The Hill Farming Research Organisation

Biennial Report 1982-83

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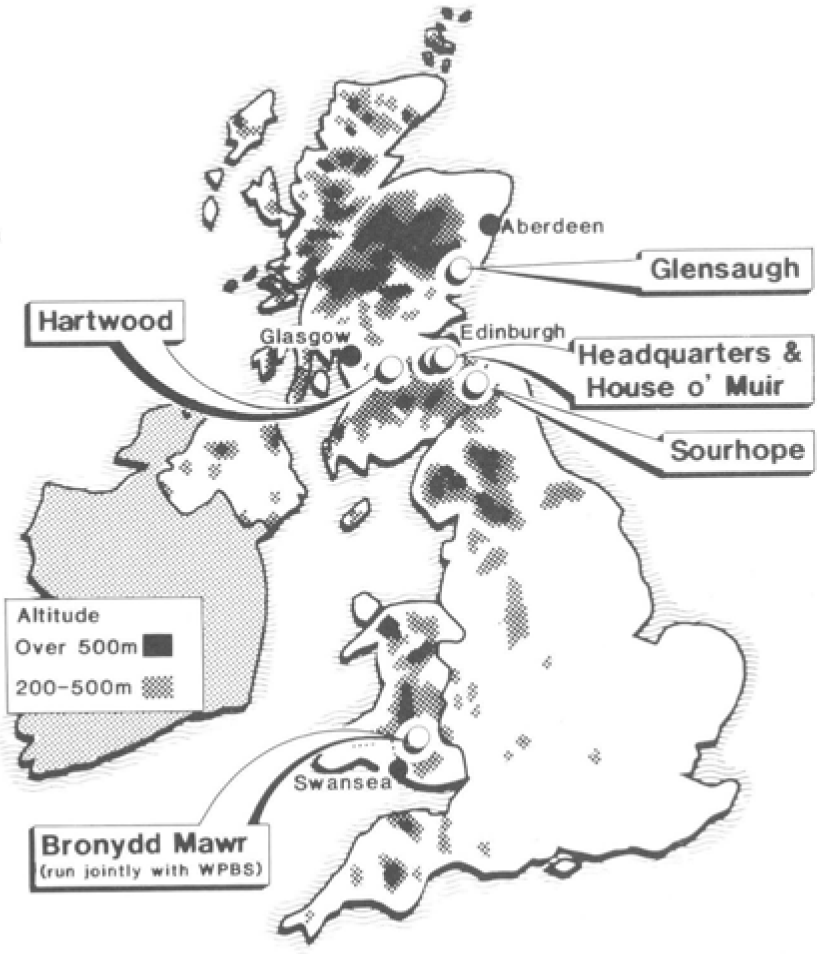
The Hill Farming Research Organisation

The Hill Farming Research Organisation, established in 1954, is an independent state-aided institute funded by the Department of Agriculture and Fisheries for Scotland. It has a Board of Management, which is appointed by the Secretary of State for Scotland, after consultation with the Minister of Agriculture and Fisheries and the Agricultural and Food Research Council. The Organisation's remit is to improve the economic viability of meat production in the hills and uplands of the United Kingdom.

Location of HFRO research stations



The HFRO headquarters are situated in the Bush Estate near Edinburgh. The Organisation has three research farms in Scotland, and a fourth, in Wales, is run jointly with the Welsh Plant Breeding Station. The research farms encompass a wide range of soil and climatic conditions.

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Red Deer Farm C. Thomson

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Sourhope Research Station

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R. W. Evans, BSc
E. A. Hunter, BSc, M. Phil
Miss H. K. Smith, BA, MSc
R. Thompson, BSc, MSc
Mrs J. Wood, BSc

Visiting Workers

G. Alexander, DAgrSc. Ian Clunies Ross Animal Research Laboratory, CSIRO, NSW, Australia. February-June 1982.
W. G. Allden, MA, MAgrSc, PhD, FAIAS. Waite Agricultural Research Institute, University of Adelaide, Australia. April-May 1982.
H. Dove, BSc, PhD, DipEd. Division of Plant Industry, CSIRO, Canberra, Australia. December 1981-November 1982.
D. G. Fowler, MSc, PhD. Glen Innes Agricultural Research Station, New South Wales Department of Agriculture, Australia. January-February 1983.
F. X de Montard, INA, MR. Station d'Agronomie of the Institut National de la Recherche Agronomie, Clermont-Ferrand, France. August 1983-July 1984.
J. D. Morton, MScAg. New Zealand Ministry of Agriculture, Greymouth, New Zealand. April 1983-October 1984.
D. Zygoyiannis, University of Thessalonica, Greece. July-August 1982.

Collaborating Institutions

Edinburgh School of Agriculture, Edinburgh. (B. E. Moseley).
Institute of Zoology, London. (A. S. I. Loudon).
MRC Reproductive Biology Unit, Edinburgh. (A. S. McNeilly).
University of Surrey, Department of Biochemistry, Guildford. (B. A. Morris).

Director's Report

This, the second of the new series of Biennial Reports covers the years 1982 and 1983. As before, the heart of the report comprises short summaries of the work carried out in the period of the report in each of the projects which together make up the research programme. The longer research reports are more extended summaries of work which has advanced to the point at which it justifies more lengthy treatment. Two review articles complete the report.

Research programmes

During the period of this report the main areas of investigation, formerly called packages, were retitled Programme Units. Their number has been increased from five to eight, and the projects within each package have been renumbered to conform to the new AFRS Information System. The new numbering system is used in the present report, except in the case of Programme Unit 1 in which the objectives have been recently changed and an earlier numbering system is used.

The eight programme units cover essentially the same range of subject matter as before but with the addition of a new programme unit on goats. Some preliminary work had indicated that the grazing habits and preferences of the goat contrasted markedly with those of the sheep. An avidity for some weed species of improved pastures, notably rushes, and a marked tendency to avoid clover suggested a possible role for goats in the maintenance of reseeded grassland. The current three year programme, which began in April 1983, also includes studies of the grazing preferences of goats on some indigenous pasture types, work on fibre production with special reference to the cashmere undercoat of the feral goat, and studies of reproduction and growth.

Wales

An initiative of the Hill Farming Research Organisation and the Welsh Plant Breeding Station to join forces in a research programme on Welsh hill and upland farming has led to the establishment of the Bronydd Mawr Research Centre. The farm of Bronydd Mawr, Trecastle, Brecon, was purchased by the Crown Commissioners in September 1983 and is leased to WPBS. The venture will be a joint responsibility of the Directors of the two institutes.

An Advisory Committee, chaired by Mr J. A. Parry, has been appointed. It comprises representatives of the HFRO Board of Management, the Consultative Committee of WPBS and AFRC and ADAS. The HFRO Board representatives are Professor D. G. Armstrong, Mr R. E. Edwards and Mr D. T. M. Lloyd.

Bronydd Mawr extends to some 164 ha and ranges in altitude from 200 m to 400 m. The farm has grazing rights on an adjacent common grazing and range. Much of the enclosed land of the farm has been reclaimed from indigenous vegetation in the last 25 years. A stock of 1000 Brecon Cheviots plus hoggs was taken over when the farm was purchased.

The WPBS will be responsible for research in pasture production. Studies of sheep performance and, in particular, aspects of reproduction in Welsh breeds and crosses will be carried out by HFRO, who will also initiate work on sheep production systems. A feature of the new programme will be joint work on the animal evaluation of herbage cultivars and the incorporation of the results of the work of both institutes in systems studies.

Visitors

The Organisation continues to receive many visitors from home and overseas — farmers, scientists, and advisers — at its farms and headquarters.

In the period of the report the Organisation received a visit from the House of Commons Agricultural Committee during their consideration of the financial policy of the EEC in relation to agriculture with particular reference to the less favoured areas. The Committee visited Glensaugh on 22nd March 1982.

The Organisation was particularly pleased to welcome Lord Selborne, the Chairman of the Agricultural and Food Research Council, to Hartwood and to headquarters on 19th July 1983 during a two-day visit to Scottish agricultural research institutes.

It was also a pleasure to receive the Hill Farming Advisory Committee for Scotland at Glensaugh on 25th April 1983. This followed a tour of Glen Esk by the Committee and a discussion of the problems of integrating grouse and sheep in the management of heather moorland.

Among the distinguished overseas visitors was a group of senior scientists from INRA, the French national agricultural research organisation. The

INRA party was led by the Director General, Monsieur Poly, and accompanied by the Chief Scientist (Agriculture and Horticulture) MAFF, and senior DAFS and AFRC staff. They visited Hartwood on 23rd June 1983 where they were met by the Chairman of the HFRO Board of Management, Mr J. A. Parry, and given an outline of the Organisation's work by the Director and senior staff.

Six members of the Italian National Committee for Agricultural Sciences (CNR) visited Britain under the auspices of the British Council, to study the organisation and funding of British agricultural research. As part of a two-day study tour in Scotland they visited the Organisation's headquarters on 4th July 1983.

The Joint Consultative Organisation Board, led by Mr Oscar Colborn, paid a visit to the Organisation on 18th February 1983 as part of their investigation into the operation of the arrangements for organising and financing agricultural research in Scotland.

Events

'Beef from Grass', a two-day event held at Bush on 29th and 30th June 1983, was jointly organised by the Edinburgh School of Agriculture and the Hill Farming Research Organisation.

An open day on upland sheep production was held at Hartwood on 10th August 1983. The event was held under the auspices of the 'Money from Grass 83' campaign.

Exhibits were prepared for a number of shows including the Royal Highland, and the Royal Show. At the latter a joint exhibit with the Grassland Research Institute was mounted on the theme 'The physiology, growth and utilisation of the grazed sward'. The Organisation was also represented at the National Sheep Association's 'Scotsheep' event.

The Director acted as Joint Director of Studies with Dr W. B. Martin, Director of the Animal Diseases Research Association, to a British Council Course on 'Sheep management and diseases' held in Edinburgh in May 1983. The course attracted scientists and advisers from nineteen overseas countries. AFRC scientists, including senior staff from HFRO, contributed many of the lectures, and the Organisation provided demonstrations and visits to its research stations.

The Organisation hosted, on behalf of the Great Britain East Europe Centre, a four day visit to Scotland by a group of senior agricultural scientists from Czechoslovakia in June 1983. The visitors were interested in beef cattle and sheep production research, and staff from the Edinburgh School of Agriculture participated in the discussions.

Board of Management

Appointments

Mr J. A. Parry, the Chairman of the Board of Management, was appointed to the Agricultural and Food Research Council in January 1983. He became Chairman of the AFRC's Animals Research Committee in June 1983.

Professor C. H. Gimingham was appointed Regius Professor of Botany at the University of Aberdeen in January 1982.

Mr C. H. Armstrong and Mr R. E. Edwards were appointed to the Hill Farming Advisory Committee for England, and Mr D. T. M. Lloyd to the equivalent for Wales, in June 1983.

Professor J. H. Prescott was appointed Director of the Grassland Research Institute on 1st January 1984.

Awards

Dr J. M. Doney was awarded a Commemorative Medal by the Agricultural University of Prague, Czechoslovakia, in recognition of his contribution to the University. Dr Doney has had an association with the sheep research work of the University for a number of years. The Commemorative Medal was presented at a conference held to celebrate the 30th Anniversary of the founding of the University.

Dr J. Hodgson, Head of the Grazing Ecology Department, was awarded an NRAC Senior Fellowship by the Department of Scientific and Industrial Research of New Zealand for one year from March 1983. Dr Hodgson worked in the Grasslands Division of the New Zealand Department of Scientific and Industrial Research during his tenure of the Senior Fellowship.

Dr Anne Rangeley was awarded a Fellowship by the Organisation for Economic Cooperation and Development for 24 weeks from October 1982 to March 1983 to work with Professor Knowles, McGill University, Canada, studying methods for measuring nitrogen fixation and denitrification in terrestrial systems.

Postgraduate degrees

The following candidates were awarded the Degree of Doctor of Philosophy; Mr J. C. Arosteguy at the University of Edinburgh and Mr S. Wilson at the University of Nottingham.

Staff visits abroad and committee service

Visits abroad

Mr J. Eadie

Consultancy visit to Italian agricultural research centres at the request of CNR, Italy, funded by the British Council to see aspects of sheep and goat research, October, 1981; Invited participant of the International Hill Lands Symposium 'Foothills for Food and Forests', Oregon State University, USA, April, 1983.

Dr J. M. Doney

Invited participant of the conference to commemorate the 30th Anniversary of the Founding of the Faculty of Agronomy, School of Agriculture, Prague, August-September, 1982.

Miss S. A. Grant

Invited participant of a mini-symposium on heathland management in the Dutch nature reserves, organised by Rijksinstiuut-voor Naturbeheer, August, 1983.

Mr W. J. Hamilton

Invited participant at the Symposium on Biology and Management of Cervidae, Front Royal, Virginia, August, 1982.

Mr C. S. Lamb

Visit to the Department of Nutrition and Metabolism at the University of Melbourne, CSIRO in Canberra and the Biochemistry Department at the University of New England, while on a trip to Australia in September, 1983.

Mrs C. A. Marriott

EEC Workshop on 'The Measurement of Symbiotic Nitrogen Fixation in the Field', Risø, Denmark, November, 1982; 5th International Symposium on Nitrogen Fixation, Noordwijkerhout, The Netherlands, August-September 1983; Participant in First FAO/IAEA/IG Research Coordination Meeting on the Use of Nuclear Techniques in Improving Pasture Management, Vienna, Austria, November, 1983.

Dr R. W. Mayes and Dr J. A. Milne

IV International Symposium on Protein Metabolism and Nutrition, Clermont-Ferrand, France, September, 1983.

Dr P. Newbould

Invited participant in EEC Workshop on Grassland Production, Braunschweig, W. Germany, June, 1982; 3rd International Symposium on Microbial Ecology, Michigan State University, East Lansing, USA, August, 1983; visit to the USDA ARS Appalachian Soil and Water Conservation Research Laboratory Berkeley, W. Virginia in August, 1983, sponsored by DAFS; invited participant in UNEP/ISEB Workshop on 'Uses of Microbiological Processes in Arid Lands for Desertification Control and Increased Productivity', New Mexico, USA, October, 1983; 6th International Symposium on Environmental Biogeochemistry, Santa Fe, New Mexico, USA, October, 1983.

Dr A. Rangeley
74th Annual Meeting of the American Society of Agronomy, Anaheim, California, November-December, 1982; EEC Workshop on 'Nitrogen Fluxes in Intensive Grassland Systems', Wageningen, The Netherlands, October, 1983.

Dr A. J. F. Russel
European Association for Animal Production Meeting, Leningrad, August, 1982; 5th World Conference on Animal Production, Tokyo, Japan, August, 1983.

Mr A. Whitelaw
International Conference of Veterinary Parasitologists, Toronto, Canada, August, 1982.

Dr S. Wilson
9th Symposium on Energy Metabolism of Farm Animals, Lillehammer, Norway, September, 1982.

Dr I. A. Wright
European Association for Animal Production Meeting, Leningrad, August, 1982.

Committee Service

International Committees

Dr P. Newbould
Member of the Scientific Advisory Committee for Swedish Project 'Ecology of Arable Land—The Role of Organisms in Nitrogen Cycling'.

Committees in the UK

Dr R. H. Armstrong
British Standards Institute Committee LEL/105 on electric fencing; Council Member of Blackface Sheep Breeders Society; Consultant to HFRO/COSAC Hill Sheep Development Project.

Mr J. Eadie
Member of the AFRC Animals Research Committee; Highlands and Islands Development Board Livestock Improvement Working Party; Highlands and Islands Development Board Advisory Committee of the Rahoy Deer Farming Project; DAFS Hill Farming Advisory Committee for Scotland; Redesdale EHF Advisory Committee; British Deer Society General Council; and the Board of Management of the Edinburgh Centre of Rural Economy.

Miss S. A. Grant
Associate Editor for Grass and Forage Science, since 1983.

Dr R. G. Gunn
Hon. Secretary for Occasional Publications of the British Society for Animal Production.

Mr W. J. Hamilton
Highlands and Islands Development Board Advisory Committee of the Rahoy Deer Farming Project; Co-opted member of the British Deer Farmers' Association Committee; Member of the Scientific Panel of the British Deer Society.

Dr J. Hodgson
Member of the JCO Grassland and Forage Committee.

Dr T. J. Maxwell
Technical Secretary of the JCO Sheep Committee; Chairman of the Technical Committee of the British Society of Animal Production; Technical Secretary of the HFRO-COSAC Steering Committee for Hill Sheep Development Project; Secretary of the HFRO/COSAC Liaison Group; Member of Pwllpeiran EHF Advisory Committee; Advisory Editor for Grass and Forage Science, to 1982.

Dr R. W. Mayes
Committee Member of the Scottish Group of the Nutrition Society.

Dr J. A. Milne
Hon. Secretary of the Scottish Group of the Nutrition Society; Council Member and Secretary of the Programmes Committee of the British Society of Animal Production; Council Member and Member of the Editorial Board of the Nutrition Society.

Dr P. Newbould
Convener of the Plant Microbial Interactions Group of the Association of Applied Biologists.

Dr A. Rangeley
Council Member of the Botanical Society of Edinburgh.

Mr A. Whitelaw
External Examiner for the Final Professional Examination for Veterinary Students in Preventive and State Veterinary Medicine.

Research summaries

Programme Unit 1

Factors affecting production of herbage from hill and upland pasture

Soil acidity and the prediction of lime requirements (*Research objective 101*)

[MJSF, KL, ADI]

In this project, factors which influence acidity in hill pasture soils and control soil pH response to lime were investigated. The work included a field trial and the development of methods for exchangeable acidity measurement and lime requirement prediction. The background to this work was discussed in the HFRO Biennial Report 1979-81, pp. 137-144.

Field studies of soil response to lime

The work described here is the continuation of a liming trial started in 1975 on acid brown soil (Linhope Series) at Stanhope in the Upper Tweed Valley (by courtesy of the Animal Breeding Research Organisation). The initial objectives were to measure the soil pH response to rates of lime up

Table 1
Effect of lime on relative yield, soil pH, exchangeable acidity and persistence of ryegrass and clover at Stanhope

Treatment	Lime applied (t/ha)	Relative yield (%L5+M) 1982	1983	1983 soil pH	1983 exch. acidity (meq/100g)	% cover of sward, 1983 clover	ryegrass
L0	0	42	37	4.34	6.73	0-10	0-10
L1	0.6	56	53	4.40	6.85	0-10	0-10
L2	1.3	60	53	4.51	6.51	0-10	0-10
L3	1.9	62	61	4.51	4.65	0-10	0-10
L4	2.5	70	65	4.64	5.41	0-10	0-10
L5	5.0	86	80	4.88	2.99	10-20	10-20
L0 + M	2.5	83	73	4.82	3.54	10-20	10-20
L1 + M	1.3	66	62	4.53	5.44	0-10	0-10
L2 + M	2.5	79	69	4.52	5.02	0-10	10-20
L3 + M	3.8	85	78	4.90	2.65	10-20	10-20
L4 + M	5.0	89	88	5.31	1.04	20-30	20-30
L5 + M	10.0	100	100	5.99	0.26	30-40	20-30

to 5 t/ha, to provide samples for a study of the effects of lime on exchangeable acidity in the soil and to observe the persistence of sown ryegrass and clover as the pH declined with time.

Because of decreasing yields in 1979, a revised design was adopted in 1980 when split plot maintenance treatments were applied to one half of each plot. The amounts of lime applied in each treatment are given in Table 1 (column 1). The maintenance treatments were repeats of the original 1975 dressings, except on the L0 plot, half of which received 2.5 t/ha.

Maintenance lime increased dry matter production and by 1983, there were significant differences between yields from each original treatment and its corresponding maintenance treatment, as the effect of the original dressings continued to decline. Although in 1983 there was no significant difference between yields from the L1-L4 plots there was a trend of increasing yield with lime rate, suggesting that even at low levels, lime was still having an effect after eight years.

Yields relative to the maximum yield are presented in Table 1. The decrease in relative yield with time, as pH dropped, is apparent for all treatments.

Vegetation records show that the proportion of the sward covered by clover and ryegrass steadily decreased with time and by 1983 only L4 + M and L5 + M allowed both clover and ryegrass cover to persist at more than 20% of the sward. These were also the only treatments which retained soil pH greater than 5.

Soil analysis showed that there was a tendency for exchangeable acidity to increase with time, corresponding to the pH decrease as the effectiveness of lime diminished. The relationship between exchangeable acidity and soil pH is illustrated in Figure 1. Exchangeable acidity falls off rapidly in the lower pH range and starts to level off at about pH 5.3. Above this pH, exchangeable acidity is less than 2 meq/100 g dry soil, implying that neither hydrogen ions nor aluminium are easily displaced by 1M KC1 solution and are therefore probably inactive towards plants (McLean, 1965). This can explain the persistence of ryegrass and clover on L4 + M and L5 + M as these were the only two plots with exchangeable acidity less than 2 meq/100 g in 1983.

It had been hoped that the experiment would demonstrate that one large lime application is not as effective as two applications at half rate.

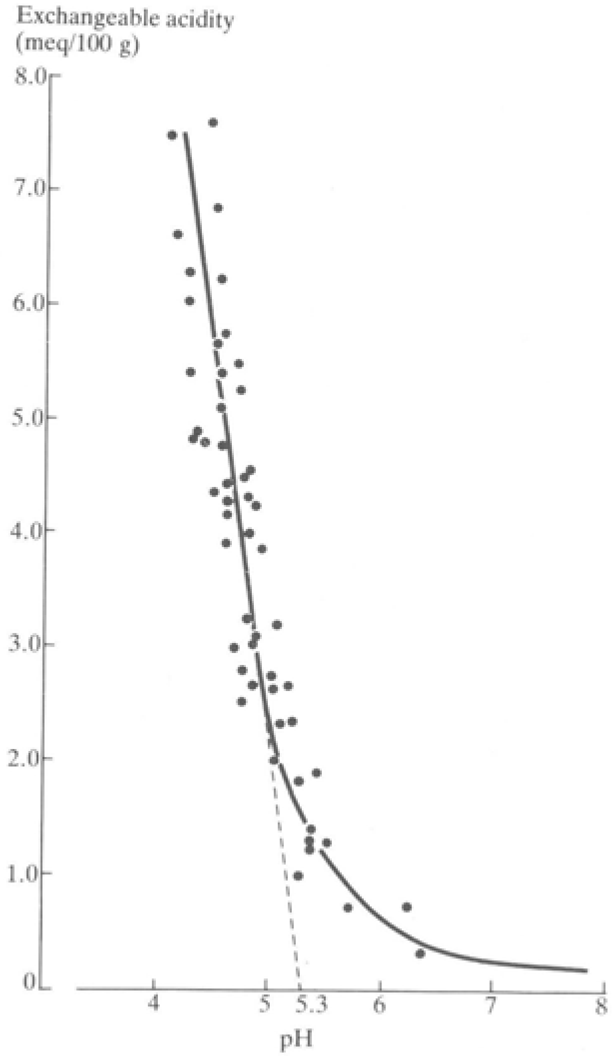

Figure 1

Relationship between pH and exchangeable acidity.

