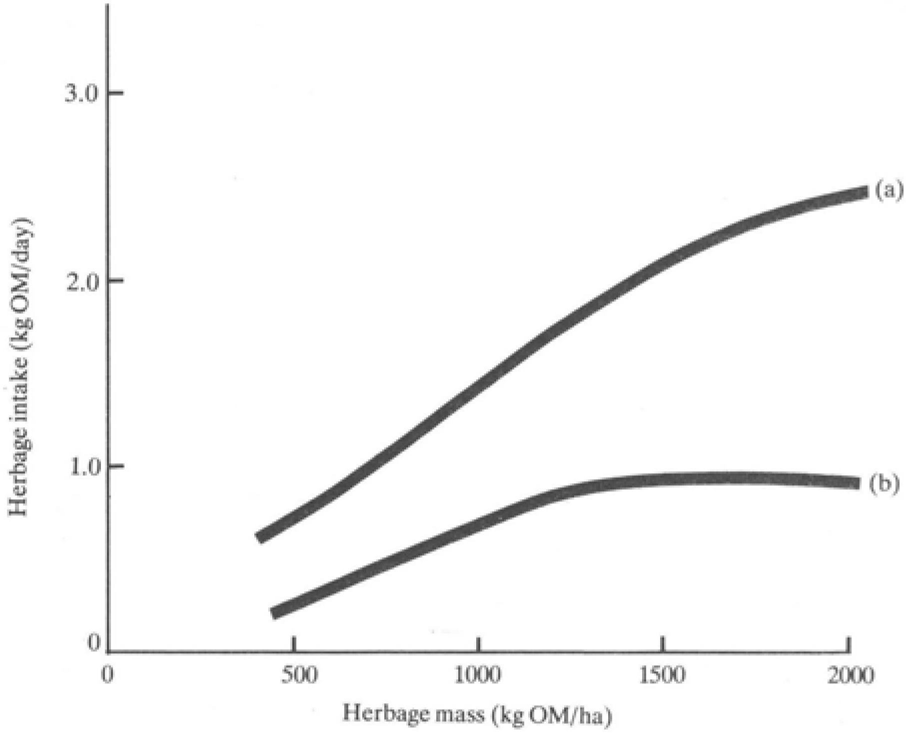


Whenever intake per bite is limited, daily intake can only be maintained if the animal bites faster during grazing, or spends more time grazing, in an attempt to compensate. These responses are frequently observed but they are seldom of a magnitude to compensate fully for a reduction in intake per bite and, in some circumstances, they do not occur at all. Intake per bite falls when animals start to graze selectively and, although the nutrient content of the herbage eaten is likely to be enhanced, it is not always certain that this will offset the disadvantage of a reduction in intake per bite, particularly as the rate of biting may fall at the same time.

Under closely defined conditions of sward and management, it is possible to condense the various sward characteristics into a single index like sward height or herbage mass. Figure 29 illustrates the relationship between herbage mass and the daily herbage intake of ewes and lambs under continuous stocking management on mixed grass/clover swards.