However statistical analysis of cumulative yields obtained up to 1980, 1981, 1982 and 1983 shows no significant differences between L2 and L1 + M; L4 and L2 + M; L5 and L4 + M. This may be explained by accidental grazing and insufficient fertiliser rates in the earlier years, which masked treatment effects.

MCLEAN, E. O. 1965. Aluminium. In *Methods of Soil Analysis, Part 2* (ed. C. A. Black *et al*), pp. 978-998. *Agronomy Monograph No. 9*. American Society of Agronomy, Wisconsin, USA.

The determination of exchangeable acidity in hill soils

Hill soil acidity is not simply due to hydrogen ions in soil solution but is also due to the hydrolysis of aluminium (Al) derived from soil minerals.

The acidity which affects plants can be extracted from the soil with a neutral unbuffered salt solution. Previously this exchangeable acidity was determined by titrating a 1 M KCl extract with NaOH to an indicator (phenolphthalein) endpoint at pH 8.2.

However it has been shown that the equivalence or isoelectric point for tri-valent aluminium varies from pH 6.2 to 7.7, depending on the concentration and form of Al present, so another technique, differential potentiometric titration, which detects the isoelectric endpoint was tested. This method involves the measurement of electromotive force (emf) after each incremental addition of titrant to the soil extract — the equivalence point of the reaction being revealed by a sudden change in potential in the plot of emf readings against the volume of titrant added.

The method was developed using standard solutions of varied Al and hydrogen ion concentrations and results were compared with values obtained for the same standards by the phenolphthalein titration. Exchangeable acidity recovered by isoelectric titration ranged from 93 to 105%, and from 90 to 126% with phenolphthalein. Statistical evaluation showed that the phenolphthalein method gave results significantly greater than those from the isoelectric method, suggesting that more titrant was added in the phenolphthalein titration than was required to convert Al^{3+} to $Al(OH)_3$.

The isoelectric method was then tested on soil extracts with standard additions of Al and hydrogen ions and satisfactory results were obtained.

It is therefore proposed that the determination of exchangeable acidity by isoelectric titration should be adopted in preference to measurement by phenolphthalein titration.

The prediction of lime requirement of acid hill soils

As reported in the HFRO Biennial Report 1979-81 (p. 141), a linear relationship exists between soil pH response to lime and the increase in cation exchange capacity ($\triangle$ CEC) between native soil pH and a target pH of 5.5. The quantity of lime required to raise the pH of a soil to 5.5 can be calculated from $\triangle$ CEC using this relationship.

However, to obtain $\triangle$ CEC, at least two measurements of CEC at different pH values must be made and this is very time-consuming. It was found that since organic matter content is also related to the increase in

CEC with pH, estimates of △ CEC can be made using only % loss of organic matter on ignition and soil pH measurements.

This procedure was employed to estimate △ CEC values for seven hill soils from which their lime requirements were calculated. Addition of the appropriate amounts of lime to the soils in the laboratory resulted in pH values not significantly different from the target pH.

It is therefore concluded that calculations based on % loss of organic matter on ignition and pH measurements offer a useful and rapid method for the prediction of soil lime requirement.

Factors affecting the availability of phosphorus for plant growth in hill and upland soils (*Research objective 102*)

[MJSF, KL, GRB, ADI]

Response to P fertiliser at Hartwood

A field experiment was started in 1982 on Rowanhill soil at Hartwood. The objective was to quantify the response of an established reseeded ryegrass/clover pasture to rates of phosphorus (P), up to 160 kg/ha, at two levels of nitrogen (N), 100 and 200 kg/ha. Preliminary soil analysis of the whole field, of which the experimental site was a small part, suggested that P status was very low.

In 1982 the only significant differences in dry matter yield between P rates occurred for the first of five harvests and the trial was continued in 1983 with further N applications in the hope that P would become a limiting factor in the lower treatment plots. However the 1983 harvests still showed no significant differences in yield. Furthermore herbage P contents were within the range reported to be non-limiting (Mengel and Kirkby, 1978). More detailed measurement of soil P content suggested that the initial P status of the site was not as low as previously thought, but was in the low to moderate category. It is therefore concluded that the site had adequate amounts of P available for plant growth even in the absence of fertiliser.

MENGEL, K. and KIRKBY, E. A. 1978. *Principles of Plant Nutrition*. p. 360. International Potash Institute, Berne, Switzerland.

The response of hill and upland pastures to additions of lime and fertilisers (*Research objective 103*)

[AR, TJM, GRB, MB]

Lime and fertilisers for establishment of a reseeded pasture on an upland soil

A small plot experiment was sown at Hartwood in 1982, the aim of which was to determine the amounts of lime and fertilisers needed to establish a perennial ryegrass/white clover pasture in a non-calcareous gley of the Caprington soil series. This soil type and the similar Rowanhill non-calcareous gley occur over a large part of the south of Scotland. The secondary aim of the experiment was to measure the apparent efficiency of the nitrogen fertiliser applied (i.e. kg DM/kg N) during the first harvest year.

Lime and nitrogen (N), phosphorus (P) and potassium (K) fertilisers were applied to all the plots in the sowing year (1982), in a factorial design. The levels were as follows: 0 and 5000 kg lime/ha; 0, 40, 80 and 160 kg N/ha; 0, 40, 80 and 160 kg P/ha and 0 and 80 kg K/ha. In the first harvest year (1983), a total of 0, 120, 240 and 480 kg N/ha were applied in three equal dressings, and 0 and 80 kg K/ha. The pasture was cut for harvest once in 1982 and five times in 1983.

In both years applications of lime, N and P significantly increased total seasonal dry matter (DM) production but K had no effect. In the sowing year, 1982, P had the greatest effect but in 1983 N was most effective. There were no interactions between treatments in either year. DM production ranged from 0.06 to 0.84 t/ha/yr in 1982 and from 1.6 to 11.4 t/ha/yr in 1983.

The botanical composition of the herbage was assessed from cuts taken in October in both years. In 1982 there was 83 to 97% perennial ryegrass in the herbage from all treatments, and in 1983 there was 87 to 100% perennial ryegrass in N fertilised treatments but only 66% in treatments without N. There was <1% white clover in herbage in 1982 and <6% in N fertilised treatments in 1983. However in the latter year treatments without N fertiliser had 2 to 39% white clover in the herbage; applications of P significantly increased the content of white clover (an increase of 1% per 3 to 5 kg P) and lime tended to increase it. Weeds were present only in the low fertiliser treatments.

Measurements were made of the effects of treatments on several growth parameters of perennial ryegrass and white clover; these were the numbers of growing points per m^2, the rate of leaf production and the weight of DM per growth point. For perennial ryegrass, lime, N and P significantly increased tiller weight but there were no other significant effects. For white clover, lime and fertilisers had more effect on the number of growing points per m^2 than on the weight of stolon growth and P also decreased the leaf appearance interval.

Nodule numbers per m^2, but not nodule size or nodule number per growth point, were increased by applications of lime and P and decreased by N. The range was from 1200 to 6200 nodules per m^2 and from 1.3 to 3.2 nodules per growth point.

Apparent efficiencies of applications of N and P fertiliser (kg DM/kg N) decreased as levels of application increased and efficiencies of N dressings were affected by the time of application (Table 2).

Table 2
Apparent efficiency of fertiliser applications in 1983 (kg DM/kg N)

	Whole season		Within season			
Fertiliser	Amount applied (kg/ha)	Apparent efficiency	Amount N applied per dressing (kg/ha)	Apparent efficiency (1)*	(2)	(3)
P**	40	38.8				
	80	26.1	Not applicable			
	160	15.5				
N	120	24.0	40	33.3	26.4	12.2
	240	18.9	80	23.0	23.6	10.0
	480	13.5	160	17.9	15.8	6.7

* N applied on 5 May (1), 23 June (2) and 1 September (3).
** P was applied in July 1982.

Based on the results of this experiment with cut plots, no return of N in excreta and with low input from nitrogen fixation, the amount of N fertiliser needed to meet the calculated requirements of an upland sheep grazing system are 120 and 250 kg N/ha for stocking rates of 10 and 15 ewes/ha respectively. Further work is needed to quantify N fertiliser needs under grazing.

Lime and fertilisers needed to upgrade a reseeded ryegrass/white clover pasture on the peaty podzol at Glensaugh

The area of heather moorland in Great Britain has been estimated at about 1½ million hectares. To increase the utilisation of heather by sheep it was suggested that distributing reseeded areas within the heather in a mosaic which is fenced off from the rest of the hill could increase its use without damaging animal performance (Milne and Grant, 1978). In 1978 (site A) and 1979 (site B) mosaic reseeds of this type were sown on the Cairn unit at Glensaugh. Establishment of the perennial ryegrass/white clover was successful in the first two years but by 1981 the pasture had deteriorated and herbage production was low; the ryegrass was yellow with few tillers and the white clover was diseased. The mean soil pH's of site A and site B reseeds in 1981 were 5.0 and 4.5 respectively.

The assumption built into the mosaic hypothesis was for a net pasture production of around 5000 kg DM/ha/yr and the aim of this work was to investigate possible reasons for the low herbage production. In 1982, an 'omission' experiment was set up on both reseeds. Treatments were applied in the spring and the pasture was cut for yield four times each season. In 1982 the target DM production was achieved on site A from treatments which received 2½ t lime/ha with 120 kg N/ha and 100 kg K/ha. In 1983 the target was achieved with further applications of 80 kg N/ha, 50 kg P/ha and 100 kg K/ha. Although pasture growth on site B was affected by the same factors as on site A, production of 5000 kg DM/ha was not attained. Clearly some other factor was limiting growth.

The botanical composition of site A was 42% perennial ryegrass, 34% white clover, 16% *Agrostis, Poa* and *Festuca* and 7% other species. Applications of lime and fertilisers increased the content of perennial ryegrass and broad leaved grasses and decreased the content of white clover and *Festuca*. Herbage from site B contained 63% perennial ryegrass, 22% white clover, 6% other grasses, 7% heather and 2% other species. Applications of lime and fertilisers increased the perennial ryegrass content at the expense of the white clover. At both sites the reduction of white clover was less when lime and K, but no N, were applied than when 120 kg N/ha was given.

The white clover was inoculated with *Rhizobium* at sowing. But because the pH of the soil was 5.0 or less at the beginning of the experiment it was thought that the survival of competitive and effective strains of rhizobia may have been affected. Using the most probable number technique 10^6 rhizobia/g soil were counted from samples taken in spring 1982 and the rhizobia were as or more effective than known effective strains. Nodulation was not a problem in the field because in July 1983 there were 6 to 26 thousand per m^2. In 1982 the seasonal rates of nitrogen fixation were measured by acetylene reduction activity (ARA). These results are discussed in the longer research report (p. 109) and it is sufficient to say here that even in the best treatment (Site A given lime, K but no N) the seasonal ARA was about half that measured at other hill sites in other years.

The occurrence of pepper spot disease on white clover leaves was counted in 1982. The disease was more prevalent earlier in the season on site B (40% of leaves infected) than site A (7% infected) but was not related to the seasonal pattern of ARA. By the end of the growing season 92 to 96% of the leaves were infected on both sites.

The response to nitrogen applications within season, but not between seasons, seems to be affected by previous dressings in the same year. In both grazed and cut pasture a response to N applied in August occurred only if N had been applied in spring or summer. The reasons for this are presently being investigated.

Table 3
Apparent efficiency of N fertiliser applications in 1982 and 1983 (kg DM/kg N)

		Whole season		Within Season			
		Amount applied (kg/ha)	Apparent efficiency	Amount N applied per dressing (kg/ha)	Apparent efficiency (1)*	(2)	(3)
Site A	1982	120	8.4	40	9.1	1.9	14.2
	1983	120	9.3	40	13.4	2.8	11.7
Site B	1982	120	5.4	40	4.8	5.0	6.5
	1983	120	7.4	40	6.8	9.9	5.4

* N applied on 14 April (1), 5 July (2) and 17 August (3) 1982 and on 16 May (1), 14 July (2) and 25 August (3) 1983.

Measurements of the apparent efficiency of use of N fertiliser are available for two seasons, and are given in Table 3. These values are much less than those recorded at Hartwood (see previous section) and part of the reason may be the greater contribution of nitrogen fixation on the no nitrogen plots at Glensaugh. Also drought in July may have reduced the effectiveness of the second dressing at Glensaugh, but these observations may not be sufficient to explain the results. It is also possible that the N applied was immobilised by soil micro-organisms although incubation experiments with the peat in the laboratory do not support this suggestion (see research objective 105).

Because of the necessity to apply fertiliser to attain required levels of production whilst also retaining the contribution by nitrogen fixation, further work will study in more detail the fate of N fertilisers in this soil and their effects on nitrogen fixation.

MILNE, J. A. and GRANT, S. A. 1978. Better use of heather hills for sheep production. *Hill Farming Research Organisation 7th Report, 1974-77*, pp. 41-48.

Soil and plant factors which influence the content of copper, molybdenum and sulphur in herbage from improved hill pastures (*Research objective 104*)

This research objective has developed out of the observation that sheep may soon become copper deficient when confined to some reseeded hill pastures. Examination of reseeded and indigenous herbages has shown that this copper deficiency is not primarily due to reductions in the herbage copper levels in reseeded pastures, although this may also occur, but to increases in herbage molybdenum and sulphur concentrations (Whitelaw *et al*, 1979). Dietary molybdenum and sulphur are known antagonists to the absorption of copper during the process of digestion in ruminants and therefore elevations in the concentrations of molybdenum and sulphur in dietary herbages cause a reduction in absorbable copper which can lead to clinical copper deficiency. This subject is reviewed in greater detail on p. 167.

Reconnaisance survey of reseeded hill pastures

[CCE, PN, GJB]

The extent to which reseeding of hill pastures can lead to copper deficiency in grazing livestock was not known nor was there relevant data to make an assessment feasible. Consequently a relatively small reconnaisance survey of reseeded hill pastures for herbage and soil has been undertaken throughout mainland Scotland. It was carried out in collaboration with the three Scottish Colleges of Agriculture and the AFRC Unit of Statistics with assistance from the DAFS Agricultural Inspectorate and the Soil Survey of Scotland (MISR). Ninety sites were sampled with equal numbers located in each college area in August and September 1982. A number of reseeds from HFRO research stations were also sampled primarily as a basis for comparison. Sites for sampling were selected according to soil type, with age since sowing and drainage status being secondary determinants. Every site had 36 herbage sub-samples and 72 soil cores bulked into 6 representative samples of each material according to a predetermined protocol.

Determinations of copper, molybdenum and sulphur concentrations in herbage samples together with estimates of absorbable dietary copper in grazing sheep (Suttle, 1983) have been made. Firm conclusions are difficult to draw as statistical analyses have not yet been completed. However, a preliminary examination of the data suggests that the absorbable copper concentrations in the herbages is lower than the requirements of grazing hill sheep for a majority of the sites (75%). The absorbable copper concentration (0.05-0.10 μg/g DM) in 50% of the sites approximates to that found in pastures which have produced clinical symptoms of copper deficiency in grazing sheep and growth retardation in young lambs. The rate of depletion of copper reserves and any subsequent deficiency in grazing livestock is dependent upon many factors. These include the copper status of the stock prior to confinement, the age and physiological state of the animals and the length of time of confinement on the reseed, as well as the absorbable copper in the grazed herbage. The preliminary findings of the survey indicate clearly that, of the sites examined, reduction of copper reserves can be expected in grazing livestock in a substantial majority, with the attendant potential to produce copper deficiencies unless remedial treatments are given.

The influence of lime and fertilisers on concentrations of copper, molybdenum and sulphur in plants
[CCE, PN, GJB, RMP]

Investigation of the effect of applying lime and fertilisers on the uptake of copper, molybdenum and sulphur by perennial ryegrass (CV S23) and white clover (CV Aberystwyth S184) has continued. The relative uptake of copper, molybdenum and sulphur in ryegrass and clover has been shown to differ. In one experiment significantly lower concentrations of sulphur and molybdenum and higher concentrations of copper were found in white clover than in perennial ryegrass. These observations, if confirmed under field conditions, may be of significance in terms of the management of reseeded pastures and may indicate an additional reason, apart from nitrogen fixation and herbage quality, to maximise the clover component of the sward.

Significant depression of the copper concentrations in both white clover and perennial ryegrass were obtained in experimental treatments which stimulated high growth rates in a peaty podzol soil. This was probably due to dilution effects together with the marginal or low level of available soil copper. During routine analysis of reseed herbages it has been observed that molybdenum and sulphur concentrations may be lower at the July harvest than earlier or later in some years. This again may reflect dilution effects. The significance of these seasonal variations has not yet been examined under field conditions.

An experiment is in progress to examine the relative uptake of copper, molybdenum and sulphur by perennial ryegrass and white clover when lime and fertilisers are applied as either laboratory chemicals or from commercially available sources. This study was undertaken as it had been shown by analysis that significant quantities of copper, molybdenum and sulphur are included in the commercially available fertilisers which had been used in previous experiments. While few results are available it is clear that significantly higher growth rates are obtained from lime applications than from pure calcium carbonate. Other experiments are in progress to assess the influence that waterlogging of soil has on the availability of molybdenum and sulphur for uptake by plants.

The results of this study are expected to produce evidence on the extent to which the incidence of induced copper deficiency in grazing ruminants may be avoided, or minimised by site selection, soil treatment and pasture management.

SUTTLE, N. F. 1983. The nutritional basis for trace element deficiencies in ruminant livestock. In *Trace Elements in Animal Production and Veterinary Practice* (ed. N. F. Suttle *et al*), pp. 19-25. *British Society of Animal Production Occasional Publication No. 7.*

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. *Veterinary Record*, **104:** 455-460.

Factors which influence nitrogen fixation and transfer by white clover in hill and upland pastures (*Research objective 105*)

Nitrogen economy of white clover plants
[CAM]

White clover contributes fixed nitrogen to the pasture system not only directly in its own herbage but also indirectly through the grass component, as a result of transfer of fixed nitrogen. Previous work has shown that there is a seasonal pattern of nitrogen fixation in hill and upland white clover swards and fixed nitrogen tends to become available for uptake by grass plants in the latter part of the growth season. During the period covered by this report a more detailed investigation of the effect of climatic variables on the nitrogen fixing activity of white clover was made. In addition, two nitrogen transfer routes which could be of considerable importance under some conditions were studied. Further work on the response of the nitrogen economy of defoliated white clover plants has been completed.

The seasonal profile of nitrogen fixing activity of upland white clover was investigated at Hartwood. Measurements were made of clover content and weather parameters, e.g. soil temperatures at surface, 5 cm and 10 cm, air temperature, solar radiation and rainfall, in order to interpret acetylene reduction data. Nitrogen fixing activity was closely related to clover leaf dry weight except during summer drought conditions, when low soil moisture content caused a decline in activity. The onset of fixation occurred about one month after clover growth resumed and increased sharply during April, when soil temperatures rose from 2 to 3.9°C. Nitrogen fixing activity in the four month period April-July contributed 70% of the annual total of fixed nitrogen. The acetylene reduction data will be converted to absolute amounts of fixed nitrogen when results from the parallel ^{15}N isotope dilution experiment are available. Seasonal nitrogen fixation is discussed further in the longer research report on p. 109.

The aerial transfer of nitrogen as gaseous ammonia from white clover to ryegrass foliage was investigated in simulated sward experiments subjected to different cutting regimes. Gaseous ammonia evolution and uptake in pasture canopies may account for a significant transfer of nitrogen in pastures in which excretal nitrogen is volatilized or alternatively under conditions favouring ammonia release, for example where there is a significant amount of senescing tissue. There was experimental evidence that transfer occurred and this was maximised in the sward subjected to a lax cutting regime. Nitrogen from gaseous transfer contributed about 1.5% of the grass nitrogen under these experimental conditions.

The role of vesicular arbuscular mycorrhizal (VAM) fungi in mediating nitrogen transfer from white clover to ryegrass was investigated. The fungi may mediate transfer via direct connection of the grass and clover root systems by fungal hyphae or through an increased capacity for transfer of root exudate due to an increase in exchange area of infected root systems. VAM infection was found to enhance transfer, but further technique development would be required before this could be quantitatively assessed.

The increase in total plant nitrogen in leniently defoliated white clover plants was investigated. There was little reduction in nitrogen fixation, perhaps because the defoliation treatment did not remove any young leaf tissue or growing tips and thus minimised the period of reduced current assimilate supply. There was increased uptake of ammonium nitrogen in the 5-10 day period following defoliation. Nitrate uptake, on the other hand, was decreased in the first 10 days after defoliation. Thereafter there was evidence of increased nitrate uptake presumably when the supply of metabolic energy no longer restricted uptake and reduction.

Bacterial nitrogen transformations in peat from a peaty podzol
[AR]

Mosaic reseeds were sown within the heather moor on the Cairn at Glensaugh in 1978 (site A) and 1979 (site B) (see research objective 103). Before sowing, the soil was limed (7.5 t/ha) and fertilised with N (55-110 kg/ha), P (150-162 kg/ha) and K (23-46 kg/ha) and in the two years following the sowing year the reseeds received dressings of 60-130 kg N/ha/yr. The aim of the fairly high fertiliser applications was to encourage the pasture to form a tight sward and to build up a reservoir of dead pasture organic matter (DPOM) in the soil. Once this had been achieved it was intended that N fertilisation would cease. The DPOM was expected, through decomposition, to become a source of N for grass growth. Nitrogen fixation by white clover would then be the main input of N into the pasture. It was hoped that a dynamic equilibrium would be reached in which decomposition of DPOM would be balanced by additions of dead plant and faecal material.

But in 1981 the perennial ryegrass in the Cairn pastures was yellow and nitrogen deficient and N cycling was obviously not proceeding as anticipated. Three possible reasons for this were suggested: (a) there was a bacterial inhibitor in the peat which prevented decomposition, (b) N released through decomposition of DPOM (C:N ratio approx. 10:1) was immediately immobilised during decomposition of the peat (C:N ratio approx. 30:1), (c) climatic factors (low temperatures for approx. 7 months and dry soils for approx. 6 weeks each year) together with soil acidity resulted in slow rates of decomposition of DPOM.

Experiments were carried out to measure potential rates of microbial N transformations in the natural (pH 3.8) and amended (pH 6.4) peaty podzol soil; lime, P and K, equivalent to the amounts added in the field were added in the latter. In order to create uniform conditions and a favourable environment for microbial activity, the experiments used peat slurries (1:10, peat:water) held in flasks which were shaken at a constant temperature of 25°C. To achieve anaerobic conditions the atmosphere in some flasks was replaced by helium or nitrogen gas. In the experiments N (conc. 50 ppm) in an appropriate form or glucose (1000 ppm) was added.

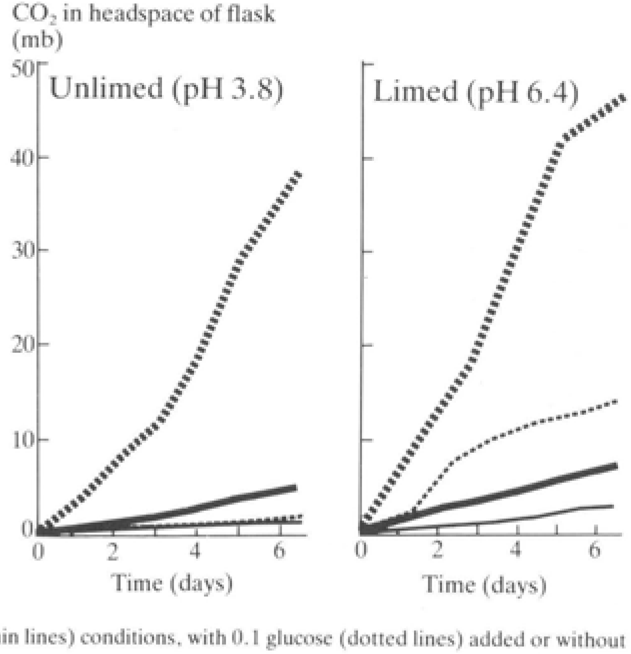

Figure 2

Carbon dioxide production from peat slurries.

In aerobic (thick lines) or anaerobic (thin lines) conditions, with 0.1 glucose (dotted lines) added or without glucose (solid lines).

Addition of glucose stimulated release of CO_2 from the aerobic and anaerobic limed peat and from the aerobic unlimed peat. This did not occur in the anaerobic unlimed peat (Fig. 2). This data demonstrates firstly that there was no general microbial inhibitor in the peat which prevented decomposition, except perhaps an inhibitor of the activity of anaerobic micro-organisms in the unlimed peat; secondly that the activity of the micro-organisms was carbon limited and was not, initially limited by N deficiency. Addition of NO_3^--N to the treatments illustrated in Figure 2 did not affect the amount or pattern of CO_2 production.

Other experiments showed that anaerobic non-symbiotic nitrogen fixation occurred only when glucose was added to the limed soil (max rate = 4 μM C_2H_4 produced/g peat/day) and that urea was hydrolysed in the limed peat within 3 hours and in the unlimed peat within 9 hours. Also nitrate was denitrified within 2 days in the limed peat but was not appreciably transformed in the unlimed peat. Nitrification, i.e. the change from NH_4^+ to NO_3^- via NO_2^-, represented by equation (1), did not occur in the soil even after liming (Fig. 3a).

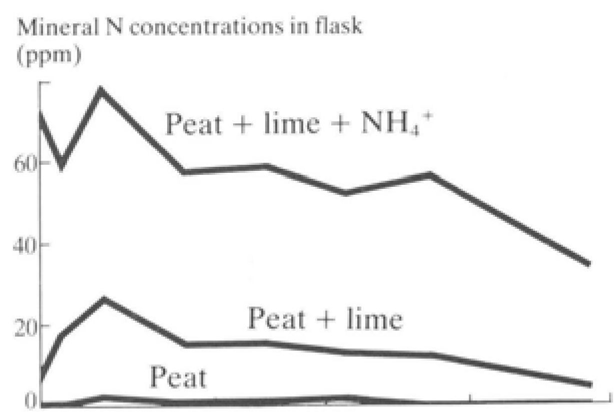

Figure 3a

N transformations in aerobic peat slurries.

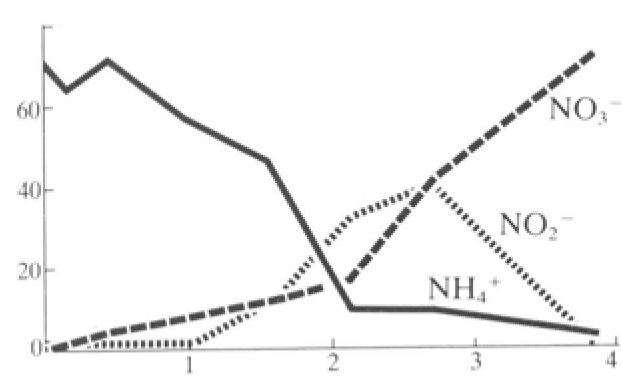

Figure 3b

N transformations in aerobic peat slurries with additional lime, NH_4^+ and *Nitrosomonas*.

$$(1)\quad \underset{\text{ammonium}}{NH_4^+} \xrightarrow{\text{e.g. } Nitrosomonas} \underset{\text{nitrite}}{NO_2^-} \xrightarrow{\text{e.g. } Nitrobacter} \underset{\text{nitrate}}{NO_3^-}$$

However, when a culture of *Nitrosomonas europaea* was added to the limed peat, ammonium was transformed and nitrate was the end product (Fig. 3b). This is surprising because there must have been a nitrite-reducing organism present in the soil which, in nature, must contain very little nitrite. These organisms are usually chemoautrophic and reduction of nitrite provides their only energy source.

Shorter experiments (up to 14 days duration) in this series suggested that there was a net mineralisation of N from the peat but results from the longer nitrification experiment indicated otherwise. In the first few days of the experiment N was mineralised but this was followed by a gradual decrease in the concentration of ammonium ions (Fig. 3a).

Clearly these experiments show that low pH (3.8) limits bacterial N transformations, but there is not a major microbial inhibitor present in the limed peat. Also N may be immobilised during decomposition of the peat but it is probably a slow process. Further work will investigate the dynamics of N transformations in the peat during a longer time period and will investigate the fate of mineralised DPOM in the laboratory and field.

This work was done in the Microbiology Department at Macdonald College of McGill University, Canada, during tenure of a study fellowship from the OECD.

Isolation and characteristics of strains of Rhizobium trifolii *indigenous to some upland Scottish soils*

[JRJ, PN with BEMoseley]

Despite the use of strains of *Rhizobium trifolii,* previously shown to be effective at fixing nitrogen on white clover when tested under bacteriologically controlled conditions, for inoculation of white clover in a range of hill soils, responses were observed in deep peat soils only (Newbould *et al.,* 1982). Competition between indigenous and introduced strains has been advanced as a possible explanation for this poor result. A study of competition between contrasted strains of *R. trifolii* was initiated to investigate this matter further.

R. trifolii isolates were obtained from naturalised white clover nodules and from soil samples collected from an area in the Cleish Hills, Scotland. Representative strains were selected after tests of each isolate's intrinsic antibiotic resistance pattern (fingerprint) and screened for their growth and serogroup characteristics and their relative effectiveness with the white clover cultivar New Zealand Grasslands Huia. Grouping of strains by fingerprint similarities was confirmed by serology, but these classifications were generally unrelated to the strains' growth rates or relative effectiveness with white clover plants. Symbiotic effectiveness, as measured by shoot dry matter production, was strongly related to total nodule fresh weight per plant. The majority of the Cleish strains, when compared with standard strains of varying effectiveness, were classified as ineffective. Information, based on fingerprinting, serogrouping, growth rates and symbioses data, was used to show overall strain relatedness, and four dissimilar strains were selected for use in a series of competition experiments, using spontaneous antibiotic resistant mutants of the selected parent strain.

The mean dry weights of white clover produced after 46 days growth under bacteriologically controlled conditions with the parent and mutant strains are shown in Table 4.

Table 4
Shoot production of white clover (NZ Grasslands Huia) grown with four parent (P) strains of *Rhizobium trifolii* and their spontaneous antibiotic resistant mutants (M)

Strain	Shoot production (g DM)
CL03 — P	5.73
— M	3.68
CL25 — P	6.28
— M	5.73
CL56 — P	21.37
— M	18.19
P3 — P	21.17
— M	31.29
LSD ($P < 0.05$)	14.76

P3 is a standard effective strain from the Edinburgh School of Agriculture collection and two of the three Cleish strains were ineffective. Despite some variation, the results indicate that the mutant re-identifiable strains can be used in competition experiments.

In paired-strain experiments the ratio of strains occupying the nodules was directly related to the ratio of the two strains in the inoculum. Regression analysis showed that competition for nodulation occurred in all cases. Three competition indices were compared and all were unaltered by nutrient solution pH, or temperature. Different plant clones, although producing significantly different numbers of nodules per plant, did not alter the competition indices. Priming a young radicle with a single strain 72 hours prior to the main inoculation (1:1 ratio of 2 competing strains) altered the nodulation ratio, with the primarily introduced strain forming the majority of the nodules. Enhancement of nodulation by an ineffective strain in competition with an effective strain reduced the shoot dry matter production of the host plant.

Use of a granular peat base rather than a spray inoculant to introduce the marked strains into an improved hill site encouraged their establishment in the soil and the number of nodules formed on plants in the first year. Liming at 5 t/ha raised the soil pH but generally did not alter the populations or nodulating abilities of the introduced strains. Correlations between soil pH and rhizobia measurements were inconsistent over time. Extractable levels of soil ammonium, aluminium, phosphorus and potassium were not related to changes in populations of the introduced strains. Proportional nodule occupancy by each marked strain was related to its soil or rhizosphere population when considered as a proportion of the total population. Thus, the competitiveness of each strain under field conditions could be measured.

The ranked orders of competitiveness of the four marked strains were similar in the enclosed tube and field experiments, and both strains were related to the ranked order of the parental strain growth rates. Nodulating competitiveness was not related to the differential ability of each strain to survive and multiply in the soil (saprophytic competence) or its effectiveness with white clover.

The results of this study encourage the view that the transfer of nitrogen fixing ability to strain CL25, the most competitive of all the *R. trifolii* isolates in this study, though presently ineffective at fixing nitrogen might produce an 'elite' strain for use under field conditions. Further work by microbial geneticists with this strain to bring about transfer of a gene which ensures effective nitrogen fixation, and by biochemists to study the biochemical processes of competition, appears justified. This work is presently being written up as a thesis for submission for the degree of Ph.D at the University of Edinburgh.

How to maximise utilised herbage production in grazed hill and upland grass and grass/clover swards (*Research objective 106*)

[JK, EMS, VAD]

This is an interdisciplinary study involving both the Plants and Soils and Grazing Ecology Departments. A summary of the research work carried out is given under research objective 011 (see p. 27). The results are discussed in greater detail in the longer research report entitled 'Grazing management and pasture production: the importance of sward morphological adaptations and canopy photosynthesis' on p. 119.

The influence of nutrients recycled by grazing animals on herbage production and on maintenance fertiliser requirements (*Research objective 107*)

[MJSF, TGC, ADI, JE]

Input-output experiments at Sourhope

In order to measure the responses to a range of pasture improvement treatments, a series of long-term experiments on three hill pasture sward types was begun at Sourhope in 1969-70.

The improvement treatments included controlled grazing, controlled grazing plus lime, phosphorus, oversown white clover and perennial ryegrass applied as a cumulative series to pastures dominated by *Agrostis*/*Festuca* (Site 1), *Molinia*/*Nardus* (Site 2) and *Nardus*/*Festuca* (Site 3).

The plots on each site were grazed simultaneously by wether sheep on three occasions each year, i.e. mid-May to mid-June, mid-July to mid-August and mid-October to mid-November.

Pasture production responses over the first ten years of the experiments have been described by Eadie *et al* (1981) and nutrient re-cycling data was summarised by Floate *et al* (1981).

Final measurements were completed on Sites 1 and 2 during 1982 and 1983 respectively. Carrying capacity, expressed as grazing days per hectare, was depressed on all treatments at all sites during 1982 and 1983 due to severe drought conditions. The trends shown in previous years, however, were still evident with little difference between the controlled grazing, lime and phosphate treatments, but a greater response shown by those treatments involving oversown clover and ryegrass.

Changes in the botanical composition of the swards have been monitored during the course of the experiment. Results show that high proportions of clover and ryegrass were achieved in the oversown treatments at all sites during the first six years of the experiment. These high levels have since been maintained in the case of ryegrass while the clover content continues to increase with time. At Site 1 all treatments except that subject to controlled grazing alone, have shown an increase in *Festuca rubra* and *Poa pratensis,* two species characteristic of good quality *Agrostis/Festuca* grasslands (King and Nicholson, 1964).

The *Molinia/Nardus* dominant pasture of Site 2 showed a rapid decline in the proportion of *Molinia caerulea* which had virtually disappeared from all treatments by 1977. Since then there has been an increase in the proportion of *Festuca rubra* and *Poa pratensis* on all treatments except controlled grazing alone. Apart from the oversown treatments there has been no reduction in the proportion of *Nardus stricta.* The *Nardus stricta* on Site 3 was largely eradicated by spraying with 'Dalapon' before treatments were applied in 1971. This led to a dramatic rise in the originally sub-dominant *Festuca ovina.* Final measurements are due to be made on this site during 1984.

EADIE, J., HETHERINGTON, R. A., COMMON, T. G. and FLOATE, M. J. S. 1981. Long-term responses 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. *British Grassland Society Occasional Symposium No. 12, Edinburgh.*

FLOATE, M. J. S., HETHERINGTON, R. A., COMMON, T. G. and IRONSIDE, A. D. 1981. Long-term responses 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. *British Grassland Society Occasional Symposium No. 12, Edinburgh.*

KING, J. and NICHOLSON, I. A. 1964. The grasslands of the forest zone. In *The Vegetation of Scotland* (ed. C. H. Burnett), pp. 168-206. Oliver and Boyd, Edinburgh.

Revised research programme

Staff resignations and the completion of work on several projects provided the opportunity to review work within Programme Unit 1. The broad aim of the programme remains the same but it has been decided to concentrate on three main topics rather than to try to cover a wider range of matters relevant to pasture production from the hills and uplands.

The first topic chosen for detailed investigation is the turnover of nitrogen in hill and upland swards. Nitrogen is the major element which influences the growth of pasture in both hills and uplands.

In the hills, nitrogen is commonly used to help establish species sown in the improvement of indigenous swards, but thereafter it is generally expected that white clover will provide a supply of nitrogen. The potential for nitrogen fixation by white clover and its transfer to companion grasses is difficult to realise, and there appear to be interactions between clover and nitrogen from fertiliser or mineralised from soil organic matter. Greater understanding of these interactions is required to enable the nitrogen supply from all sources to be optimised so as to give predictable quantities of herbage production.

In the uplands, information on and knowledge of the annual cycle of feed required for meat production systems has improved greatly in recent years. But how to provide this from grazed pasture in a predictable manner is limited by lack of understanding of the factors influencing responses to nitrogen. There is a clear need to understand and quantify the processes involved in the nitrogen cycle of grazed upland swards, and to understand how to exploit the potential of white clover. Accordingly, five research objectives have been elaborated to address this complex and highly interactive set of processes.

Work on the pasture production aspects of induced copper deficiency in grazing livestock in the hills will continue and this provides the second major area of study. Knowledge of the soils and pasture improvement techniques whose choice and manipulation respectively might ameleriorate occurrence of the deficiency is required.

Thirdly, although considerable progress has been made jointly with the Grazing Ecology Department to understand the effects of pasture utilisation on production and intake from predominantly grass swards, it is now necessary to extend this understanding in swards containing white clover. Thus, work on this research objective will continue but with greater emphasis on clover-containing swards. Links between this objective and the studies of nitrogen fixation are obvious and will be encouraged.

The revised research objectives which apply to the three main areas of study are as follows:

Establish the influence of the quantity and nature of soil organic matter on the supply of nitrogen for grass growth in grazed swards (001).

Investigate how nitrogen fixation is affected by grazing management and seasonal inputs of fertiliser N (002).

Determine rates, and factors affecting the transfer of fixed N from clover to grass (003).

Quantify transfer of N via the grazing animal from ingested herbage to the available soil N pool (004).

Model the turnover of N in grazed pastures and develop strategies for usage of fertiliser N in animal production systems (005).

Assess the soil and plant factors which influence the content of copper, molybdenum and sulphur in herbage on improved hill pastures (006).

Understand how to maximise utilised herbage production in grazed hill and upland grass and grass/clover swards (007).

Programme Unit 2

Ecology of grazing systems

Identification of the characteristics of hill plant communities and determining their suitability for sheep: indoor studies

(*Research objective 009*)
[RchdHA, DRC, TGC, MMB, HKS]

Further investigations have been completed into the relationships of intake and digestibility to fibre constituents of sown and indigenous herbages fed to sheep (HFRO Biennial Report 1979-81 pp. 40-41). This work is currently being submitted for publication in two papers concerning the potential quality of indigenous herbages and the estimation of the quality and quantity of such herbages eaten by grazing animals.

Recently Penning and Johnson (1983) have shown the promise of the indigestible fraction of acid detergent fibre (IADF) as an internal indicator for the direct prediction of intake of sown herbages by grazing animals. This technique has scientific and practical advantages and is currently being evaluated at HFRO for use with a wider range of herbages, using feed and faecal samples from previous studies. The ADF residues from these are digested with cellulase derived from *Trichoderma reesei* (Novo Enzymes Ltd). Preliminary investigations are taking place into optimum temperature and lengths of digestion period.

PENNING, P. D. and JOHNSON, R. H. 1983. The use of internal markers to estimate herbage digestibility and intake. 2. Indigestible acid detergent fibre. *Journal of Agricultural Science, Cambridge*, **100**, 133-138.

Investigating the scope for manipulation of the composition and nutritive value of hill swards by controlled grazing

(*Research objective 010*)
[JH, SAG, RchdHA, DES, MMB, LT, TGC, HKS]

The fieldwork for the first phase of the comparative study of diet selection by sheep and cattle grazing a series of indigenous plant communities at different seasons of the year (HFRO Biennial Report 1979-81, pp. 37-40) was completed in 1980. The processing of samples and data has now been completed and the work is currently being prepared for publication. The second phase of this study, designed to examine the scope for manipulating the botanical composition and agricultural potential of selected communities by grazing management, and the impact on the nutrient intake of animals during both the manipulative and subsequent control phases, will begin in 1984.

The criteria for selecting communities for the second phase were based on: a) the existence of a specific role for, or problem in the utilisation of, a given plant community in sheep-only production systems, b) evidence suggesting possible advantages of cattle grazing to the plant community (e.g. complementary grazing behaviour offering possibilities for the control of undesirable species), c) evidence of possible damage to the community as a result of cattle grazing and d) the nutritional value of the diet.

Using these criteria *Calluna* moor was eliminated from the selection. Although sheep and cattle showed a considerable overlap in dietary preference, cattle grazed the *Calluna* shoots less selectively and ingested more of the woody part of the shoot. As well as damaging the *Calluna* this resulted in lower levels of digested herbage intake in cattle than in sheep, especially relative to maintenance requirements (Table 5). *Agrostis-Festuca* was eliminated on the grounds that there is a well-defined role for this community in sheep systems and there is little evidence of any damage to productivity as a result of intensive sheep grazing (Hodgson and Grant, 1981).

Table 5
***Calluna* organic matter digestibility (OMD) and intake of digested organic matter (DOMI, g per kg $w^{0.75}$/d) by grazing sheep and cattle**

Date	Sheep		Cattle	
	OMD	DOMI	OMD	DOMI
May (1978)	0.446	9.4	0.326	8.9
April/May (1980)	0.505	12.3	0.363	8.7
July (1977)	0.466	15.1	0.411	12.8
October (1977)	0.399	13.4	0.361	12.7
October/November (1978)	0.460	16.5	0.391	14.7
Assumed maintenance requirements	—	25	—	44

In *Nardus-Festuca-Deschampsia* grassland the avoidance of *Nardus* and other tall, coarse plants by grazing sheep is such that in sheep-only systems these undesirable species are likely to increase in cover. In phase 1 of the study it was shown that the inter-tussock *Festuca-Deschampsia* and the small patches of broad-leaved grasses were preferred by both sheep and cattle. However, it is also clear that as the available herbage on the inter-tussock areas was reduced over the years; the amount of *Nardus* eaten by the cattle increased substantially while that eaten by sheep increased very little (Figure 4). Work will continue with this community in phase 2. It will be burned, and controlled grazing to maintain the inter-tussock areas at designated sward heights will be used to investigate the scope for *Nardus* control by grazing. Sheep, cattle and goats will be used and nutrient intakes measured to estimate the nutritional cost of controlling *Nardus* by grazing.

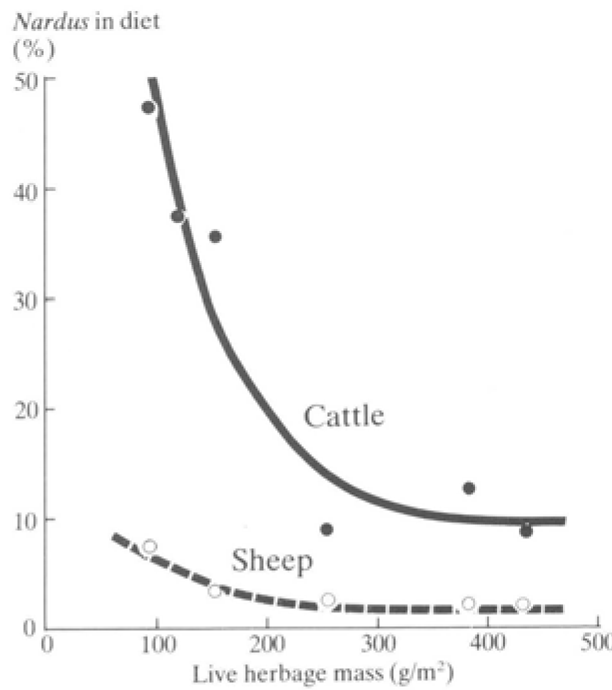

Figure 4

Relationship between live herbage mass on the inter-tussock areas and proportion of *Nardus* in the diets of sheep and cattle grazing *Nardus*-dominant pasture.

Molinia-dominant grassland has also been selected for study in phase 2. This community affords herbage of high feeding value during June-August (Table 6). In a two-pasture sheep system the sheep mainly graze improved pasture at this time of year. The herbage available on *Molinia* communities could be used for hill cattle. However, it is known that heavy grazing eliminates *Molinia* and it is proposed to investigate the level of utilisation compatible with retention of *Molinia*.

Table 6
***Molinia* grass heath. Diet organic matter digestibility (OMD) and intake of digestible organic matter (DOMI, g per kg $w^{0.75}$/d) by grazing sheep and cattle**

Date	Sheep		Cattle	
	OMD	DOMI	OMD	DOMI
June (1979)	0.768	52.7	0.746	80.8
July (1980)	0.757	69.0	0.741	78.0
August (1979)	0.737	48.0	0.693	69.4
September/October (1980)	0.681	43.2	0.657	56.2
Assumed maintenance requirements	—	25	—	44

The maintenance of a satisfactory species balance in mixed *Molinia-Calluna-Eriophorum* communities poses problems which merit investigation. For example, is it possible to maintain a given species balance by judicious manipulation of summer/winter grazing pressures with cattle/sheep? Also, if separate areas of *Molinia*-dominant or *Calluna*-dominant vegetation are established for summer and winter grazing respectively, how can these best be maintained? Work on these questions, however, is likely to be held in abeyance while the work on *Nardus* and *Molinia* communities proceeds.