Fig. 29

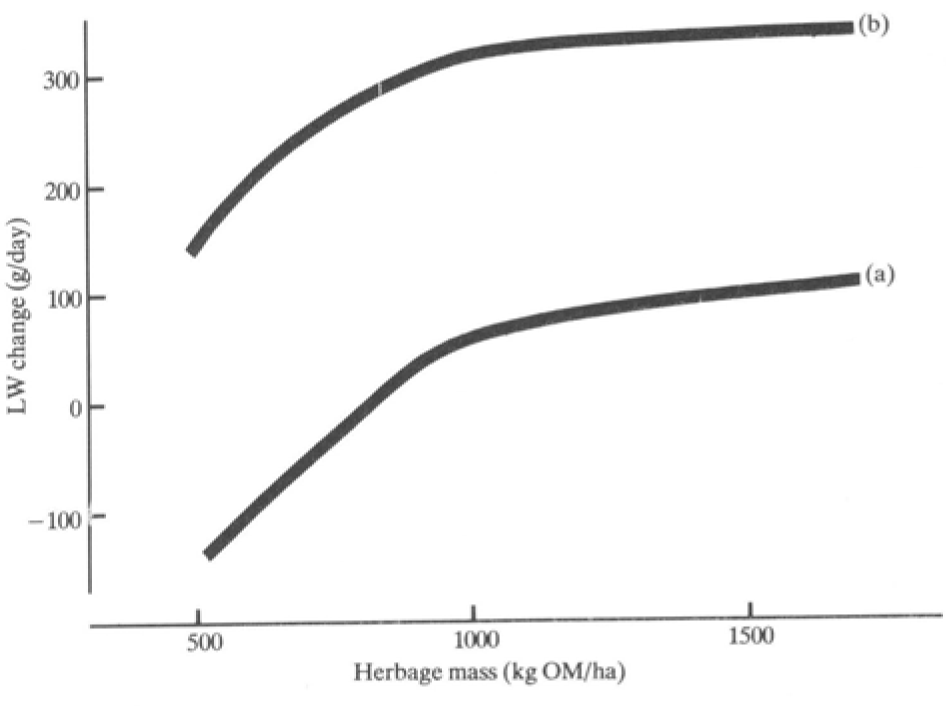
The influence of herbage mass maintained under continuous grazing management upon the herbage intake of (a) ewes and (b) lambs on a mixed grass/clover sward (from Bircham, 1981)



There is frequently a conflict between interest in achieving high intake per unit area and high intake per animal. High performance per individual and high efficiency of conversion of ingested herbage are directly related to high herbage intake per individual but this can often only be achieved at the expense of a relatively low stocking rate and consequently of low total intake per unit area. The sensitivity of these relationships depends, in part, upon the livestock enterprise in question. Where young animals are grazing on their own, their growth rate is likely to be very sensitive to sward conditions influencing herbage intake. If they are grazing with their dams, however, in circumstances where the dams can help to buffer sward limitations by providing milk at the expense of their body reserves, then the sensitivity of the young to varying sward conditions may be substantially reduced. Taking lactating ewes with single lambs as an example, the associations between herbage mass maintained under continuous stocking management, the daily weight change of ewes and the daily weight gains of their lambs are shown in Figure 30. When stocking rate differences were taken into account in the experiment of Bircham (1981), the production of weaned lamb per ha was maximised at a level of herbage mass (Figure 31) similar to that at which net herbage production was maximised (Figure 24).

Fig. 30

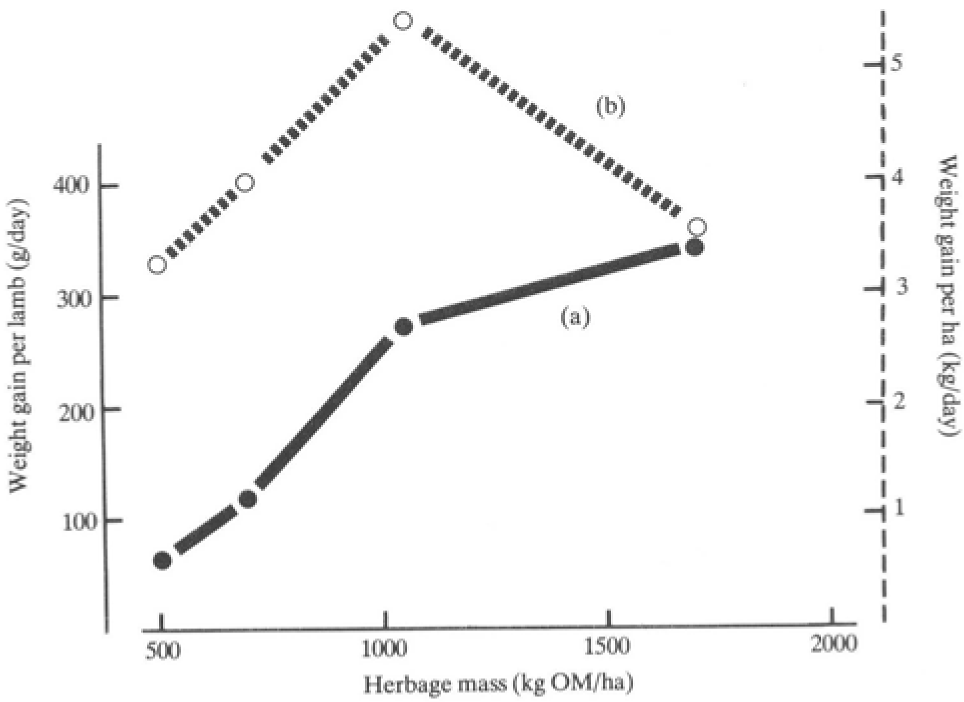
The influence of herbage mass maintained under continuous grazing management on (a) the weight change of Greyface ewes and (b) the growth rates of their lambs (from Bircham, 1981; Milne, Maxwell and Souter, 1981; Milne, Maxwell, Agnew and Sibbald, 1982)