HODGSON, J. and GRANT, S. A. 1981. Grazing animals and forage resources in the hills and uplands. In *The Effective Use of Forage and Animal Resources in the Hills and Uplands* (ed. J. Frame), pp. 41-57. *British Grassland Society Occasional Symposium No. 12.*

The influence of fluctuations in sward conditions upon net herbage production and utilisation in grazed swards (*Research objective 011*)

[JK, SAG, GTB, LT, EMS, VAD]

This is an interdisciplinary study involving members of both the Plants and Soils (research objective 106) and the Grazing Ecology Departments. The early studies examining the relationships between sward state and herbage growth rate, consumption and losses to senescence on continuously stocked pastures were largely completed by 1980. These have been followed by two kinds of investigation. Firstly, studies were made of the influence of management change on continuously stocked swards in crossover experiments, in which previously laxly grazed swards were subjected to hard grazing and vice versa. Secondly, studies of rotational grazing were carried out. These involved the investigation of carbon flux, growth rate and the balance between growth and senescence during both the regrowth and grazing down phases. From these experiments evidence was obtained which suggested that higher (seasonal) growth rates could be obtained by including a periodic release from grazing in otherwise continuously stocked pastures. This finding has been followed up during 1983. The results obtained from all these studies are described and discussed in some detail in the longer research report entitled 'Grazing management and pasture production: the importance of sward morphological adaptations and capony photosynthesis', see p. 119.

Herbage growth and utilisation of swards grazed by cattle and sheep

[JH, JCA, RchdHA, MMB, WGS, RT]

This study links with the early studies concerning net herbage production on continuously grazed swards (research objective 011). At the start of the period covered by this report there was limited evidence to suggest that the rate of net herbage accumulation is greater on swards grazed by sheep than on those grazed by cattle. However, the evidence was not unequivocal and in some cases the effect of animal species and of grazing pressure appears to be confounded.

Two field experiments were conducted on mixed species (*Lolium perenne* L., *Poa annua* L. and *Trifolium repens* L.) swards to examine the effects of cattle and sheep grazing alone or in combination on plant tissue and tiller turnover. Established swards of perennial ryegrass and white clover with variable contents of *Poa annua* were continuously stocked from May to September with either sheep or cattle or a combination of both. Animal numbers were adjusted frequently to maintain sward height as near steady state as possible.

In the first experiment swards grazed by ewes and lambs or by yearling female cattle were compared. The swards were maintained at sward surface height of 2.0-2.5 and 3.0-3.5 cm (sheep), and 2.0-2.5, 3.0-3.5 and 6.0-6.5 cm (cattle), equivalent to herbage masses of 1700, 2100 and 3100 kg OM/ha. Estimates of the rates of herbage growth, senescence and net production (growth minus senescence) were derived from measurements on individually identified tillers, and active meristematic points on clover, on three occasions during the season.

The study has now been terminated and written up as a PhD thesis (Arosteguy, 1982). The main findings were as follows:

Tiller populations were lower on cattle-grazed than on comparable sheep-grazed swards, and this was largely due to high rate of tiller disappearance on cattle-grazed swards. The differences in tiller density were in turn responsible for differences in growth and net production rate.

There were seasonal differences in the botanical composition of the diet selected by cattle and sheep, and these differences were reflected in the higher digestibility of the diets selected by sheep.

The herbage intake of both cattle and sheep increased with the level of herbage mass maintained, and sheep spent more time grazing than cattle. At the lower herbage mass sheep appeared to be better able to maintain rate of intake than cattle. There were similar proportions of under-grazed herbage on the plots grazed by the two species, although under-grazed areas on cattle swards were taller than those on sheep swards.

In the second experiment, swards continuously stocked by wether sheep or yearling cattle, singly or in combination, were maintained at sward surface heights of about 3.0 and 4.5 cm, equivalent to herbage masses of 1600 and 1900 kg OM/ha.

Tiller density in cattle-stocked swards was lower than in the mixed- and sheep-stocked swards, and observations confirmed higher rates of tiller disappearance under cattle grazing. The effect of the reduced tiller density on herbage growth and net production rates was partially confirmed. Sheep grazed alone or in combination selected diets with higher proportions of lamina than cattle, and the proportion of lamina selected by both animal species was lower when grazing in combination than when grazing alone. The proportion of the area left undergrazed was similar for the two species grazing alone and in combination. It is concluded that tiller density has a direct effect on the stability in the rate of herbage production, and that competitive, rather than complementary grazing activities are likely under intensive mixed-stocking systems.

AROSTEGUY, J. C. 1982. Herbage growth and utilisation on swards grazed by cattle and sheep. *PhD Thesis, University of Edinburgh.*

The interrelationships between sward structure and the ingestive behaviour and nutrient intake of grazing animals

(*Research objective 014*)
[JH, AJC, RchdHA, GTB, MMB, HKS]

This project was initiated to achieve a better understanding of the relationships between sward structure (particularly height and density), and herbage intake and grazing behaviour (grazing time, bite rate and bite size) and to study how they differ between animal species. The results of previous studies are contradictory and the effects of sward height and density on intake and grazing behaviour are often confounded.

In this work herbage intake and ingestive behaviour are measured in sheep and cattle grazing a range of single species gramineous crops which vary markedly in structure. Between May and October 1983, seven crops were grazed at Hartwood. The species included rye, barley, perennial ryegrass (two varieties) and red fescue; rye and the shorter perennial ryegrass variety were sown and grazed twice. Sward density was varied by sowing each crop at different seed rates. All crops were grazed at approximately the same (vegetative) growth stage. The plots were stocked at a fixed herbage allowance by both young wether sheep and young cattle.

Sward structure measurements made on the crops included sward height, herbage mass, sward bulk density, tiller density, canopy structure and leaf and tiller angles. Leaf area and leaf tensile strength will also be measured. Animal measurements included herbage intake, grazing time, bite rate, diet digestibility and diet composition. Potential voluntary intake and *in vivo* digestibility were measured for each crop in indoor pen-feeding studies using wethers.

Results from the grazing trials are currently being analysed. Grazing behaviour and herbage intake measurements will be related to sward conditions within each plot as it was grazed down. Results will then be compared for the different densities within a crop, and between crops.

The influence of the structure of forage crops upon nutrient intake and grazing efficiency of sheep (*Research objective 016*)

[RchdHA, JH, MMB, DRC, HKS]

The overall research programme concerned with the finishing of hill and upland crossbred lambs aims to obtain information which will facilitate the allocation and manipulation of feed resources before and after weaning. This involves controlling lamb growth rates and body composition changes more precisely in relation to time of marketing and market requirements. Forage crops have an important role in lamb finishing, but despite a good supply of apparently nutritious food, lamb performance is usually only moderate. At the start of the period covered by this report there was little objective understanding as to why this should be so, particularly concerning the factors influencing forage intake. This work was initiated to increase understanding of the relationships between forage intake and lamb performance, and it complements other studies on supplementation and on animal factors influencing lamb performance within the Organisation (research objectives 025 and 047).

A preliminary study showed that *in vivo* digestibility (OMD) of rape leaf and stem was at least as high as that of young grass. However voluntary intake by pen-fed or grazing lambs or adult wethers was little over half that expected with grass of such high digestibility. Intake of 'leaf' was higher than that of stem, and intake and digestibility of petiole exceeded that of lamina. Stem digestibility declined with grazed height (by about 0.25 percentage OMD units per cm), with intake declining at a faster rate. Further pen-feeding and grazing experiments in 1982 examined the effect of the differences in potential quality of these components of the rape crop on lamb performance.

Herbage intake digestibility trial indoors

Harvested forage from a rape crop was separated into lamina, petiole, upper stem (2/3) and lower stem and these components and the whole crop were chopped and offered *ad libitum* to individually penned lambs.

Measurements of intake indoors may not reflect true potential because of possible differential effects of chopping on intake of the components. However there were significant differences between the levels of intake of some components which were notably high for petiole and low for lamina (Table 7). OMD values were higher than previously quoted values for rape, particularly for petiole and upper stem.

There were no statistically significant additive effects on intake (OMI), digestibility (OMD) or digestible organic matter intake (DOMI) between components as evidenced by whole crop values, though the differences in DOMI illustrate the potential implications for performance of lambs grazing different components.

Table 7
The composition of rape herbage offered (% DM of whole crop cut to ground level) with digestibility (OMD), intake (OMI) and digestible organic matter intake (DOMI) (g/hd/day)

	Lamina	Petiole	Upper stem	Lower stem	Whole crop	SE with sig. of difference
Composition(%)	23.2	22.6	31.9	22.4	100	
OMD	0.84	0.89	0.86	0.77	0.84	0.007***
OMI	460	694	650	524	639	42.3**
DOMI	386	620	559	405	533	34.2***
IVOMD	0.82	0.92	0.88	0.77	0.88	—

** $p < 0.01$; *** $p < 0.001$.

The relationship between OMD and *in vitro* digestion (IVOMD) is different from that of highly digestible grass. In order to avoid bias in prediction of OMD of lambs grazing rape, and in subsequent estimations of intake, routine *in vitro* digestion procedures have used samples of rape from the two digestibility trials as standards.

The impact on lamb performance of anti-metabolites in forage particularly S-methyl cysteine sulphoxide (which acts as an intake depressant), is not yet known, since estimation of these compounds (by the Scottish Crop Research Institute) is not yet complete.

Grazing experiment

In collaboration with investigations into the effects of supplementation (research objective 047) and copper oxide therapy (research objective 029) the performance and intake of light and heavy Blackface lambs grazing 'leaf' was compared to that of similar lambs on 'stem' using a leader:follower system. Live-weight gains (g/head/day) of lambs (Table 8) grazing leaf were much greater than those on stem; in addition those of the light lambs were slightly greater than of heavy lambs, especially on leaf.

Detailed comment on the relationships between diet composition, intake, performance and crop utilisation awaits completion of chemical analysis. However the superior performance on leaf is consistent with the results of the indoor work.

Digestibility values (Table 8) were measured on hand plucked or clipped samples from the grazed horizon of the crop. Those for leaf (0.87) were very close to those of the indoor experiment. Stem (0.86) was close to that for harvested upper stem; this was expected since the portion of stem grazed equated roughly with the harvested upper stem.

Table 8
Grazing experiment on rape. Live-weight gain (LWG-g/head/day) and diet composition (% identified components)

	Leaf			Stem		
Lamb weight:	Light	Heavy	Mean	Light	Heavy	Mean
LWG	173	146	159	111	104	107
	Lamina	Petiole	Stem	Lamina	Petiole	Stem
Composition	49.3	46.6	4.2	0.2	5.5	92.6

SED between mean LWG: crop – 10.0, crop × wt. – 14.2.
95% of samples was identified: weeds were less than 1%.

The results suggest that there may be scope within Brassica crops to manipulate lamb performance and crop utilisation by varying crop morphology (i.e. leaf:stem ratio, or canopy height), and thereby influencing the quantity and quality of the forage eaten. More information on forage intake is required both for management and plant breeding objectives. It is intended in the first instance to examine diet composition and intake of rape, while varying the crop structure. Work has begun, in collaboration with the Animal Production Department, in which shorter term differences in diet composition were created by set-stocking or strip-grazing giant rape at varying herbage allowances. The herbage intake results will be of particular interest as previous research on grass swards has shown that forage intake from highly digestible material amply distributed in the grazed horizon leads to high daily intakes. However, this has not been observed in brassica crops.

Lengths of time spent grazing, ruminating and idling were measured to aid interpretation of intake using resistance band bitemeters and mini-recorders loaned from the Grassland Research Institute (see Electronics, p. 104). These were calibrated by visual observations which also enabled bite rates to be measured concurrently. Data analysis is incomplete but it is apparent that bite rates, lengths of grazing periods and time spent grazing were all lower than is found on grass swards.

Programme Unit 3

Factors affecting sheep performance in hill and upland environments

Control of ovulation rate and embryo loss in ewes by manipulation of pasture and animal factors at mating (*Research objective 017*)

[RGG, WFS, ADMS, DAS, AJS]

Effects of herbage mass between weaning and mating on intake and reproductive performance of hill and upland ewes in different body conditions

Studies have continued to examine the application of research findings based on hand-feeding experiments to grazing sheep. Herbage intake by Scottish Blackface and North Country Cheviot hill ewes on ryegrass/clover pasture in the pre- and post-mating periods has been shown to decline during the period of a synchronised mating, and to be particularly low after mating. The depression in intake at mating may be simply due to the disturbance associated with seeking out the ram and with mating, but the post-mating depression may be due to a decline in herbage digestibility, related to sward structure and the amounts of herbage available. A low post-mating intake can result in a reduction in live weight, and this has been shown to be associated in turn with a depression in reproductive performance. The management of swards for grazing during this period must therefore be designed to maintain as high a level of intake and digestibility as possible.

The high reproductive response to good nutrition prior to and over the mating period shown to occur in the North Country Cheviot breed on high levels of pasture over mating, particularly in ewes that are in an intermediate condition score range of 2.5/2.75 at 5 weeks before mating, has been observed consistently in experiments carried out over the last 5 years. Lambing rate to first mating of such ewes (1.50) is significantly greater ($P < 0.05$) than that of ewes in fat ($\geqslant$ score 3) and lean ($\leqslant$ score 2.25) condition (1.26 and 1.26). Furthermore, the increase has been shown to be greater in flocks grazing amounts of herbage just sufficient to maintain live weight and condition over mating (1.43 vs. 1.10 and 0.93), than in ewes grazing amounts on which all ewes gained substantially (1.54 vs. 1.40 and 1.47).

An experiment was set up to assess the impact of using two different grazing systems to provide high and low levels of herbage mass to ewes in the pre-mating period. In the first system, the low herbage mass was supplied by the residue left after ewes had grazed the same area at high herbage mass. Over two years of such a system, the ewes being offered the high herbage mass produced significantly more lambs to all matings (1.61) than did those being offered the residue (1.34) ($P < 0.001$). This was accompanied by a significant difference in litter size (1.64 vs. 1.45, $P < 0.05$). In the second grazing system the herbage masses offered to the ewes 5 weeks prior to mating, were generated by allowing two different periods of ungrazed regrowth after heavy grazing, namely 6 and 3 weeks. There was no significant difference in either lambing rate to all matings (1.44 vs. 1.27) or litter size (1.67 vs. 1.62).

There are two possible and complementary explanations for this result. First, that the lower lambing rate of the ewes on the higher level of herbage (1.44 as compared with 1.61) was a consequence of a decline in quality of intake as they ate into the stem and senescent material at the base of the deep sward. Second, that the higher litter size of the ewes on the lower level of herbage (1.62 as compared with 1.45) was a consequence of the higher quality of the leafy herbage available and ingested. Even at the low levels of herbage available in the latter case, some 4.5 cm declining to 2 cm, there appeared to be sufficient to at least maintain live weight until after mating.

Studies on the Border Leicester × Scottish Blackface (Greyface) upland ewe have also concentrated on these relationships between pasture management during the pre-mating recovery period and ewe reproductive response. The effects of saving pasture for use prior to and during mating, when herbage growth has usually ceased, have been examined. Pasture can be saved either by closing off an area or by stocking at a low enough level to allow more to accumulate than is being eaten. Saving by closing off does not appear to be very efficient as the resultant development of a deep sward of more than some 2500 kg DM/ha, i.e. some 10 or 11 cm in height, leads to a rapid depression in quality and an increase in senescent material at this wet time of year. In one experiment, the percentage of digestible organic matter (OMD) of saved pasture declined while being grazed at 18 ewes/ha from about 0.82 in late October to 0.77 in late November, while that of continuously grazed pasture stocked at 6 ewes/ha over the same period rose from 0.78 to 0.80.

Saving pasture has not led to any improvement in reproductive performance where herbage amounts have been maintained above 1500 kg

DM/ha until after mating. It appears that this is the threshold amount below which live weight starts to decline at this time of year. Such a relationship is, however, dependent on the structure of the grazed sward, the amount and digestibility of the herbage and the appetite of the ewe. There is evidence that live weight will begin to decline when digestibility falls below 0.75 and intake falls below 800 g DM/day.

Saving pasture has proved useful in restricting the development of excessive ewe body condition before mating, which is a consequence of the increased stocking rate associated with closing part of the available grazing for later use. Studies have shown that too high a level of condition before mating can depress reproductive performance, particularly by increased barrenness. A decline in lambing rate with increasing condition at mating has been demonstrated in Greyface ewes (score 3 = 1.91; score 3.25 = 1.74; score 3.5 = 1.62). A similar dynamic response in this crossbred to that demonstrated previously in the hill breeds, has been shown to take place. Ewes in intermediate body condition prior to flushing on saved pasture exhibit a greater reproductive response than ewes in both leaner and fatter condition. Care must therefore be taken to avoid getting ewes too fat prior to mating.

Comparison of reproductive performance in East Friesland × North Country Cheviot ewes with that of pure-bred North Country Cheviot ewes on the same pasture

Part of a flock of North Country Cheviot (NCC) ewes was mated to East Friesland rams to produce cross ewes (EF × NCC) for studies on extended lactation. Over 2 years, comparison has been made of the reproductive responses of the pure-bred and cross Cheviot ewes in a study on the optimisation of pasture-use by ewes in different body conditions in the pre-mating period. Two levels of herbage standing crop (equivalent to high and maintenance levels of nutrition) were provided over the 5 weeks prior to a synchronised mating, and live-weight and body condition responses were monitored. Data were available from the gimmer stage of two age groups of cross ewes and from the second year's production of the older age group, giving a total of 90 ewe records. These were compared with their pure-bred contemporary age groups, which gave 106 ewe records. All ewes were mated with NCC rams.

Between-breed differences in body condition score are likely to be related to differences in the deposition of internal and subcutaneous fat reserves. Since the cross ewes had consistently lower scores than did the pure-bred ewes, comparison at the same condition score is not justified. Pre-mating live weights were very similar in both cross and pure-bred ewes, ranging between 54 and 66 kg according to age and the level of herbage offered. Cross ewes had substantially higher lambing rates per ewe mated than did pure-bred ewes at all three lambings.

The overall mean lambing rates were 1.68 and 1.27 for the EF × NCC and NCC ewes respectively, associated with pre-mating mean live weights of 60.8 and 60.2 kg. Lambing rate in the EF × NCC ewes was less affected by live weight and therefore by herbage availability than it was in the NCC ewes. This is shown from the regression of mean lambing rate (LR) on mean live weight (LW) in the above six groups of ewes in each breed class. In the EF × NCC the following equation was derived:

$$LR = 0.0078LW + 1.2033$$

while in the NCC the equation was:

$$LR = 0.0283LW - 0.4351$$

From these equations, a change in live weight of 5 kg can be expected to result in a change in lambing rate of only 4 percentage units in the EF × NCC compared with 14 percentage units in the NCC.

Within limits, the reproductive performance of EF × NCC ewes may be more consistent than that of NCC ewes, when in an environment with variable pre-mating nutrition.

Establish reproductive potential in ewes by nutritional control of growth and development (*Research objective 018*)

[RGG, JMD, WFS, ADMS, DAS]

Previous studies have suggested that reproductive potential in mature ewes is influenced by nutritional standards during the juvenile growth stage, and that the response achieved is dependent on an interaction with nutritional standards in adult life. Potential fecundity appears to be positively correlated with body size. Although body size is generally a function of nutritional standards throughout life, the evidence suggests that it is not just the achieved size *per se* that is important but, more specifically, the nutritional circumstances which determine size have a profound direct effect at certain specific stages of development on subsequent reproductive performance.

Present evidence is largely based on the effects of treatments imposed during the first 12 months of life and, particularly, the later stages of this period. These treatments were possibly too insensitive and imposed too late to measure the full extent of the effects. The period of greatest sensitivity is more likely to be during the embryonic stage and/or in early post-natal life. Nutrition during the first summer of life has also been shown to be of greater importance to growth (and perhaps to development) than nutrition during the following winter.

An experiment has therefore been set up on House o' Muir to study whether different levels of nutrition in defined developmental stages can produce differences in reproductive potential in animals which have achieved the same adult size. It is also planned to study the extent to which such differences in potential can be realistically achieved in different adult nutritional environments.

The effects of nutrition in two specific 100-day periods, the last 100 days of pregnancy and the first 100 days of life, are being examined.

The effects of nutrition on plasma FSH, LH, prolactin and progesterone and on ovulation rate and lambing rate (*Research objective 019*)

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

Effects of level of feed intake on endocrine status and reproductive performance

The reproductive performance of Cheviot ewes is dependent on pre-mating food intake (Gunn *et al,* 1979) as well as body condition at mating (Gunn and Doney, 1979) but the underlying endocrine mechanisms through which nutritional factors affect reproduction are not known. An understanding of these would permit more precise control of reproduction through conventional nutritional manipulation and perhaps by artificial means such as manipulation of the endocrine state by drugs and antibodies. This experiment was designed to investigate in detail, the profiles of LH, FSH and prolactin during the luteal and follicular phases of the cycle prior to mating.

Two groups of 20 Cheviot ewes were fed to achieve condition scores of 2.0 and 2.5 respectively by 4 weeks before mating at a synchronised oestrus in November. Animals in the low condition group were then fed *ad libitum* and the remainder were given a maintenance ration so that they were in similar levels of condition but had different intakes at mating. Thereafter, half of the ewes of each group were fed *ad libitum* and the remainder given a maintenance ration until slaughter 3 weeks later.

The mean ovulation rates for ewes with high and low intakes before and during mating were 1.95 and 1.40 respectively. The difference was reflected in the mean numbers of embryos present at slaughter, 1.75 and 1.00 respectively. The rate of ova wastage was not affected by level of post-mating intake.

LH, FSH and prolactin profiles during the luteal phase of the cycle prior to mating were not affected by nutritional treatment. During the 3 days prior to oestrus onset, ewes which had the higher intake and higher ovulation rate had higher circulating FSH and prolactin levels and a higher LH pulse frequency (basal LH secretion is typically low with temporary 2 to 5 fold increases, or pulses, occurring at intervals of 30 min to 8 hr). Progesterone levels following mating were not affected by pre-mating intake but were affected by contemporary nutrition, being higher in animals on the lower intake.

The results indicate that intake influences ovulation rate and reproductive performance through changes in LH, FSH and prolactin in the 3 days before mating. The absence of differences in levels of these hormones earlier in the cycle suggests that intake affects the numbers of follicles that rupture rather than the number that grow to an ovulatory size.

GUNN, R. G. and DONEY, J. M. 1979. Fertility in Cheviot ewes. 1. The effect of body condition at mating on ovulation rate and early embryo mortality in North and South Country Cheviot ewes. *Animal Production*, **29**, 11-16.

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. *Animal Production*, **29**, 17-23.

Reproductive performance and endocrine status of Greyface ewes in high condition scores at mating

Ovulation rate and lambing rate of Greyface (Border Leicester × Scottish Blackface) ewes are both positively related to body condition at mating. Consequently, it has been recommended (MLC, 1981) that upland ewes should be in a condition score of 3.5 at mating. However, it has long been recognised that excessive fatness can depress reproductive performance and recent studies have shown that improvement of body condition above a score of around 3.0 may be counterproductive. The aim of this experiment was to compare the reproductive performance and associated endocrine status of ewes in condition scores of 2.75 and 3.5 at mating.