This is one example in which there appears to be little need for compromise between the sward conditions necessary to ensure high herbage production and those required to ensure high efficiency of herbage utilisation and conversion into animal product. There may be

Fig. 31

The influence of herbage mass maintained under continuous stocking management in (a) LWG of individual lambs and (b) lamb production per ha per day from Greyface ewes and lambs grazing mixed grass/clover swards (from Bircham, 1981)



greater disparity in other cases, however. For example, although cattle and sheep (and young and mature animals) appear to show very similar patterns of intake in response to variations in sward characteristics like herbage mass, sward height or herbage digestibility, it is probable that the levels of herbage mass shown to be quite satisfactory for sustaining acceptable lamb growth rates would not sustain adequate growth rates in growing beef cattle (Table 24).

Table 24

The influence of herbage mass on the herbage intake of grazing cattle and sheep (J. C. Arosteguy, unpublished data)

	Herbage mass (kg OM/ha)		S.E.
	1000	1500	mean
Herbage intake (kg OM/day)			
Cattle	2.8	4.5	0.11
Sheep	1.3	1.6	0.12

Interaction F ratio 37.75***

GRAZING MANAGEMENT AND ANIMAL PRODUCTION

From the foregoing analysis, it is clear that grassland management is a matter of achieving a balance between animal production objectives, maintaining the productivity of the sward and utilising herbage before it enters the stages of death and decay. In practice, the management of grass in grazing systems has to be done on a relatively simple but objective basis. In this context, it is important to relate sward and animal performance to specified sward conditions rather than to arbitrarily chosen grazing intervals or stocking rates, since the latter provide no rational basis on which to determine management responses to changing conditions. For present purposes, evidence would suggest that progress towards developing a more objective method of grazing management for farmers could be achieved by using herbage mass as the criterion on which to base decisions.

The responses in herbage production and animal production to variations in sward conditions, which were outlined earlier, indicate the scope for manipulation. However, they need to be set against the background of the seasonal pattern of variation in herbage production and in the nutrient requirements of animal populations, which dictate that management decisions must often involve a compromise between the current demands of sward and animals and the maintenance of long-term stability. The discussion of management systems which follows is based on the results of recent studies carried out at HFRO to define the seasonal variations in herbage mass appropriate to efficient systems of upland sheep production. These studies have been carried out largely in the context of continuous grazing management. There is little evidence to suggest that any production advantage will be gained from more complex management procedures and continuous stocking makes it particularly easy to relate management decisions to estimates of herbage mass. However, there is no reason why the principles should not apply to alternative methods of grazing management.

In early lactation, the potential herbage intake of the lactating ewe is about 50% greater than that of the non-lactating ewe and therefore the demand for herbage is high in this period of lactation. In early spring, before substantial growth of grass has taken place, herbage supply will invariably limit herbage intake and the production of milk must then be maintained either from a supplementary feed source or by the utilisation of body reserves. Even when a concentrate supplement is used, the influence of herbage mass on lamb growth is still evident and a herbage mass in excess of 750 kg DM/ha is essential for ewes in early lactation if growth rates in excess of 300 g/day are to be obtained with twin lambs (Table 25).