Before mating, at a synchronised oestrus in November, the ewes in moderate condition were given a live-weight maintenance ration but animals in the very high condition group were increasing their body condition until mating and were being fed *ad libitum*.

The mean ovulation rate of ewes in moderate condition was lower than that of the very fat ewes (2.33 v 3.36). While this difference was to some extent reflected in the mean potential litter size/ewe pregnant (1.80 v 2.00) the potential number of lambs/ewe put to the ram was higher for ewes in moderate condition (1.42 v 1.10).

The fertility of ewes of all groups was less than normal because they were mated at a synchronised oestrus following prostaglandin $F_{2\alpha}$ injection. The low potential lambing rate/ewe put to the ram of the very fat ewes, compared with that of ewes in moderate condition, was attributable to two factors. Firstly, of the ewes that conceived, very fat animals had a higher rate of ova wastage (41% v 23%). A second, unexpected, factor was the failure of four of the animals in this category to show oestrus following prostaglandin injection, although only one of these ewes failed to ovulate.

A subsequent experiment was designed to determine whether the reduction in potential lambing rate was a function of the high level of body condition or high intake. Endocrine profiles of ewes in different body condition groups (> score 3.5 or 2.5/2.75) by 4 weeks before mating were investigated in the post-mating period in order to determine whether or not luteal function and luteotrophic hormone secretion was altered by body condition.

Two of the ewes in moderate condition were not mated. Ewes of the very fat group had only a marginally higher ovulation rate (2.00 v 1.88). While the difference in the corresponding potential mean litter size/ewe lambing was greater (2.00 v 1.65) the higher incidence of returns to service and embryonic death in the very fat ewes resulted in a very similar number of lambs born/ewe mated (1.58 v 1.56).

It is concluded that while the advantages of good body condition at mating and of flushing prior to mating are not in doubt, the feed inputs required to achieve condition scores of the order of 3.5 are not necessarily justified by the associated improvements, if any, in ovulation and lambing rates. Indeed, feeding good condition ewes at a high level so that they can achieve an even higher level of condition at mating (say 3.5 or more) can be counterproductive.

The pre- and post-mating endocrine profiles of these animals are being determined.

MEAT AND LIVESTOCK COMMISSION. 1981. *Feeding the ewe*. MLC, Bletchley.

Effects of body condition of ewes at mating on their endocrine status, follicle development and ovulation rate

In a preliminary study (HFRO Biennial Report 1979-81 pp. 5-7) body condition at mating was found to affect circulating levels of LH, FSH and prolactin in ewes around the oestrus period, as well as ovulation rate. The aim of this experiment was to investigate the hormone profiles in detail, not only in the days immediately prior to ovulation, but also in the preceding luteal phase of the cycle.

Two groups of 11 cast Scottish Blackface ewes were fed to achieve condition scores of 2.75 or 1.75 and then offered a live-weight maintenance ration throughout the experimental period. Blood samples were collected from all ewes at 15 minute intervals for a 10 hour period during the luteal phase and an 8 hour period in the follicular phase of the cycle following an injection of prostaglandin $F_{2\alpha}$. Samples were also collected at 3-hour intervals during the first day of oestrus. All samples were analysed for FSH, LH and prolactin.

The ewes were slaughtered at 11 to 14 days after oestrus and ovaries recovered. Ewes of the high condition group had more large ($\geqslant$ 4 mm) follicles (3.1 v 1.7) and a higher mean ovulation rate (1.8 v 0.9).

No consistent differences with condition were recorded in LH profiles but during both luteal and follicular phases of the cycle prior to oestrus, circulating levels of both FSH and prolactin were significantly higher in ewes in good condition. There were no differences with ovulation rate in the levels of these hormones.

During early oestrus, prolactin levels were higher in animals in good condition but levels of LH and FSH were similar for the two treatments.

At this time, FSH levels were lower in ewes with multiple ovulations than in those with single ovulations while the opposite trend was observed in prolactin levels and LH levels were similar for the two categories.

It appears that circulating levels of FSH and prolactin were affected by the animals' body condition. The absence of a relationship between ovulation rate and hormone values indicates that the effects of condition on ovulation rate were not directly mediated through these changes in hormone profiles. However, the development of greater numbers of large follicles in ewes in good condition may have been stimulated by the higher FSH and prolactin levels recorded and this may have resulted in a higher ovulation rate in the ewes in good condition. Thus body condition may affect the ovulation rate of ewes through changes in the number of follicles capable of rupturing rather than through changes in the proportion of large follicles induced to rupture.

The biological significance of the higher prolactin concentrations in ewes in good condition during oestrus is not clear, but it is possible that this difference, and the difference in FSH concentrations with body condition, are merely a function of changes in other hormones at this time and are not directly involved in the determination of ovulation rate.

The role of prolactin in the control of follicle growth and development (*Research objective 020*)

[SMR, IDL and ASMcNeilly]

In previous experiments, circulating prolactin levels were found to be affected by intake and body condition. While the role of prolactin is not clear, these observations suggest that it may be involved in the processes of follicle growth and development and, perhaps, in the determination of ovulation rate. The aim of this work was to investigate the role of this hormone by suppressing secretion for a period of at least two oestrous cycles, the approximate time required for small antral follicles to grow to maturity, and to determine the effects of this treatment on endocrine status, follicle function and ovulation rate.

Two groups of 10 Scottish Blackface ewes with a uniform condition score of 2.75/3.0 were used. During the luteal and follicular phases of the cycle prior to a synchronised oestrus blood samples were collected from all ewes at 15 minute intervals for periods of 8 to 10 hours for the purposes of LH, FSH and prolactin determinations. For 30 days before this oestrus, and between oestrus and slaughter, 10 to 14 days later, ewes of one group were injected intramuscularly, twice daily, with bromocriptine, a prolactin-suppressing drug. Ewes of the other group were injected with the carrier solution only.

At slaughter, the ovaries were recovered and follicles removed, counted, measured and divided into constituent cell types. These were cultured to determine their LH binding and steroidogenic capacities.

Treatment with bromocriptine did not significantly alter the mean interval between prostaglandin injection and oestrus onset (bromocriptine: 38.1 hr; control: 34.1 hr). There was a trend towards a lower mean ovulation rate in control ewes (bromocriptine: 1.80, control: 1.33). Luteal function, as measured by circulating progesterone levels was normal in both groups of ewes. Hormone determinations are not yet complete.

Ovulation rate and lambing rate of ewes passively immunised against testosterone (*Research objective 021*)

[SMR, JMD, RGG, GG, WFS, ADMS, IDL, DAS and BAMorris]

While the reproductive response of ewes actively immunised against steroids is known to be dependent on live weight, it is not known whether or not the response of ewes to passive immunisation is similarly altered by live weight or body condition at mating. Indeed, it has not yet been demonstrated that the lambing rate of ewes of hill and upland breeds such as Scottish Blackface and Greyface can be improved by this technique. This experiment was designed to investigate the response of ewes of these breeds to immunisation against testosterone when in poor or moderately good condition at mating.

Sixty draft Scottish Blackface and 37 draft Greyface ewes were allocated to one of 4 initially similar groups and fed to achieve condition scores of 2.75/3.0 (2 groups) or 1.5/1.75 (2 groups) by two weeks before mating at a synchronised oestrus in December. One week before mating, ewes of one group in each condition score category were injected intravenously with 25 ml of anti-testosterone serum (titre = 1:100,000) while the others were injected with a similar volume of 'blank' serum obtained from non-immunised wethers. The anti-testosterone serum was collected from other sheep which had been 'vaccinated' against testosterone so that they produced antibodies to this hormone.

Ovulation rates were determined by laparoscopy approximately a week after mating. Ovulation rates were probably under-estimated, particularly in the ewes in good condition because of difficulty of observation caused by large amounts of internal fat. However, the recorded ovulation rate of ewes of both breeds with condition scores of 2.75/3.0 was about 25% higher in treated animals. There was no consistent increase in the recorded ovulation rate of ewes in poor condition.

Despite higher estimated mean ovulation rates, immunised ewes in good condition did not have an improved lambing performance. Mean litter sizes of Greyface ewes in good condition which lambed to the first mating were 1.71 and 1.80 for treated and untreated animals, respectively. Corresponding values for Blackface ewes were 1.75 and 1.73, respectively. Immunisation resulted in a very small improvement in lambing rate in ewes in poor condition. There was no difference between treated and untreated ewes in the incidence of returns to service (20%).

It appeared from this experiment that the reproductive performance of ewes of these breeds was not improved by immunisation against testosterone despite the fact that the mean ovulation rate of ewes in good condition was increased by the treatment. However, the accuracy of the ovulation rate estimates was not satisfactory and the possibility cannot be ruled out that embryo survival rates may have been affected by the laparoscopy procedure. For this reason another experiment of similar design was initiated using only Blackface ewes, with a similar range of condition scores and a slightly higher dose of antiserum (33 ml of 1:100,000). Control animals were not injected with any serum. In this experiment ovulation rate was determined by slaughtering a proportion of the ewes (50 from each treatment group) at about 55 days after mating. The remaining animals (40 from each group) were allowed to lamb.

In this experiment the treatment induced improvements of about 50% in the potential lambing rate of ewes in poor to moderate condition (up to condition score 2.5) but the increase was much smaller in ewes in good condition which generally had multiple ovulations without immunisation against steroids. No ewes had more than 3 ovulations. Results from this experiment are discussed at greater length in the longer research report on p. 131. The nutritional consequences of an increased litter size in ewes in low or moderate condition remains to be determined.

Lactation patterns of various genotypes as affected by herbage intake on different swards *(Research objective 022)*

[JMD, WFS, ADMS, DAS]

The project on lactation and lamb growth, for which the overall objectives were described in the HFRO Biennial Report 1979-81, pp. 7-9, involves studies on the factors affecting milk production by the ewe (research objective 022), the influence of variation in milk intake on the level and pattern of herbage intake by the lamb in the pre-weaning period and the relationship between intake of milk or herbage and live-weight gain (research objective 023) and on the consequences of intake and growth during the lactation period on subsequent intake and growth after weaning (research objective 025).

Earlier work on the effect of genotype on lactation yield and pattern made use of crossbred ewes, resulting from the mating of a dairy-type sire (East Friesland) with Scottish Blackface ewes. Results from a number of studies had shown that this crossbred tended to produce a higher peak lactation and a more sustained level of production in late lactation than did the pure Blackface. The difference in milk production appeared to be associated partly with a corresponding difference in recovery of live weight during lactation and partly with a difference in herbage intake, especially during the declining phase of lactation. The magnitude of differences was found to depend on the quantitative and qualitative characteristics of the grazed pasture.

Studies on the use of a dairy-type sire for the production of crossbred ewes were extended to the North Country Cheviot as the maternal breed. A small-scale preliminary trial with this cross in its first lambing season suggested that the advantages over the pure Cheviot in milk production may not be as marked as in the cross involving the Blackface.

A further study was carried out in 1983 using ewes of three breed types — North Country Cheviot (NCC) (4 ewes with twins, 6 with singles), East Friesland × NCC (EFC) (6 twin, 6 single) and Scottish Blackface (SBF) (5 twin, 5 single). The ewes were mated to Dorset Down rams at Glensaugh after a synchronized oestrus and transferred to a prepared sward at Hartwood immediately after lambing in early May. The pasture was a first year reseed with a ryegrass and clover mixture. It was intended to produce and maintain a sward of around 1600 kg DM/ha and a sward height of around 5 cm at the beginning of the grazing period and to maintain this character throughout lactation and, after removal of the ewes, for a further period when the lambs would continue on the same area. Climatic conditions in the late spring and summer combined with low plant density and lack of clover establishment resulted in a herbage availability which did not reach the minimum desired level until after the ewes were weaned at 11 weeks post-partum.

Milk production of the ewes was measured weekly, faecal output was estimated continuously by a chromic oxide dosing/sampling technique and the digestibility of the grazed herbage was estimated weekly by *in vitro* analysis of extrusa samples from oesophageally fistulated ewes grazed with the experimental flock. Live weight and body condition were recorded weekly.

The poor pasture profile and semi-drought conditions were reflected in the milk production results. Instead of following the more usual pattern of an increase in yield to a peak at around 4-6 weeks the yields declined continuously from the time the ewes were transferred to the pasture. There were no significant differences between breed types at any stage of lactation although the yields of the EFC, especially rearing twins, were marginally higher than the NCC and the yields of SBF ewes were, in general, below both other breeds. By week 10 the mean yield of EFC ewes was down to 1.4 and 1.2 kg/day, respectively, for twin- or single-suckled ewes and all others were below 1.0 kg/day. Herbage organic matter (OM) digestibility declined from 0.82 in May to 0.79 in July. The results from the analysis of faeces samples are not yet available so the extent to which the lactation patterns were affected by intake constraints is not known. Ewe live weights fell in early lactation and had not, in general, recovered to the immediate post-lambing level by weaning. Hence the primary objective of this phase of the study, to compare breed types under optimum grazing conditions was not achieved.

Interrelations of milk and herbage intake and of growth in lambs (*Research objective 023*)

[JMD, ADMS, DAS, WFS]

Earlier reports have described the development of a field system for controlling individual milk intake by artificially-reared lambs at pasture. In 1982 a group of 24 male lambs of several breed types was obtained over a period of 4 days by removal of a twin lamb from non-experimental ewes. These were trained to the artificial rearing system and allocated to one of 4 groups which were offered either a sustained (S) or a normal (N) lactation pattern on a sown ryegrass/clover sward (R) or on an *Agrostis*/*Festuca* hill pasture (H). The lactation patterns were intended to provide a peak mean intake of 2 kg/day at 4 weeks of age in all groups (actual mean 1.9 kg/day on the sown pasture and 1.7 kg/day on the hill pasture). By the 12th week, when the experiment ended, the mean daily intakes were 1.4 kg and 0.2 kg, by the S and N groups respectively irrespective of pasture type. Total faecal collections were made on 4 days of each week on all lambs from 4 weeks of age.

In all groups faecal dry matter output increased progressively from the 4th to the 12th week and the H groups tended to have a greater output (non-significant) than the R groups in most weeks. Herbage digestibility as estimated by analysis of faecal nitrogen did not differ significantly in the two locations. Irrespective of location, the apparent herbage intake of the N lambs was consistently higher than that of the S lambs confirming the negative relationship between milk and herbage intake found in previous studies. The relationship of live-weight gain to the components of intake differed slightly to the previous results. In both studies there was a significant regression on both total intake from milk and herbage and on milk alone. In the present experiment however, a greater response of herbage intake to a reduction in milk availability resulted in a lower relationship between live-weight gain and milk intake. It is possible that the differences were associated with differences in herbage mass rather than sward composition and further study is planned to investigate this aspect.

In 1983 this project was combined with the study of ewe breed effects on lactation described above (research objective 022). The herbage intake of all male lambs in the experiment was measured by total faecal collection from the age of 8 weeks until weaning (and for a further 4 weeks after weaning). Estimates of herbage intake were calculated on a basis of intake digestibility as measured by the analysis of extrusa samples from the fistulated ewes and, together with milk intakes in the same period, were converted to a common basis of mean daily energy intake. The provisional estimates of milk, herbage and total energy intake (MJ/d) during the last 3 weeks before weaning at 11 weeks of age are shown in Table 9 together with mean weaning weight.

These results suggest that irrespective of genotype, twin lambs did not compensate for a lower milk intake by a higher herbage intake in late lactation nor was there any consistent pattern of compensation for differences in milk intake between breeds. The results are, of course, confounded by differences in lamb genotype and, perhaps by behavioural differences associated with maternal differences of ewes grazing as a mixed flock. Within breed, however, they do support the previous results on the importance of milk supply as a component of total intake and a determinant of weaning weight, even in late lactation.

Table 9
Energy intake (MJ/d) from milk (M), herbage (H) and both sources (M + H) in weeks 8-11 post-partum and weaning weight (W) (kg) in week 11

	Twin-reared				Single-reared			
Breed of ewe	M	H	M+H	W	M	H	M+H	W
NCC	1.99	5.54	7.53	19.5	5.75	7.32	13.07	26.7
EFC	3.08	6.19	9.27	22.5	6.71	5.36	12.07	27.0
SBF	2.36	6.07	8.39	17.3	4.65	6.21	10.86	23.3

The endocrine status of lactating ewes in relation to milk production and associated nutrient partitioning (*Research objective 024*)

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

The endocrine mechanisms which determine whether nutrients are converted to milk or tissue in the ewe are poorly understood. While the actions of many of the hormones involved have been investigated individually, the ways in which they interact and are affected by lamb number, diet composition, ewe breed and season are not known. The aim of this work was to investigate the blood hormone and metabolite profiles in ewes rearing single or twin lambs at different times of year (January and April). It was anticipated that the different circulating concentrations of prolactin associated with season would aid the interpretation of the role of this and other hormones in milk production and nutrient partitioning.

Ewes rearing twin lambs had higher milk yields and a slightly lower milk fat content than ewes rearing singles. Overall this was not associated with a greater rate of loss of body condition although live-weight losses were greater in the twin-rearing group. Mean plasma concentrations of glucose, non-esterified fatty acids, total protein, albumin, urea and prolactin were not affected by litter size but 3-hydroxybutyrate concentrations were higher and insulin concentrations were lower in ewes rearing twins.

While there was no significant difference in milk yield, milk composition or blood metabolite concentrations with season, mean insulin concentrations were found to be lower in April and mean prolactin concentrations were higher.

The results indicate that ewes rearing twin lambs utilise a greater proportion of their body fat reserves for milk production compared with ewes rearing single lambs, partly due to alteration of circulating insulin levels. While the increase in mean 3-hydroxybutyrate concentrations with litter size indicate that fat metabolism was affected, the plasma protein and urea concentrations suggest that protein metabolism was not affected by the number of lambs reared. The absence of any difference in milk yield with season suggests that differences in circulating prolactin concentrations do not affect milk production or nutrient partitioning, at least at the relatively high levels investigated. Measurements of growth hormone, cortisol, thyroxine and tri-iodothyronine are in progress.

Growth and body composition of lambs on grass and forage crops in relation to intake and growth before weaning (*Research objective 025*)

Intake and growth of the lamb after weaning
[JMD, ADMS, WFS, DAS, ARS]

The lambs described in research objective 023 (p. 46) remained on the same pasture after weaning, with suitable adjustment of grazing area to maintain the desired pasture profile. Herbage intake estimation was continued by total collections of faeces on 4 days/week for a further 4 weeks. Provisional estimates of mean daily energy intake over this period are given in Table 10.

Table 10
Mean energy intake (MJ/day) in the 4 week period after weaning

Breed of ewe	NCC	EFC	SBF
Twin lambs	7.14	8.39	7.49
Single lambs	10.30	8.01	8.44

By comparison with Table 9 it can be seen that mean herbage intake had increased considerably from that in the equivalent pre-weaning period.

The post-weaning increase in herbage intake was significantly higher ($p < 0.05$) in single lambs than twins. However, with removal of milk supply, the total intake of all lambs fell and the absolute fall was greater in the single lambs due to the difference in milk supply in late lactation. The differences in post-weaning increase of herbage intake may have been associated either with the absolute levels of pre-weaning intake or with the live-weight differences which were, themselves dependent on pre-weaning intake. In either case it appears that live weight at weaning may be a determinant or an index of potential intake and of associated growth after weaning.

In 1982 this factor, live weight at weaning, was incorporated into a study of the finishing of lambs on a forage crop (rape) after an intermediary period on pasture with high or low herbage mass. Scottish Blackface lambs were selected in two weight classes at weaning — light (18-22 kg) or heavy (27-32 kg). Lambs were sent for slaughter on reaching a minimum weight of 37.5 kg and a condition score of 2.75. Two further factors were involved in this study. The lambs were derived from two distinct strains of the breed and half of the lambs were offered 400 g/day of a rolled barley supplement to the forage crop. Supplement treatment had no effect on the results but the source of lambs had a significant effect on the proportion of lambs reaching a suitable standard of finish irrespective of weight. This aspect will require further study and analysis. In relation to initial weight class, irrespective of other factors the results clearly showed the effect of weaning weight on the ability to finish in such a system. It was found that 33.3% of the heavy lambs finished before the forage crop was exhausted as compared with only 0.8% (1 lamb) from the light-weight class. No measurements of intake were made but the results do tend to confirm the importance of weight at weaning on subsequent live-weight gain.

Effects of zeranol (Ralgro) on the growth, performance and blood chemistry of pasture finishing lambs
[SMR, JMD, DZ, WFS, ADMS, IDL, DAS]

While the effects of growth promoters on ruminants has been extensively investigated, little is known of the effect of zeranol on the growth of lambs finished on pasture and in particular, the effect of supplementary feeding on the response to this substance is unknown. The endocrine mechanisms through which the effects are mediated are imperfectly understood. The aim of this work was to investigate the endocrine and blood metabolite changes associated with zeranol implantation in lambs finished on grass with or without supplementary feed.

Forty lambs aged 12 weeks and with a mean live weight of 31 kg were weaned and allocated to initially similar treatment groups: PZS (pasture + zeranol + supplement), PZ (pasture + zeranol), PS (pasture + supplement) and P (pasture only). They were all grazed on the same pasture for 9 weeks and then slaughtered. Animals were weighed and blood samples were collected at weekly intervals. These were analysed for glucose, non-esterified fatty acids, urea, albumin, insulin, growth hormone (GH), thyroxine (T_4), tri-iodothyronine (T_3), cortisol and prolactin.

The mean daily live-weight gain of untreated lambs on pasture (166 g/d) was only slightly improved with either supplement (167 g/d) or zeranol (185 g/d) alone but there was a significant interaction between these factors which resulted in a very much higher daily gain in lambs of the PZS group (234 g/d).

It was found that most of the supplement given to lambs of the PS group simply replaced a proportion of the herbage intake. In contrast, lambs of the PZS group consumed about 65% more herbage than those of the PS group and had a significantly greater intake than lambs of any other category. There was no evidence that the greatly increased growth rate of PZS lambs was attributable to increased efficiency of utilisation, i.e. the effect of zeranol and supplement on growth was a function of increased intake only.

Blood metabolite concentrations were affected more by the age of the lamb than by the treatments but the recorded profiles indicate that both protein and energy metabolism were altered by zeranol and supplement.

During early parts of the treatment period, mean circulating levels of the protein anabolic hormones, insulin and GH, were significantly higher in lambs of the PZS group than in those of any other groups. Prolactin secretion, which is altered by feed intake and body condition, was unaffected by zeranol or supplement. Similarly, concentrations of cortisol, a hormone known to affect protein metabolism, were also unaffected. While T_4 and T_3 concentrations were not affected by zeranol treatment, T_4 levels were higher in lambs given supplement and T_3 levels were reduced compared with those of animals on pasture only. It is possible that changes in thyroid hormone status enhanced the response to zeranol in lambs given supplement through effects on metabolic rate.

The determination of foetal numbers in pregnant ewes

(*Research objective 027*)

[AJFR, IRW, ARS, TJM]

Recent trials with real-time ultrasonic scanning equipment have shown this to provide a safe, accurate and rapid means of determining foetal numbers in pregnant ewes. The technique can be used successfully between 50 and 100 days of pregnancy which, given the normal spread of gestational ages, means that it can be applied in flocks at about 12 to 14 or 15 weeks after the beginning of mating. Accuracies of diagnosis of pregnancy of more than 99%, of differentiation of barren, single- and multiple-bearing ewes of 98%, and of determination of actual foetal numbers of 97% can be achieved in practice at a scanning rate considerably in excess of one ewe per minute. The principal benefits of the application of this technique to commercial sheep flocks include savings in feed costs, reduction in both lamb and ewe mortality and the simplified and more efficient management of the flock at lambing. The use of the technique is considered more fully in the report on p. 141.

Economic assessment of the benefits following detection of foetal number in sheep

The potential savings following detection of foetal number in a sheep flock are based on the identification of barren ewes to save late pregnancy feeding and the identification of single-, twin- and triplet-bearing ewes so that late pregnancy feeding can be matched to their separate requirements. Single-bearing ewes are often overfed in late pregnancy when the anticipated flock lambing percentage is greater than 100, identification of single-bearing ewes can therefore save feeding costs. Twin- and triplet-bearing ewes are often underfed in late pregnancy and, as a consequence, a proportion of these lambs die in the first few days after lambing because they are too small to survive. Identification of multiple-bearing ewes allows late pregnancy feeding to be more closely matched to their requirements so that multiple lambs are heavier at birth with a better chance of survival and so that the incidence of metabolic disorders, such as pregnancy toxaemia, is reduced. A further advantage of the identification of multiple-bearing ewes is that they can be given special attention at lambing to reduce the number of ewe and lamb deaths that occur with unattended, difficult births. The savings therefore come from lower feeding costs, better lamb survival leading to higher weaning percentages and more lambs sold and fewer ewe deaths. Consequently fewer lambs are retained as flock replacements and more lambs are sold or, if replacement stocks are not kept, fewer replacement gimmers are bought in. A further potential benefit in some flocks is that ewes identified as barren at an early stage can be sold at a time when ewe prices are near their maximum.

An economic assessment of some of these effects on flock performance has been carried out by use of a specially written computer program.

Results for hill flocks indicate that gross margin (GM) can be increased by up to £3.50 per ewe if scanning is used to identify bearing types and if the savings referred to above are applied. The greatest increase is with flocks lambing around 120% and the increased GM is made up of £1.30 from reduced lamb losses, £1.50 from reduced ewe losses, £0.70 from saved feed. Increases in GM in excess of £1.50 per ewe can be achieved for flocks with lambing percentages above 100.

Results for upland flocks with lambing percentages between 120 and 160 indicate that increases in GM of between £3.50 and £4.80 per ewe can be achieved. Increases for lowland flocks with lambing percentages in the range 160 to 200 are between £4.80 and £0.29 per ewe, the smallest increase being for flocks lambing at 200% where a very high proportion of the flock will be carrying two lambs so savings are minimised. It has also been assumed for these intensively managed flocks that no savings through reduction of ewe and lamb losses can be achieved.

A realistic charge for a commercial scanning service, based on the experience of one season, appears to be 50p per ewe, assuming that more than 200 ewes per day are scanned. In general, flocks lambing between 120% and 180% gain the greatest economic advantages from the early detection of foetal number.

The shearing of housed pregnant ewes

[RbnHA, AJFR, IRW]

In recent years there has been an increasing interest in this country in the shearing during winter of housed pregnant ewes. Of the several advantages claimed for this practice the principal one is that it results in an increase of about 10% in lamb birth weight. A study of the reports of experiments conducted on this subject does not provide any clear evidence of the physiological basis of this response, although it has been postulated by some workers that the effect is due to the alleviation of heat stress in unshorn housed ewes. The published reports also indicate, however, that ewes have generally been fed hay or silage *ad libitum* and that in those experiments in which roughage intakes have been measured those of the shorn ewes have invariably been greater than those of the unshorn animals. The stimulating effect of shearing on appetite is well documented.

Two experiments were conducted at Sourhope in successive years with respectively 112 and 194 Scottish Blackface ewes to study the effects of shearing during pregnancy on lamb birth weight and subsequent growth rate and in which measurements indicative of nutritional state and heat stress were made. The ewes were shorn in late January shortly after housing and commenced lambing in mid-April. In all cases balanced groups of shorn and unshorn ewes received the same restricted quantities of feeding.

All groups of shorn ewes showed a mean live-weight loss of some 2 kg (after making due allowance for the weight of wool removed) shortly after shearing relative to the weight change of the unshorn ewes. Thereafter live-weight differences remained relatively constant. Differences in plasma 3-hydroxybutyrate concentrations indicated that this initial live-weight loss was probably attributable to short-term increases in heat production and energy expenditure. The general levels and patterns of change in plasma 3-hydroxybutyrate concentrations suggested that the restricted feeding regimes adopted were such as to prevent other than a very moderate and wholly acceptable degree of undernourishment during late pregnancy.

All lamb birth weights were very satisfactory, singles averaging 4.7 kg and twins 3.8 kg, but in no case was there any difference in the birth weights of lambs from shorn and unshorn ewes. Neither was there any effect of shearing on the subsequent growth rate of lambs to weaning.

The mean rectal temperatures and respiration rates of the unshorn ewes were consistently higher than those of the shorn ewes, but only moderately so and were certainly not elevated to the extent noted by Australian workers who demonstrated reductions in lamb birth weight resulting from impaired placental development due to heat stress. The elevated respiration rates noted in the unshorn ewes in our studies are interpreted as a means of dissipating heat and which was wholly effective in preventing heat stress. It is concluded that the effects of shearing on lamb birth weight noted by other workers in this country are more likely to be attributable to a stimulation of voluntary food intake following shearing than to the alleviation of any heat stress.

Investigate methods of preventing hypocuprosis and cobalt deficiency in sheep (*Research objective 029*)

[AW, ARF, AJM]

The effectiveness of cupric oxide needles in the prophylaxis and therapy of ovine hypocuprosis has been established. Used orally they are safer than parenterally administered copper compounds, their longevity of action is excellent and carcass blemishes are absent. Their efficiency in preventing ill-thrift in growing lambs and swayback has been demonstrated, and the findings have been used in the development of a commercial product, now available.

Studies have also shown that Cheviot lambs are as susceptible to induced hypocuprosis as Scottish Blackface lambs.

The detection of cobalt bullets in live sheep

[IRW]

A sensitive metal detector developed by ARM Chambers (formerly of this Organisation) and kindly loaned by Whites Electronics of Inverness has been used in trials at Sourhope to study its effectiveness in detecting the presence of cobalt bullets in live sheep. During the course of these trials it became apparent that the instrument was effective in detecting one type of bullet but that it could not detect the presence of a second type. Analysis of the two types of bullet by X-ray spectrometry showed that detection was dependent on the iron rather than the cobalt content of the bullet. The older type, containing 57% cobalt oxide and only traces of iron could not be detected in the live animal, whereas the presence of the type now in use at Sourhope and containing 30% cobalt oxide and approximately 10% iron is very readily and accurately determined. The instrument is easily used and the presence or absence of a cobalt bullet in live sheep can be confidently established at a rate of several animals per minute. It is concluded that the instrument could be useful in identifying the small proportion of sheep which lose their cobalt bullets and in determining the need to administer routinely a second bullet to sheep after a period of three to four years as is currently practiced in some flocks.

Programme Unit 4

Beef cattle in hill and upland environments

Introduction

The objective of the beef cattle research programme is to quantify and obtain an understanding of the biological factors influencing production from suckler cows and their calves, with the ultimate aim of improving the efficiency with which hill and upland resources are used for beef production. Until 1981 this objective had 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 suckling calves. These programmes have continued at Hartwood during the last two years and a new third line of research on the nutrition and performance of the weaned suckled calf has been added. This work is located at Glensaugh where facilities for the individual feeding of 64 weaned calves have been created in the accommodation formerly used for the suckler cow studies.

The determination of nutrient requirements and *in vivo* changes in body composition in beef cows (*Research objective 031*)

[AJFR, IAW, EAH]

Late pregnancy nutrition of suckler cows

The current advice on the nutritional management of suckler cows is generally given in terms of target condition scores which should be achieved at specific key points, such as calving and rebreeding, in the annual production cycle. Information is available from the results of earlier experiments on the effects on production of nutrition during late pregnancy of suckler cows in good body condition three months before calving. Other more recent work has provided useful data on the energy value of changes in live weight and body condition, from which it is possible to estimate the contribution to nutritional requirements which can be met from tissue catabolism. These estimates and published information have been used to calculate the feed inputs required to achieve prescribed changes in the body condition of suckler cows during late pregnancy.

An experiment was recently conducted to validate these calculations of feed requirements to manipulate the body condition of suckler cows in late pregnancy. A further aim was to study the effects on production of different levels and patterns of feed input to cows varying in body condition 12 weeks pre-partum and at calving.

Forty-eight November/December calving cows (30 Blue-Greys and 18 Hereford × Friesians) were used in the experiment. Initial body condition score was manipulated during the summer by differential grazing to give a range, at 12 weeks pre-partum, of approximately 1.75 to 3.5 which is considered to be the range likely to be encountered in practice irrespective of system of management. Levels of feeding calculated to change condition score from the initial level to target condition scores of either 2.0, 2.5 or 3.0 at calving were applied during the final 12 weeks of pregnancy, with the constraints that gains in condition should not exceed 0.5 units and losses should not exceed 1.25 units. The calculated food inputs required to achieve the prescribed condition score changes were applied in two patterns, either at a constant daily rate over 12 weeks or in increasing amounts with levels being changed at intervals of 4 weeks. The effects of the pre-partum nutritional treatments on post-partum production were assessed against an initially low level of nutrition, the cows being fed for maintenance plus 2 kg milk/day for 8 weeks or until the beginning of rebreeding on 1 February, whichever was the shorter. Thereafter the level of feeding was increased to meet the requirements of maintenance plus 12 kg milk/day. Measurements of milk production and calf growth rate were made during the first two months of lactation.

The results analysed to date suggest that the data used to calculate the feed inputs required to bring about prescribed changes in the body condition of suckler cows in late pregnancy give credible results in practice. The mean difference between target and actual condition scores at calving were negligible although both positive and negative changes in condition were slightly less than prescribed. Pattern of feeding during late pregnancy had no measureable effect on calf birth weight or post-partum performance. The effect of condition score at calving on post-partum production was small although it appears that there may be a threshold between condition scores 2.0 and 2.5 below which milk production is adversely affected.

The relationships between energy intake, actual condition score and condition score change during late pregnancy provide much needed information on the effect of body condition on energy requirements during late pregnancy and on the efficiency of use of both dietary and tissue energy in cows gaining and losing body condition. This will supplement similar information from studies on non-pregnant, non-lactating suckler cows.

Factors affecting the concentrations of blood metabolites

Recently published results from earlier experiments showed that circulating concentrations of certain blood metabolites could be used as a means of assessing in quantitative terms the adequacy of energy intake of beef cattle. For example, plasma 3-hydroxybutyrate (3-OHB) concentration was a particularly useful index in cows during late pregnancy, while plasma non-esterified fatty acid concentration was closely related to and a potentially useful index of energy status in all the situations examined. The results also indicated that factors such as dietary energy concentration and pattern of feeding were likely to influence the circulating concentrations of certain metabolites, making it imperative that relationships used for predictive purposes are derived under the conditions in which they are to be applied.

An experiment was conducted to gain a fuller understanding of the effects of such dietary factors on the circulating concentration of the major metabolites and to obtain information on the relationships between blood metabolite concentrations and energy status in silage-fed animals. For convenience sheep were used as the experimental animals. Twelve twin-bearing pregnant Greyface ewes were individually fed during the last six weeks one of three diets, viz. hay, silage or a concentrate containing 20% straw. Each sheep was fed the same diet throughout, but during four successive 10-day periods they were switched in an ordered fashion between either a high (15 MJ ME/day) or low (9 MJ ME/day) level, fed either continuously or once daily. Blood samples were collected from each ewe 8 times per day for the last 3 days of each period. Samples of rumen fluid were withdrawn once towards the end of each period. Concentrations of plasma 3-OHB, free fatty acids, glucose, urea, albumin and total protein as well as rumen volatile fatty acids will be determined.

To date only the 3-OHB analysis has been completed. The pattern of intake of hay and silage had little effect on diurnal variation presumably because the rate of fermentation in the rumen of these diets is slow. There appeared to be a difference in the concentration of 3-OHB between the two patterns of feeding of silage. With the concentrate diet, the pattern of feeding had a large effect on diurnal variation with the once-daily feeding regime resulting in maximum 3-OHB concentrations about 9 hours after feeding. The type of diet also affected circulating 3-OHB concentrations with the hay diet giving the highest pre-feeding concentration, the concentrate diet and once daily feeding of silage the lowest concentrations and the continuously fed silage an intermediate value.

The relationship between winter nutrition and grazing management in lactating beef cows (*Research objective 033*)

[AJFR, IAW, JH, EAH]

Earlier experiments with spring-calving suckler cows and calves have shown that performance at pasture, assessed primarily in terms of milk production and calf growth rate, is affected by nutrition both prior to and following turnout. For example, in cows fed sufficient nutrients for the production of either 2.25 or 9 kg milk per day from calving in March/April until turnout in mid-May, those on the lower level of feeding showed a greater increase in milk production (from 7.2 to 11.6 kg/day) following turnout than did those which had previously received the higher level of feeding (from 9.4 to 10.1 kg/day). Also, from turnout until the conclusion of the experiment in September, the cows on the lower level of feeding prior to turnout produced more milk, although not significantly so, than did those which had previously been on the higher level of feeding (11.7 and 10.8 kg/day).

Herbage mass or sward height has also been shown to affect production of grazing cows and calves. For example, in spring-calving cows grazing perennial ryegrass swards maintained at two contrasting sward surface heights (8.0 and 5.6 cm) those with the higher herbage mass (2900 kg DM/ha) had superior live-weight changes (+ 0.36 v − 0.11 kg/day), produced more milk (10.7 v 9.6 kg/day) and had calves which gained weight more rapidly (1.25 v 1.01 kg/day) than cows on the lower herbage mass (1700 kg DM/ha).

A recently completed experiment was designed to examine the effects of similar pre- and post-turnout nutritional factors on the performance at pasture of cows at two stages of lactation. Sixteen cows which had calved in November/December and 32 which had calved in March/April were allocated to different nutritional regimes prior to turnout and were grazed at two contrasting levels of herbage allowance (sward surface heights of 3-4 and 8-10 cm) for a period of eight weeks. Thereafter the earlier calving cows were withdrawn from the experiment and the later calving cows re-allocated to the two pasture treatments.

Increases in milk production following turnout were noted in both the November/December and March/April calving cows. Although, as would be expected, the level of milk production of the more recently calved cows was higher prior to turnout (7.15 v 5.18 kg/day) the increase in milk production following turnout was similar at both stages of lactation (4.19 v 3.90 kg/day). During the eight weeks following turnout the mean levels of milk production from the November/December and March/April calving cows were 9.37 and 11.05 kg/day respectively.

In this particular experiment, level of nutrition prior to turnout had no measurable effect on milk production at pasture but had a significant effect on cow live-weight change during the eight weeks following turnout, those which had been on the lower level of feeding gaining more (59.4 and 65.6 kg for cows calving in November/December and March/April respectively) than those which had previously been on the higher level of feeding (46.9 and 49.1 kg for those calving in November/December and March/April respectively).

The major effect of herbage mass in this experiment was also manifest in cow live-weight change at pasture, those on the higher herbage mass gaining more weight during the eight weeks following turnout (75.5 and 86.6 kg for cows calving in November/December and March/April respectively) than those on the lower herbage mass (28.8 and 28.1 kg for November/December and March/April calving cows respectively).

Herbage mass had little effect on the live-weight gain of the March/April born calves (1.058 v 0.934 kg/day for the high and low herbage masses respectively) but had a significant effect on the live-weight gain of the November/December born calves (1.356 v 1.070 kg/day). This significantly higher rate of live-weight gain of the older calves grazing the higher herbage mass was probably due in part to their ability to achieve relatively high levels of herbage intake.

Previous results have demonstrated the ability of the suckler cow to catabolise body reserves to maintain relatively high levels of production during extended periods of undernourishment. These results show that the provision of improved nutrition following a period of undernourishment can lead to substantial production responses even late in lactation and to rapid replenishment of previously depleted body reserves.

The influence of nutrition and grazing management on production in twin-rearing cows (*Research objective 034*)

[AJFR, IAW, EAH]

Levels of milk production averaging 10 kg/day for several months can be relatively easily achieved with single-suckling beef cows. Relationships between calf performance and cow milk production indicate that attempts to improve rate of calf live-weight gain (LWG) by increasing milk production beyond about 10 kg/day are likely to result in only a small response of about 0.025 kg LWG/day/kg increase in milk production. There is also evidence that from about six weeks of age calves with a restricted intake of milk will eat more solid food than calves consuming larger quantities of milk, although the additional solid food intake is unlikely to compensate fully for the difference in the milk intake. These factors suggest that there may be advantages to be gained from the twin-suckling of beef calves as a means of increasing substantially the output of weaned calf per cow and thereby reducing the cow overhead costs per kg weaned calf. The results of an earlier experiment with single- and twin-suckling cows support these contentions.

A recently completed experiment was designed to study the responses to nutrition during early lactation and at pasture of milk production from spring-calving cows rearing one or two calves and of calf live-weight gain.

The experiment was conducted with 14 Blue-Grey cows rearing 8 single-suckled and 12 twin-suckled calves and with 12 Hereford × Friesian cows rearing 9 single-suckled and 6 twin-suckled calves. From calving in March/April to turnout cows within each rearing class were fed for three levels of milk production viz. 2.5, 10 or 17.5 kg milk/day. From turnout in mid-May until the completion of the experiment in mid-September all cows and calves grazed together.

The results of this experiment have not yet been analysed, but preliminary data on calf growth rates at pasture are available. At turnout there was a relatively small effect of rearing type on the weight of calves from Hereford × Friesian cows (singles 82.2 kg v twins 78.3 kg) but a larger effect in calves from Blue-Grey cows (singles 69.4 kg v twins 58.3 kg). At the conclusion of the experiment in mid-September the respective weights were 205.0, 170.0, 172.5 and 140.0 kg giving daily gains at pasture of 1.01 and 0.75 kg/day for single- and twin-reared calves from Hereford × Friesian cows and 0.85 and 0.67 kg/day for single- and twin-reared calves from Blue-Grey cows. The final weights of Hereford × Friesian cross and Blue-Grey cross twin-reared calves were 83 and 81% of the weights of the respective single-reared animals, figures which correspond closely to those previously observed. The most interesting comparison is that between the twin-reared calves from Hereford × Friesian cows and the single-reared calves from Blue-Grey cows where the combined effects of differences in weight at turnout and growth rate at pasture resulted in very similar live weights at the conclusion of the experiment.

Effects of pre- and post-weaning nutrition on performance of weaned suckled calves (*Research objective 036*)

[IAW, AJFR, EAH]

The Organisation's beef cattle research programme has recently been extended to include work on the weaned suckled calf. During 1982 and 1983 this new part of the programme concentrated on the relationship between imposed levels of winter performance and that achieved at pasture during the following grazing season.

An experiment, which is discussed within the wider context of the weaned suckled calf research programme elsewhere in this report (p. 153), was conducted at Glensaugh to gain an understanding of the inverse relationship between levels of winter and summer performance and to examine the effects on this of both animal and pasture factors. A total of 119 weaned Charolais-cross calves of both sexes from Blue-Grey and Hereford × Friesian cows in the autumn- and spring-calving Hartwood herds were used in the two years of this study. During winter they were individually fed restricted quantities of silage and barley to create differences in rate of live-weight gain and weight at turnout; during summer they were grazed on pasture maintained at two contrasting levels of herbage mass. Changes in body condition score and ultrasonically measured fat depth were monitored regularly throughout the experiment.

The results, some of which are presented on p. 154, show evidence of what is generally termed "compensatory growth" in that those which gained least weight during winter housing gained most weight at pasture and *vice versa*. As would be expected, performance at pasture was affected by herbage mass, but it was of particular interest to note that the effects of winter treatment were as evident in the animals grazing the lower herbage mass, where voluntary intake was restricted, as in those on the more abundant pasture of the higher herbage mass. There were no differences in performance between the two genotypes examined, but at pasture the steers and spring-born calves grew more rapidly than did the heifers and older autumn-born animals.

Examination of the results has led to the formulation of a hypothesis of the central role of body composition in the relationship between nutrition and performance of weaned suckled calves. It is suggested that body composition influences rate of live-weight gain through effects on both voluntary food intake and the composition of tissue gain. This hypothesis, which is consistent with results from work on lactating suckler cows, requires to be examined in greater depth, but the results obtained to date have already contributed to a better understanding of the basis of compensatory growth in beef cattle and have provided information relevant to the ultimate development of more efficient beef production systems.

The effect of once-daily suckling on reproductive efficiency

(*Research objective 037*)

[AJFR, IAW, EAH]

The act of suckling a dam by its offspring is known to prolong the duration of post-partum anoestrus. Suckling stimulates prolactin secretion which has an inhibitory effect on gonadotrophin production and hence on follicular development. Reports in the literature show that this inhibitory effect of prolactin can be at least partially suppressed in beef cows by reducing the frequency of suckling with the result that the anoestrous period is shortened and cows can be rebred more quickly.

An opportunity was taken during the course of a recent experiment at Hartwood to examine the effects of restricting the suckling of beef cows by their calves to 0.5 h per day on the reproductive performance of the cows and on the growth rate of their calves. A total of 48 single-suckling beef cows were allocated to treatment and control groups according to genotype, order of calving and nutritional treatment in the immediately preceding experiment. In the control group calves had free access to their dams at all times except for a period of six hours once every two weeks when estimates of milk production were made. In the treatment group calves were separated from their dams for 23.5 h per day from one month of age for a mean period of about 4 weeks. All calves were offered good quality hay *ad libitum* from an early age.

A substantial number of the cows were sold during pregnancy and records of calving date are available on only 25 animals: 13 Blue-Greys (8 treatment and 5 control) and 12 Hereford × Friesians (7 treatment and 5 control). Contrary to expectations and aspirations the effect of the treatment was to lengthen significantly the calving interval. Mean calving interval was 363 days with values for the separation treatment and control of 371 and 354 days respectively ($P < 0.001$).

In the fourth week of lactation, i.e. at the beginning of the once-daily suckling regime, there was no difference between treatment and control cows in level of milk production (6.89 and 6.72 kg/day respectively). By the sixth week the treatment had depressed milk production by 1.37 kg/day (5.22 and 6.59 kg/day respectively) and by the eighth week the difference had increased to 1.51 kg/day (4.81 and 6.32 kg/day respectively). Despite this effect on milk production calf live weights were not affected by the treatment. Weights of treatment and control calves at 4 weeks (57.2 and 56.2 kg respectively) and at 8 weeks (75.4 kg in both groups) were not significantly different, and it is assumed that the treatment calves compensated for a reduced milk intake by increasing their voluntary solid food intake.