Table 25

The influence of herbage mass and supplementary feeding of lactating ewes on the growth of their lambs (Milne, Maxwell and Souter, 1981)

	Lamb LWG (g/day) 0-6 weeks			S.E. of
Herbage mass (kg OM/ha)	500	750	1500	mean
Concentrate supplement (g OM/ewe/day)				
0	250	313	332	9.2
480	266	288	—	
960	256	322	—	

To achieve a herbage mass of this order early in the season, it is important to apply nitrogenous fertiliser as soon as plant growth starts to accelerate. A useful indicator is provided by soil temperature at 100 mm depth. Fertiliser application should start as soon as this reaches 5.5°C and responses can be expected from rates of fertiliser application up to 80-90 kg N/ha. Stocking of the grazed area should then be delayed until there is a clear indication that the swards are growing adequately. The accumulated degrees by which the 100 mm soil temperature exceeds 5.5°C can be used as an objective index; accumulated degrees in excess of 20 being necessary before substantial herbage growth can be assumed.

In practice, due to the lack of flexibility that occurs on some farms at this time of year, it may not be possible to avoid stocking areas before these conditions are met. However, if herbage mass is reduced to 500 kg DM/ha the growth of the sward will be seriously impaired (Figure 24). This will delay the time at which areas can be closed for conservation, extend the period over which supplementary feeding has to be given and may reduce the stocking rate for a substantial part of the grazing season.

Grazing ewes are extremely sensitive to variations in sward conditions, particularly in early lactation. In one recent study, for example, in which herbage mass increased steadily to 2000 kg DM/ha under continuous stocking and was then grazed back to 1500 kg DM/ha, there was a substantial reduction in the digestibility of the herbage ingested by the ewes and a consequent reduction in herbage intake and the growth rate of their lambs from 370 to 200 g/day. Both herbage digestibility and lamb growth rate increased again as grazing pressure was adjusted to hold herbage mass at about 1500 kg DM/ha (Milne, Maxwell and Souter, 1981).

During mid-lactation, pastures will be at a stage when seed head emergence is taking place. To prevent the emergence of the reproductive stem and the consequent decline in the digestibility of the ingested herbage requires that the grass plant be defoliated with a frequency and intensity which effectively removes the stem and inflorescence at an early stage in their development. In practice, this generally means that swards have to be maintained at below 1800 kg DM/ha. Provided that herbage mass remains below this level, ingested organic matter digestibility can be maintained at a level above 0.80 well into the summer (Maxwell *et al.,* 1979; Milne *et al.,* 1981).

During the peak phase of spring growth, these conditions can only be maintained by closing up a proportion of the grazed area for conservation. The extent of the area closed for conservation will be influenced by the amount of winter forage required and the need to sustain lamb growth during the period of conservation on the remaining grazed area. The amount of conserved forage required for winter feed by the upland ewe is usually in the region of 80-100 kg. A hay crop will yield about 6 t/ha in an upland environment with modest amounts of nitrogen. The area of pasture required to provide this feed can be calculated and estimates of animal performance, on the basis of the herbage mass remaining on the grazed areas, can be made from the above relationships (Table 26). This provides an objective basis for striking a balance between animal performance on the one hand and the provision of winter forage on the other.

Table 26

The interrelationships between stocking rate, requirements for winter feed, herbage mass maintained on grazed areas and the performance of ewes and lambs before weaning (T. J. Maxwell, unpublished data)

To provide 100 g hay per ewe for winter when producing 6 t hay per ha:

for annual stocking rate (SR) (ewes/ha)	requires a SR during conservation (ewes/ha)	giving a lamb growth at herbage mass of (kg DM/ha) 600	1000	and a ewe live-weight change at herbage mass of (kg DM/ha) 600	1000
		g/day		kg (6 wks)	
10	12	246	344	−2.3	+5.8
15	20	186	246	−7.1	−2.2

Ultimately, this decision is an economic one, related to the seasonal price changes of weaned or finished lambs and the cost of bought-in winter feed. To make this assessment, it is necessary to be able to predict lamb growth and ewe live-weight recovery during the summer and autumn. Information about the latter is required since the economic calculation is not only concerned with lamb growth and date of finish but also with the number of finished lambs. The number of lambs finished will be a function of the number born which is strongly related to the live weight of the ewe at mating, this in turn being influenced by the rate of live-weight recovery in the summer.