The observed effect of the restricted suckling regime on calving interval, and by inference the probable effect on duration of the post-partum anoestrous period, are clearly at variance with those reported by other workers. The reason for this is not clear. Although the number of observations was certainly fewer than desirable the effect of a 17-day lengthening of the calving interval was very highly significant. It is of interest, however, that although the treatment not unexpectedly reduced cow milk production, there was no adverse effect on calf performance.

Investigation of the efficacy of cupric oxide needles in bovine hypocuprosis (*Research objective 038*)

[AW, ARF, AJM, JM]

The use of cupric oxide needles in the prevention of hypocuprosis in sheep has been well established. The attractive features of this form of therapy in safety, longevity and efficacy of action, and freedom from injection blemishes, suggested that an evaluation of the use of cupric oxide needles for the bovine was worthwhile.

Two trials were undertaken. The findings in each demonstrated that treated animals were maintained in copper sufficiency, and had significantly higher daily live-weight gains than control animals which were hypocupraemic. Additionally in one trial a comparison with a copper calcium edetate injectable preparation (Coprin. Glaxovet U.K.) showed that the cupric oxide needles were effective over a longer period in sustaining adequate plasma copper concentrations.

Programme Unit 5

The husbandry of red deer

Studies in the lifetime performance of the red deer (*Research objective 039*)

[WJH, JE]

The three cohorts of hinds being monitored for this study are the A, B and C cohorts born in 1970, 1971 and 1972 respectively. All were artificially reared as calves on 3 different levels of nutrition during their first winter of life. These were 1 kg/hd/day, 0.91 kg and 0.68 kg respectively, of a good quality concentrate with hay fed *ad libitum.*

During their lifetime the hinds have grazed the heather hill, the hill reseeds and upland sown pastures. Comprehensive data is available on their reproductive performance. The average number of possible pregnancies per hind was 10.4, and the average number of calves born was 9.8 (94.7%). The death rate in calves both perinatal and up to weaning in September was 11.2%, and the average number of calves weaned per hind was 8.75 (84%). Some 7.0% of the hinds have died over the period and less than 5.0% were yeld. There appears to be no deterioration in lifetime performance up to 10 calf crops.

Studies on the utilisation of hill and pastoral resources on hill systems of deer meat production (*Research objective 040*)

[WJH, TJM]

Between 1981 and 1982 the possibility of farming red deer more extensively on upland sown pasture was investigated. The study was concerned with comparing two different hill systems, one included a hill outrun on which hinds were mated and then wintered and the other examined the wintering of hinds in a paddock of approximately 3 ha where they were fed a controlled ration of hay and concentrates. They were mated on the sown pasture area. Each of the herds were grazed during the spring and summer on 3.4 ha of permanent sown pasture.

A more detailed account of this study is included in the longer research report, "Progress in research on red deer farming" on p. 159.

The nutrition of hind and stag calves in their first year in relation to their subsequent performance at pasture (*Research objective 041*)

[JAM]

Red deer calves weaned from hinds grazing hill or upland swards in September or October range in live weight from 35 to 45 kg. Current systems of production involve slaughter of the calf at 16 months of age or 75-80 kg and this is also the target live weight for hind calves before entering the breeding herd at the same age. A period of inappetence in January and February makes it difficult to achieve high growth rates in winter and winter feed costs are also high relative to the price of the end-product. Consequently the compensatory growth in the following summer at pasture shown by calves given low levels of winter feeding may have an important role.

Two experiments have been conducted where different levels of winter nutrition have been imposed followed by summer grazing on predominantly perennial ryegrass swards from May until September. A complete pelleted diet, AA6, was used to provide the winter levels of nutrition but trials have shown that hay or silage can be successfully used to feed calves during the winter. At *ad libitum* levels of feeding, live-weight gains during January and February were 90 g/d but were higher in December, March and April (130-200 g/d), so that calves weighing 45 kg at housing and fed *ad libitum* gained 10-15 kg more than those given a maintenance level of feeding over the winter period. Live weight of calves at housing had no effect on subsequent winter growth rates nor did the level of feeding in January and February influence live-weight gains in March and April.

In both experiments live-weight gains were higher in the first 6 weeks after turnout for those calves that had the lowest levels of nutrition in the winter. Compensation amounted to 30-50 g/d when over this period live-weight gains ranged from 130-200 g/d. During July and August live-weight gains were somewhat lower (100-170 g/d).

In one experiment this was associated with a reduction in herbage mass because of drought which may have limited herbage intake. In this experiment no effect of level of winter nutrition on calf growth rate was observed in the latter part of the grazing season, but in the other experiment compensatory growth continued to be exhibited until the end of August. Figure 5 shows live weights of the calves at housing, turnout and at the end of August for the different winter treatments.

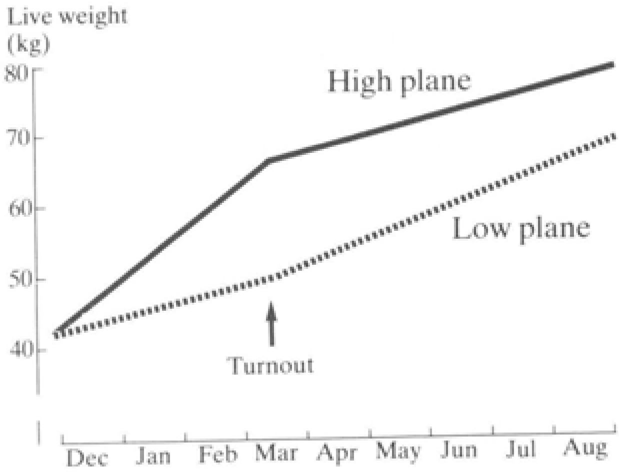

Figure 5

Effects of high and low planes of nutrition on the subsequent growth of red deer yearlings at pasture.

Although compensatory growth after lower levels of winter feeding resulted in an additional 5 kg of live-weight gain compared to those calves that were well fed, high levels of winter feeding had already increased live weights by 10-15 kg. Knowing the costs of winter feed and summer grazing and the price obtained for the end-product it is now possible to undertake an economic analysis of the various strategies. Notwithstanding the strategy adopted for winter nutrition and grazing the following summer, it is important to obtain high live weights at housing. These depend upon an early calving date and high calf growth rates during lactation and in the late autumn.

Relationships between nutrition and performance in grazing red deer hinds and calves (*Research objective 042*)

[JAM, ASI Loudon]

As with hill sheep, hill vegetation has been shown to limit lactation performance of hinds and calf growth rates. Hinds on an upland sown sward maintained at herbage mass of 2000 kg DM/ha yielded on average 60% more milk over the lactation period than hinds on a heather and *Agrostis*/*Festuca* vegetation. Milk yields of hinds on the upland and hill swards at day 40 of lactation were 2.2 and 1.5 kg/day respectively and declined to 1.1 and 0.6 kg/d at day 100. Calf growth rates reflected milk yield differences and were 40% greater on the upland sward (upland sward 369 ± 14.5 g/d, hill sward 257 ± 9.5 g/d). The poorer performance of hinds and their calves on the hill sward was due to a lower quality of diet ingested and to behavioural limitations on intake exhibited when hinds grazed indigenous swards of relatively high species diversity. Biting rates were lower (33 v 56 bites/min) and grazing times higher (11.7 v 6.0 h) on the hill sward when compared to the upland sward.

On upland swards relationships between herbage mass and calf growth rate appear to be similar to those that have been established with sheep. With a herbage mass maintained at less than 1500 kg DM/ha (sward height, 3 cm) calf growth rates from birth in May until weaning in September were 45 g/day less than from a sward maintained at 2000 kg DM/ha (sward height, 6 cm). After weaning in mid-September before the rut, calf growth rates at pasture in the autumn have been found to be low (130 g/d), even though sward heights were 4-6 cm. The poor growth rates have been associated with a stress-related disease, Yersiniosis. Inclement weather conditions and the lack of shelter have been implicated and necessitate housing of the calves in early November. Milk yields of hinds at weaning are in the order of 1 kg/d and there may be advantage to calf growth rates in delaying weaning until the end of the rut.

A delayed weaning, however, may adversely affect reproductive performance particularly in relation to date of calving, which is of crucial significance to the live weight of the calf at the end of its first grazing season. Evidence has been obtained that an increase in suckling frequency during lactation can delay rebreeding after weaning by 6 days. The lower milk outputs of the hinds on the hill sward were associated with higher suckling frequencies and elevated plasma prolactin levels compared to those of hinds grazing the upland sown sward. Whether reproductive performance of the hind would be influenced by a continuation of suckling into the mating period remains to be determined as does the effect of a continued milk supply on the growth rate of calves in the autumn.

Programme Unit 6

The effect of nutrient supply and supplement use on digestion, metabolism and performance of grazing sheep

The amount and type of supplements to give to ewes in mid-pregnancy (*Research objective 043*)

[JAM, AMS, AJS]

The lamb birth weights of Scottish Blackface ewes grazing a predominantly heather hill have been found to increase by at least 10% through feeding 200 g/d of barley/urea supplement in mid-pregnancy when the ewes were fed according to current recommendations in late-pregnancy. Figure 6 shows that the increases in birth weight were associated with a reduction in ewe live-weight losses in mid-pregnancy. However live-weight losses were vastly different between years, although the increases in birth weight associated with the feeding of supplements in mid-pregnancy were similar in each year. This suggests that the additional supply of 2 MJ metabolisable energy (ME)/day from the supplement may not necessarily be acting to spare the ewe's fat tissues but may be directly providing glucose or amino acids to the tissues, in particular for placental and foetal growth. From previous results it can be estimated that microbial protein synthesis in the rumen would have been increased by supplementation such that 40% more amino acids could have been absorbed by the supplemented ewes. The greater amounts of amino acids absorbed may have stimulated placental development in mid-pregnancy and by this means increased lamb birth weight.

Evidence to support this latter hypothesis has been obtained from a field experiment where two supplements differing only in the amount of rumen undegradable protein were given to ewes in mid-pregnancy (day 30-90 of pregnancy). Both groups of ewes were fed according to current recommendations in late pregnancy. The birth weights of twin lambs from ewes given the supplement containing the greater amount of rumen undegradable protein were higher than those from the control treatment ewes. The protein supplement could have increased ME intake by stimulating herbage intake but the lack of difference between treatments in ewe live-weight loss in mid-pregnancy is not consistent with such a theory.

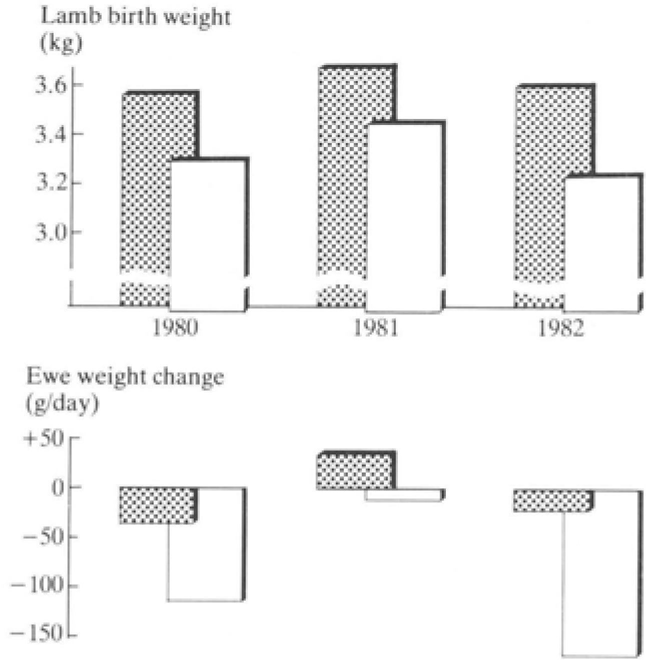

Figure 6

The effect of supplementation in mid-pregnancy on performance of Scottish Blackface ewes.

Supplemented
No supplement

The interaction between level of supplementary feeding in mid-pregnancy and type of supplement given in late pregnancy was examined in a flock of Scottish Blackface ewes with a lambing rate of 1.2 and grazing a predominantly heather hill. Increasing the amount of rumen undegradable protein in the supplement in late pregnancy had no effect on lamb birth weights from single- or twin-bearing ewes, when groups of ewes were supplemented or unsupplemented in mid-pregnancy. However supplementation in mid-pregnancy increased lamb birth weight, stressing the importance of mid-pregnancy nutrition in the development of the foetus. The newly acquired ability to detect foetal number under farming conditions and thus to differentially feed single- and twin-bearing ewes in late pregnancy makes it more important to obtain an understanding of the interactions between mid- and late-pregnancy nutrition under grazing conditions.

The high between-animal and between-day variation in intakes of supplement given as feed-blocks has continued to be observed. The high rank correlation coefficients found for supplement intake in a group of ewes on different occasions, suggested that a knowledge of the reasons for the variability in intake might lead to a reduction in variability. However observations using time-lapse photography have suggested that variations in intake are associated with social behaviour around the feed-block which is not easily manipulated. A simple method for detecting ewes not ingesting feed-block or using them infrequently has been developed and preliminary testing has been successful.

The identification of nutrient limitations in late pregnancy and the provision of supplements to remove these limitations

(*Research objective 044*)

[RWM, CSL, PMC]

Whilst the benefits of feeding supplements to grazing ewes in late pregnancy are well known, the cost of supplementation remains considerable, in spite of restriction of feeding levels allowing some utilisation of the ewe's body reserves to occur. The identification of the nutritional factors affecting lamb birth weight and body condition would enable supplements to be formulated so that the absorbable nutrients supplied by the overall diet match the needs of the pregnant ewe more effectively, leading to a potential reduction in supplement input.

Current recommendations for energy and protein needs in late pregnancy do not take into account the specific nutrient needs of the foetus and placenta, nor the degree to which they can be met by the mobilisation of the ewe's body reserves. The considerable needs of the pregnant uterus for glucose and amino acids are, in relation to estimates of the extra ME required for pregnancy, greater than can be supplied from glucose precursors and amino acids derived from either maternal body reserves or from currently recommended diets. This implies that ewes in late pregnancy may, in terms of lamb birth weight and body composition change, be able to respond to additional absorbable protein and glucogenic energy supply. The effects of changing the dietary supply of absorbable protein and glucogenic energy in late pregnancy at differing ME intakes were investigated in two experiments with housed Blackface ewes; determination of the amounts of nutrients absorbed, together with quantification of production rates and routes of metabolism of some important metabolic intermediates were made to aid the interpretation of the production responses obtained.

When ewes were fed 90% of estimated ME and protein requirements and additional protein (formaldehyde-treated soya bean meal) replaced an equal amount of glucogenic energy, given as sodium propionate, in the diet substantial increases in lamb birth weight (17%) and N retention by the ewes were observed. As expected the amounts of non-ammonia N absorbed were increased by the additional protein in the diet whereas the glucose production and oxidation rates were unchanged in spite of large differences in the sources of glucose carbon.

In a similar experiment the effects of altering the dietary glucogenic energy supply whilst maintaining ME intakes at 60% of estimated requirement were investigated. Reducing the dietary glucogenic energy content from 35% to 19% of ME intake, together with a reduction in protein supply from 120% to 100% of estimated requirement, caused significant reductions in lamb birth weight and ewe N retention. When dietary glucogenic energy was reduced and protein intake was maintained at 100% of estimated requirement, the glucose production rate was reduced by 18%, but glycerol and 3-hydroxybutyrate production rates were substantially increased by 85% and 245% respectively. The increased glycerol turnover, together with an observed increase in plasma non-esterified fatty acid concentration, suggests that body fat mobilisation had increased, implying that there was a reduction in the efficiency of utilisation of total ME accompanying a likely shortage in glucogenic citric acid cycle intermediates.

The results of these experiments indicate that, under experimental conditions, both dietary protein and glucogenic energy supply could limit lamb birth weight at low ME intakes, and that these nutrients need consideration in determination of the ewe's feed requirement. Whilst the importance of non-glucogenic ME has not yet been established, its dietary level could also influence the rate of utilisation of body reserves.

These findings provide a basis for estimating the needs of the grazing pregnant ewe for absorbable protein and glucogenic energy, although these remain to be assessed under grazing conditions where the effects of supplements in influencing total nutrient supply by their interactive effects with herbage also remain to be elucidated.

The amount and type of supplement to feed to ewes in relation to pasture supply in early lactation (*Research objective 045*)

[JAM, AMS, HMcC, CSL, HD]

With the dates of lambing favoured in most upland sheep systems there is a period from 2-8 weeks after lambing when sward characteristics limit herbage intake of the ewe and thus milk yield and lamb growth rates. Over this period growth rate of herbage is similar to or less than its defoliation rate. At herbage masses of 1000 kg DM/ha or less and at sward surface heights of less than 4 cm, lamb growth rates over the first 6 weeks of lactation have been found to be reduced significantly. Supplements based on sugar beet pulp and white fish meal produced higher lamb live-weight gains than a conventional barley and soya bean meal supplement when both were given to single- and twin-bearing Greyface crossbred ewes grazing perennial ryegrass swards with herbage masses of less than 1000 kg DM/ha. The reasons for the increased lamb growth rates in both instances could be an increased supply of acetate for milk fat synthesis or an increased supply of absorbed protein increasing milk protein synthesis. Information on the mechanisms involved is necessary to define the composition of supplements to be given in early lactation. Evidence from indoor experimentation has suggested that increasing protein supply in early lactation will increase milk yield. However it is not known to what extent the high levels of N in grazed spring herbage can be captured by rumen bacteria to supply sufficient absorbed protein, and whether the addition of a suitable energy supplement would assist this capture. It also remains to be established whether a source of rumen undegradable protein will further increase levels of performance.

These ideas were tested in an experiment with 96 Greyface ewes rearing predominantly twins and lambing at the end of April. On swards maintained at less than 1000 kg DM/ha comparisons were made between an unsupplemented treatment, an energy supplement provided by 600 g/d sugar beet pulp and 600 g/d of a protein supplement containing 50% molassed sugar beet pulp and 50% formaldehyde-treated soya bean meal. Both supplements provided the same amount of ME and were fed for 7 weeks. All ewes grazed swards with herbage masses of 1600-2000 kg DM/ha until weaning at 14 weeks. The experiment was replicated four times and on one of the replicates interpretative measurements were made.

The energy supplement increased lamb live-weight gains and ewe milk yield compared to the unsupplemented treatment (see Figure 7) and these were associated with higher microbial protein synthesis rates in the rumen and greater non-ammonia N (NAN) flows at the abomasum, indicating capture of N from herbage in the presence of the energy supplement. As would be expected the rumen undegradable protein source increased NAN flows at the abomasum and this was associated with higher milk yields and lamb live-weight gains on the experimental replicate used for the interpretative measurements. However over all the replicates there was a smaller advantage in favour of the protein supplement. In a further experiment in which smaller amounts (400 g/d) of similar supplements were given to Greyface ewes lambing in early April there was only a small advantage in feeding a protein supplement.

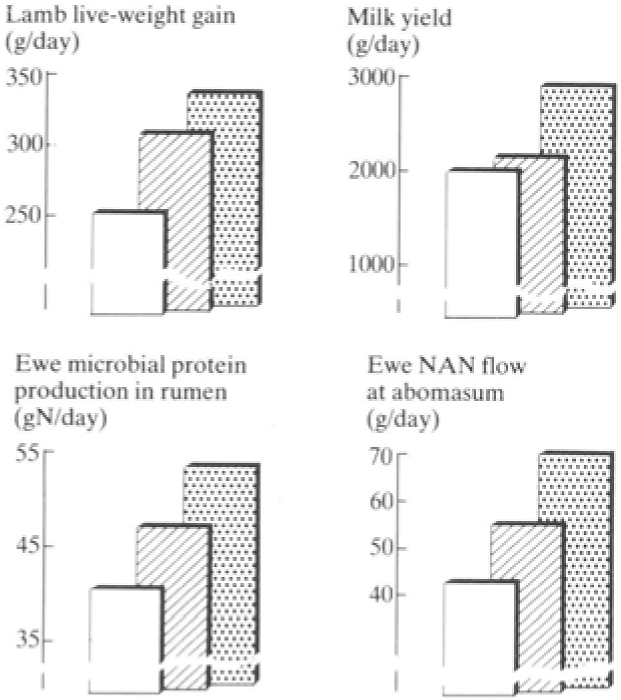

Figure 7

Effect of supplementary feeding in early lactation on ewe and lamb performance.

No supplement
Energy supplement
Protein supplement

Live-weight gains of lambs from the end of supplementary feeding to weaning in two experiments have been found to be higher on those treatments which produced the lowest live-weight gains in early lactation. No evidence was found of changes in ranking of milk yield between treatments after supplementation ceased. The reason for this compensation in lamb growth may be associated with earlier rumen development in those lambs which receive less milk. They may subsequently achieve greater levels of herbage intake when ewe milk supply declines. Consequently, the economic benefits of feeding large amounts of protein supplement in early lactation cannot be justified on the basis of the lamb weaning weights observed in these experiments.

However small amounts of energy supplement such as molassed sugar beet pulp should be given as a supplement to upland crossbred ewes in moderate body condition until sward surface heights are consistently above 4 cm.

The identification of factors influencing the supply of nutrients from milk and herbage to the lamb at pasture (*Research objective 046*)

[RWM, PMC]

Under most pasture-based systems of sheep production the lamb receives a diet of both milk and herbage for much of the first four months of life. During this period the lamb has the potential for very rapid growth and so an understanding of factors affecting nutrient supply is central to the development of production systems to optimise lamb growth.

Whilst the major determinants of nutrient supply to the lamb are the relative intakes of milk and herbage, the efficiencies of their digestion may also be important. Interactions between milk and herbage digestibility are possible since the two feeds are digested in the main in different sites in the digestive tract, and large changes in the anatomy and functioning of the gut take place during this period. Because milk has considerably higher metabolizable energy and protein contents than herbage, independent determinations of intake and digestibility of each are necessary in order to make reasonable estimates of digestible nutrient intake. Separate estimations of milk and herbage digestibility can be made using a regression approach but their accuracy is questionable since it is valid only if no interactions occur and large numbers of observations are required. An alternative approach is to determine the digestibility of components which are peculiar to herbage or milk, either naturally present or by labelling with radioisotopes.

In an experiment using individually housed lambs, estimates of milk digestibility have been obtained by determining the digestibilities of tritiated milk-fat and milk protein when tritium-labelled ewe's milk was incorporated in the milk-replacer diet. The digestibility of the freshly-cut ryegrass/clover herbage in the lambs was determined as its fibre digestibility (neutral detergent fibre, acid detergent fibre and cellulose). Measurements were made as the animals progressed from a diet of milk replacer only, through periods of mixed feeding with declining milk intakes until the lambs received only herbage. The results showed that as milk intake was progressively restricted and herbage intake increased there was a statistically significant decline in milk fat digestibility from 99.4% to 97.6% and in milk protein digestibility from 98.5% to 96.1%. The digestibilities of the fibre components of herbage were not affected by age, milk intake or herbage intake; any variations were reflected in the *in vitro* OM digestibility of the herbage. Whilst the magnitude of the observed decline in milk digestibility was small the voluntary intakes of herbage were low. At higher herbage intakes milk and herbage digestibility may be altered to a greater extent.