Once the main phase of reproductive growth is past, more fluctuation can be allowed in sward conditions, although the evidence shown in Figure 24 suggests that this will be at the cost of some loss in net herbage production. Closing up a grazed sward for conservation will itself result in a loss of viable tillers but we have no clear idea of the extent to which this will affect current and subsequent herbage production. In the later phases of lactation, ewe live-weight change and lamb growth rates appear to be more strongly influenced by variations in herbage digestibility than in herbage mass. However, the evidence suggests that, if ewes are to achieve a satisfactory live weight by the time of weaning, it will be necessary to maintain herbage mass in excess of 1600 kg DM/ha. More information is needed on this important phase of the annual cycle of production.

The period prior to and during mating is one in which the growth of grass is declining rapidly and growth has often ceased before mating is complete. This means that herbage must be accumulated to provide adequate feed over the mating period but amounts of herbage in excess of 2500 kg DM/ha will almost certainly incur a nutritional penalty as animals progressively graze down through a sward and encounter dead and decaying herbage (see Figure 27). To limit this effect, it will be necessary to increase grazing pressure in the late summer, particularly after weaning, in order to graze swards clean before herbage is allowed to accumulate. This will in itself provide an option for taking a second cut for conservation. The herbage intake of ewes during the mating period will be affected by their body reserves as well as by herbage mass and digestibility (Gunn, 1982) and the effects of saving pasture for use during mating on the herbage intake and reproductive performance of ewes are currently under investigation.

CONCLUSIONS

These examples illustrate ways in which information on the influence of specified sward conditions upon herbage production and utilisation on the one hand and herbage consumption and animal performance on the other can be incorporated into practical systems of livestock production and used to guide management decisions. It is not yet possible to make comprehensive recommendations about the levels of herbage mass appropriate to all phases of the seasonal cycles of herbage and animal production but the principles governing management decisions can be clearly demonstrated.

The foundation of this view of grazing management is a keen awareness of the herbage mass on a sward and the rate at which it is changing and, in order to make progress, this needs to be put on a quantitative basis. The direct measurement of herbage mass is not at present feasible on most farms but measurements of sward height may provide a satisfactory alternative within the confines of uniform swards and management procedures and, with experience, visual assessments of herbage mass should be adequate for most practical purposes. Whatever the assessment procedures adopted, quantitative information on herbage mass and the associated sward characteristics from farms and research centres will greatly improve the effectiveness of communication between farmers, advisers and scientists on most aspects of grassland management. It will also provide a firm basis on which to assess objectively on the farm the balance to strike between stocking rate, herbage production and fertiliser nitrogen inputs. Greater precision in decision making should provide the basis for greater predictability and improved performance in both biological and financial terms.

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LECTURES BY STAFF

Dr Robin H. Armstrong:

Sheep management on the hill.
UKF Conference on Hill Land Improvement, Perthshire, 1979.

Mr J. Eadie:

Animal production from the hills and uplands.
British Association for the Advancement of Science, Edinburgh, September 1979.

Animal production in the hills and uplands of Great Britain.
Presented to the Instituto Nacional de Investigaciones Agrarias, La Coruna, Spain, October 1979.

The future of livestock farming on the hills and uplands in the eighties.
Kelso and District Agricultural Discussion Society, November 1980.

Dr R. G. Gunn:

Factors affecting ewe fertility.
Refresher course on sheep management and health, Royal (Dick) School of Veterinary Studies, Edinburgh, January 1981.

Factors affecting fertility in sheep.
Spring Meeting of the Society for Animal Breeding, February 1981.

Dr A. Haystead:

Interaction between nodule effectivity and efficiency of nitrogen fixation.
Symposium on Energetics of Nitrogen Fixation, Michigan State University, May 1980.

Pasture research at HFRO.
Paper presented at CSIRO Western Australia Laboratories, Perth, January 1981.

^{15}N - methodology in nutrient cycling research.
Paper presented at the CSIRO Western Australia Laboratories, Perth, March 1981.

Mr A. Whitelaw:

Trace element deficiencies.
National Sheep Association, Lauder, December 1980.

Some aspects of liver fluke control.
Sheep Veterinary Society, September 1980.

Deficiency diseases and their control.
Refresher course on sheep management and health, Royal (Dick) School of Veterinary Studies, Edinburgh, January 1981.