Supplementation strategies for finishing lambs grazing forage crops in the autumn (*Research objective 047*)

[JAM, HMcC]

It has been found difficult to predict the growth rates of lambs on forage crops, and when these crops are supplemented. The objective of the research is to provide a better nutritional basis for the provision of supplements to lambs grazing forage crops in order to achieve desired live-weight gains and carcass compositions. In the first instance the current understanding of the nutritive value of the rape crop was examined.

The live-weight gains of finishing lambs on rape have been found to be in the order of 100 g/d when leaf is grazed and somewhat less when rape stem is ingested. From a knowledge of the intakes of rape by lambs and the chemical composition or rape leaf and stem, it was thought that lamb growth rates would be limited by ME supply rather than the amount of protein absorbed. To test the hypothesis that to achieve lamb growth rates greater than 100 g/d it would be appropriate to feed a predominantly energy supplement, groups of 36 Scottish Blackface lambs grazing rape leaf or stem were allocated to the following treatments: no supplement, 275 g DM rolled barley or 275 g DM rolled barley with 50 g DM soya bean meal as a rumen degradable source of N.

The live-weight gains and the protein and energy gains in the carcass and the proportion of fat in the carcass for the lambs grazing the rape stem are shown in Fig. 8. Data for the lambs grazing the leaf showed the same pattern of treatment differences. Live-weight gains were highest on the barley and soya bean meal supplement. This was reflected in higher carcass weights and higher protein gains. However total energy gains did not differ between treatments. In part this was due to the higher fat content in the carcass of lambs given the barley supplement, although there were also differences in the composition of the non-carcass components. These results indicate that current knowledge of the digestion of rape in the rumen is inadequate to provide a good basis for predicting the type of supplement to feed with this crop. Degradability of N in the rumen was found to be high and release of N to be rapid, which may have limited microbial protein synthesis and may thus offer an explanation for the lack of response in live-weight gain to the barley supplement. This work has stimulated an examination of N digestion in the rumen of a range of forage crops which is currently under way.

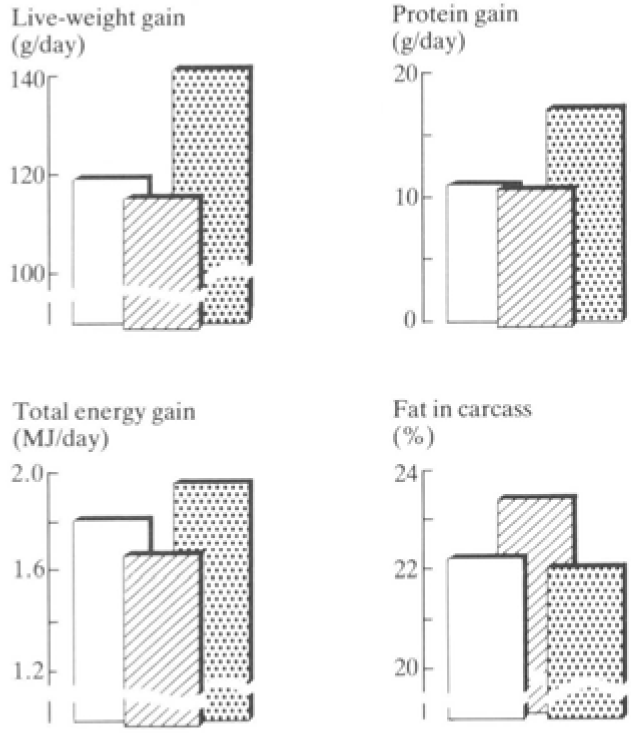

Figure 8

Results for lambs grazing rape stems when given supplements.

No supplement
Barley
Barley & Soyabean meal

There was also evidence from this experiment that the protein to energy ratio of the diet can influence carcass composition in the Scottish Blackface lamb and this is currently being investigated.

Factors influencing the rate of adipose tissue change in pregnancy and lactation (*Research objective 048*)

[JAM, SW, HMcC]

The amounts and composition of supplements given to grazing ewes in pregnancy and lactation are influenced to some extent by the rate at which it is desirable to utilise the fat tissues of the ewe. This rate is likely to depend upon the nutrient intake from pasture, the fat content of the ewe, the relationship between current and subsequent rates of adipose tissue use, and the degree to which adipose tissue use may be regulated in pregnancy and lactation.

As part of research objective 049 models of lipolysis and lipogenesis have been constructed for ewes during the last month of pregnancy. These have provided insights into adipose tissue change and the metabolism of fatty acids by the single-bearing Scottish Blackface ewe in pregnancy. Rate of lipolysis, as measured by the entry rate of non-esterified fatty acids (NEFA) into plasma, increased rapidly as pregnancy proceeded from 200 g/d at day 120 to approximately 350 g/d at day 140 of pregnancy, in ewes given the same amounts of food. Rate of lipolysis was also sensitive to changes in level of feeding, doubling intake reduced lipolysis by 40%.

Even when ewes were given diets resulting in states of moderate undernourishment, large amounts of NEFA (400-680 g/d) appeared to be re-esterified within adipose tissue. However the rate of esterification was reduced at lower levels of intake, and also declined in the latter stages of pregnancy. The importance of these findings is that 25-40 g of glucose, i.e. approximately 15-35% of the daily production of glucose by the ewe, may be required for the synthesis of glycerol-3-phosphate for re-esterification at a time when glucose supply to the foetus could be limiting. The amount of glucose required for the re-esterification of NEFAs is greater than the amount of glucose that can be derived from the glycerol released by lipolysis.

The proportion of NEFA oxidised to CO_2 remained relatively constant at approximately 0.6 in late pregnancy. In contrast, the proportion of acetate, the other major energy substrate for the ewe's tissues, which was oxidised to CO_2, increased from 0.7 at day 120 to almost 1.0 at day 140 of pregnancy. The low level of oxidation of NEFA presumably reflects re-esterification of NEFA and implies a limitation on the extent to which fat tissues can be used in late pregnancy.

Lipogenesis, as measured by the incorporation of ^{14}C-acetate into adipose tissue *in vivo,* remained at a relatively low level throughout late pregnancy. In an experiment with Greyface ewes nursing twin lambs in the first 8 weeks of lactation and fed diets differing in energy to protein ratio, similar low levels of lipogenesis were observed with both diets. These results are interpreted as indicating that adipose tissue changes in late pregnancy and early lactation are mediated by changes in lipolysis rather than changes in lipogenesis.

Development of methods of measuring short-term changes in the fat tissues of the ewe in pregnancy and lactation (*Research objective 049*)

[JAM, SW, PEM]

To meet research objective 048 in the context of the grazing sheep measurements of changes in the content of adipose tissue over periods of 2-4 weeks are required. Current methods of measurement, such as the comparative slaughter technique, are inadequate because they are imprecise over the short periods under study and require the slaughter of large numbers of animals. Indirect measurement methods, such as those based on body water dilution or on ultrasonic measurements, also lack sufficient precision. Blood metabolites have been advocated as indices of adipose tissue change but their use has met with only limited success to date.

An alternative approach is to examine whether metabolic indices found within samples of adipose tissue obtained using biopsy techniques could be used to predict short term adipose tissue change. For example, changes in enzyme activities in adipose tissue or the ratios of the activities of enzymes of lipolysis and lipogenesis offer possibilities as metabolic indices. Models of *in vivo* lipolysis and lipogenesis for ewes given different feeding levels in pregnancy have been developed using isotope-dilution techniques (see research objective 048) and changes in enzyme activities assessed against changes in the models. Several of the lipogenic enzymes (acetyl CoA carboxylase, glucose-6-phosphate dehydrogenase and isocitrate dehydrogenase) show promise as predictors of lipogenesis.

Lipogenesis, as measured by the incorporation rate of ^{14}C-acetate *in vivo* and also by the activity of acetyl CoA carboxylase, has been shown to vary with adipose tissue site and also within sites. However, no interaction between adipose tissue site and treatment has been observed. The most suitable biopsy site for obtaining samples has been found to be subcutis area of the flank.

The concentration of cyclic-AMP which is required for activation of the enzyme hormone-sensitive lipase in adipose tissue would appear to be one of the few predictors of lipolysis which could be potentially useful. It is currently being assessed in conjunction with *in vitro* incubation techniques to predict the rate of lipolysis *in vivo*.

Development of methods for determination of nutrient supply and metabolism in grazing sheep (*Research objective 050*)

[RWM, CSL, PMC, JAM]

In order to interpret production responses to dietary inputs a knowledge of the processes of digestion and metabolism is necessary. Techniques which are presently available for quantifying nutrient absorption and metabolite production rates have been limited by the need to restrain animals such that continuous infusions of digestion markers and isotopic tracers can be carried out. In most instances such measurements made indoors may not truly represent the processes of digestion and metabolism in grazing animals. The diet (grazed herbage) cannot be faithfully represented indoors and the effects of exercise and the weather may also influence metabolic responses. In order that the digestion and metabolite utilisation in grazing animals may be studied attempts have been made to evolve suitable techniques.

A portable infusion pump has been developed which is capable of pumping at constant rates for at least 10 days. The power supply to the peristaltic pump is stabilised with a voltage regulator to maintain motor speed if the battery voltage changes. This pump has successfully been used to infuse digesta markers and ^{14}C-labelled tracers into the rumen of grazing sheep to enable estimation of, respectively, abomasal flow rates and volatile fatty acid production rates. The pump has also been used for concurrent intravenous tracer metabolite ([^{14}C] glucose and [^{14}C] 3-hydroxybutyrate) infusion and continuous withdrawal of jugular blood. The withdrawal of blood from the sheep by the pump is achieved by the simultaneous infusion of anticoagulant solution through a narrow-bore tube to within 1 mm of the inner end of the implanted catheter and withdrawal of blood at four times the anticoagulant infusion rate.

In indoor studies the quantitative determination of carbon exchange between metabolites is achieved by separate tracer infusions on separate days when the sheep are fed continuously to maintain steady-state conditions. This approach may not be possible outdoors where large day-to-day variations in metabolite flux rates probably occur. For this situation the use of separate ^{13}C- and ^{14}C-labelled tracers infused on the same occasion would enable more reasonable estimates of carbon transfers to be made outdoors. Experiments indoors have shown that blood CO_2 entry rates and incorporation of carbon from CO_2 into glucose using [^{13}C] sodium carbonate are almost identical to values obtained by the use of [^{14}C] sodium carbonate. These results indicate that a two-pool model of C transfers between glucose and blood CO_2 can be constructed from a single mixed intravenous infusion of [^{13}C] carbonate and [^{14}C] glucose. However, alterations to the portable infusion and blood-sampling systems for grazing animals will be necessary as it has been found that the silicone rubber pump tubes are permeable to CO_2 and cross-combination of label can occur between blood and infusate solutions. Further work is in progress to enable a series of discrete blood samples to be obtained automatically from the grazing sheep.

Whilst the processes of digestion and metabolism have a profound effect upon nutrient supply to the grazing animal, voluntary intake of grazed herbage remains the major determinant. The use of *in vitro* digestibility measurements on herbage samples together with faecal output measurements, has enabled reasonable estimates of intake to be made under certain conditions. However, the method is not suitable when supplements are given. Since the supplement can strongly influence herbage intake there is a need for some other means of estimating herbage intake in grazing animals receiving supplements. One possible approach is to use an indigestible component of herbage as a marker. The use of herbage n-alkanes (present in cuticular lipids) is currently being investigated; these were chosen as they are discrete chemical compounds, easily analysed, relatively inert and are not subject to contamination by soil or microorganisms. Preliminary results from a trial using lambs fed freshly-cut ryegrass/clover suggests that n-alkanes of chainlength C_{33} and C_{35} could be successfully used as markers, as their respective faecal recoveries were 91% and 98%. Different herbages and supplements have been found to contain different proportions of each n-alkane which increases the potential usefulness of the approach.

Establishing the requirements by ewes for supplements around the mating period (*Research objective 051*)

[JAM, RGG, AMS, AJS]

The aim of management systems for hill and upland ewes in the autumn is to provide a high plane of nutrition in the period from 6 weeks before the start of mating to near the end of the mating period. One approach is to attempt to manipulate the accumulated herbage during this period (see research objective 017). An alternative strategy may be to provide additional nutrients in the form of supplements. Knowledge of the nutrient intake from pasture prior to and during the mating period is limited as is knowledge of the responsiveness of ovulation rate and embryo wastage to specific nutrients. Most evidence suggests that responses are mainly a function of ME intake although more recently the amount of amino acids absorbed has also been suggested as being important to ovulation rate.

To explore the benefits that could accrue from supplementation over the mating period two experiments have been conducted with Scottish Blackface ewes in moderate body condition. Comparisons have been made of the reproductive performance of ewes receiving supplements in the 3 weeks prior to and in the 3 weeks after the start of mating with that of unsupplemented ewes. Herbage masses and sward heights declined from 2200 kg OM/ha and 4.5 cm 3 weeks before mating to 1400 kg OM/ha and 2 cm respectively 3 weeks after mating. Under these sward conditions unsupplemented ewes lost 4 kg in live weight and over a quarter of condition score in the 6 week period. There was no change in the live weight or body condition of the supplemented ewes. Supplementation with 600 g/d of a barley/white fish meal supplement increased lambing rate from 1.25 to 1.41 and litter size from 1.33 to 1.53. These results demonstrate the role that supplementation could play in improving reproductive performance. However the amount and type of supplement still remains to be determined and an understanding of the mechanisms involved requires to be further developed.

Programme Unit 7

Systems studies in ruminants

Hill sheep

The purpose of the studies concerned with hill land is to test the principles which determine the integration of resources in improved systems of sheep production. Field scale studies have been carried out in the widely different but limited range of environments represented by the Sourhope, Glensaugh and Lephinmore 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 is 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 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 the stocking rate and level of individual sheep performance obtained 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 the 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 these studies, two kinds of pasture resources are identified. One, of high nutritional quality, is used primarily 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 mainly throughout the winter and between weaning and pre-mating. Lambs are removed from the system at weaning, except for the replacement ewe lambs, which may either be accommodated on an enclosed grazing during the winter or off-wintered. In the following summer the ewe hoggs graze 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.

The evaluation of improved systems of sheep production from grassy hills (*Research objective 052*)

[RbnHA, JE, TJM, ARS, GG, EVD]

The area chosen for this study at Sourhope (Hairney Law/Auchope) extended to 283 ha, rising from 250 to 490 m, with 35-40% 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. The first phase of the study was based on the improvement of indigenous hill vegetation by grazing control. Initial capital inputs were restricted to the fencing of the *Agrostis/Festuca* pastures, and the retention of extra stock ewe lambs to allow a build up of stock numbers. The study has been reported in detail up to and including 1976 (Armstrong *et al*, 1978).

In the second phase of the study beginning 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 the spring of 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 lactation, there are 17.8 ha of reseeded ground. During the period 1974 until 1980 stock numbers were increased slightly from 600 to 631 ewes.

Table 11
Production Data Hairney Law/Auchope

	Stock nos.	Weaning %	Total weight lambs weaned (kg)	Total weight wool (kg)
Pre-development (5 yr average)	387	90.6	7924	869
Maximum production Phase I (1972)	528	104.7	14046	1369
End Phase I (1974)	600	91.5	14329	1454
End Phase II (1980)	631	118.2	19471	1887
1981	649	104.0	17905	1610
1982	674	120.3	20149	1590
1983	683	110.5	19486	1723

Table 11 summarises the production data from the unit prior to development, the peak level of production in the first phase in 1972, at the end of the first phase in 1974, the end of the second phase in 1980 and for the last three years when stock numbers have been increased by up to 14 per cent (683 ewes).

Since the beginning of the project lamb output has increased by 250% and wool output has more than doubled. The study continues with 662 ewes in 1984.

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 1982 a further £6,343 has been invested, raising the total capital invested to £7,032. The flock gross margin during the period 1980 to 1982 has increased from £11,907 to £14,385.

The cash flow at prevailing costs and prices has resulted in a cumulative balance of £30,750 at the close of 1982. In addition to this, there should be added the extra stock valuation of £11,601, giving an overall cumulative balance of £42,351. 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. The extent to which this land improvement can support increased stock numbers is currently being evaluated.

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). *Hill Farming Research Organisation 7th Report, 1974-77*, pp. 69-101.

Investigation of the lifetime performance of ewes (Hairney Law/Auchope)

Data covering 16 years and 1020 ewe records with a full five years of data have been examined to explore relationships between ewe performance in earlier and later parities; ewes which died at any stage or were culled from the flock have been excluded.

Ewes which gave birth to twins in each of their first three years of production gave birth to one lamb more in their final two years of production than ewes lambing singles in each of their first three years. This finding was confirmed by examining the number of lambs born in the final production year to ewes producing either singles or twins in each of their first four years of production. The difference was on average, half a lamb. These results indicate that ewes may be selected for high lifetime performance on the basis of their recorded lambing performance in their first three productive years.

It is also possible from the records to trace the maternal ancestry of high performing ewes for up to six generations. The levels of lambing performance achieved by the ancestors of high performing ewes (based on their first three years performance) have been investigated. It shows in the current 3-crop ewes in the flock that there is a significantly higher lambing performance which is positively associated with the lambing performance of their dams; there is also a similar trend in the 4-crop ewes but it is not significant.

Examination of the flock records in this way provides a basis for selecting future ewe lamb replacements in association with other important physical characteristics required of the future breeding ewe.

The evaluation of improved systems of sheep production from *Calluna-Eriophorum* bog (*Research objective 053*)

[ARS, TJM, EVD]

The effect of live weight of ewe lambs at weaning on their subsequent lifetime performance

Data for 796 ewes, from the Midhill Development Project at Lephinmore, for which there exists full lifetime records (i.e. from birth to final production year) were analysed to ascertain the effect of replacement ewe lamb size on lifetime performance.

Table 12
Mean lifetime production from categories of ewe lambs retained as flock replacements

Weight of ewe lamb when selected	1 Number in class	2 Total Wt of lamb reared per ewe (kg)	3 Total No. of lambs reared per ewe	4 Mean Wt per lamb reared per ewe (kg)	5 Total No. of productive years per ewe
<22 kg	54	87.4^{ac}	3.83^{ac}	22.0^{ab}	4.18^{acd}
22-24 kg	145	74.1^{b}	3.22^{b}	20.9^{a}	3.76^{b}
24-26 kg	212	85.3^{a}	3.67^{a}	21.8^{a}	3.93^{abd}
26-28 kg	176	98.9^{c}	4.16^{c}	23.6^{b}	4.20^{c}
28-30 kg	127	99.2^{c}	4.17^{c}	23.1^{b}	4.23^{c}
30-32 kg	54	93.3^{c}	4.13^{c}	22.1^{b}	4.14^{cd}
>32 kg	28	98.0^{c}	4.03^{ac}	22.5^{b}	4.32^{cd}
Total	796	89.6	3.83	22.2	4.05

Means (within columns) with different superscript letters are significantly different at the 5% level.

Table 12 shows the means of various production parameters for ewes classified on their live weights as lambs at weaning. Total weight of lamb weaned per ewe (Table 12, column 2) shows that ewe lambs weighing more than 26 kg produce, over a lifetime, 10-15 kg live weight more of weaned lamb than lighter ewe lambs. This increase in production results from three factors; a greater number of lambs reared (column 3), a higher mean live weight per lamb (column 4) and a longer production life (column 5). Birth type of the ewe lamb (single or twin) had no significant effect on any of the production parameters shown in Table 12 nor had the live-weight gain made by the ewe lambs in their hogg year.

There is no clear explanation of the reduction in all production parameters for the 22-24 kg weight group, nor conversely for the increase in the

<22 kg weight group, since birth type of the ewe lamb had no significant effect. The investigation is continuing.

The evaluation of improved systems of sheep production from *Calluna* moorland (*Research objective 054*)

[TJM, JE, JAM, RDMA]

The land resources comprise 182 ha of heather-dominant moorland at Glensaugh (Cairn) rising from 200 to 460 m and include 23 ha of permanent grassland. Up to November 1978, a system of management similar to that outlined in research objective 052 was used relative to the seasonal allocation of stock to the enclosed permanent grassland and hill areas. The six year average level of production from the unit (1973-1978) with 198 ewes was a weaning percentage of 93 and a total lamb output of 4663 kg.

During 1978 and 1979 two areas of the hill, 17.2 ha and 15.7 ha respectively, were enclosed, and in each eight 0.5 ha blocks of reseeded pasture, distributed evenly throughout each enclosure were created. 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; stocking rate has been set during this period to use up to 40% of the current season's shoots of heather within these areas. Ewe pre-mating live weights increased up to 57.5 kg (November 1980), the average weaning percentage for the three years 1979-1981 being 102.4 and average total lamb output being 5212 kg. While these levels are greater than those between 1973-1978 subsequent levels have declined, in part as a consequence of poor levels of herbage production from the reseeded blocks within the enclosed hill paddocks which have given rise to lower ewe pre-mating live weights and a lower level of reproductive performance. The low levels of herbage production have been investigated in detail by the Plants and Soils Department (see research objectives 103 (p. 8) and 105 (p. 14)); the indications are that in order to sustain levels of herbage production of not less than 5000 kg/DM/ha a minimum annual application of 80 kg of nitrogen per hectare will be required. In the light of this information and the need to improve the overall level of utilisation on the open hill the project is under review and will enter a new phase during 1984.

The evaluation of improved systems of sheep production based on off-wintering with and without land improvement (*Research objective 055*)

[RbnHA, JE, TJM]

Stocking rates in traditional sheep production 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 suggested that these may be recouped to only a very limited extent by improved individual sheep performance, and that substantial increases were 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 study has attempted to measure the responses in terms of both stocking rate and individual performance from systems of production in which ewes are in-wintered and which either have, or do not have, access to improved and reseeded land in the summer.

The study has taken place at Sourhope on two similar areas, the Rigg and Gairs, 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 (see research objective 052). The ewes are housed from the beginning of January and latterly have been lambed in the sheds.

Until 1978 25 suckler cows were grazed during the spring, summer and autumn on each unit such that the number of grazing days on each unit was the same.

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 ewe live weights which the two areas could reasonably be expected to sustain at mating. At that point the breed of ewe was changed and Scottish Blackfaces were progressively introduced from 1975. The flocks became wholly Blackface in 1979.

Table 13
Production Data for Rigg and Gairs

	Rigg (without land improvement)			Gairs (with land improvement)		
	Ewe Nos.	Weaning %	Total weight lambs weaned (kg)	Ewe Nos.	Weaning %	Total weight lambs weaned (kg)
SC Cheviots — with cattle (1970-1974)	241	89.8	5066	238	90.1	5209
Scottish Blackface — no cattle (1979-1983)	267	120.8	9073	276	123.4	10106

Table 13 provides a summary of the production data from both units, firstly during the period 1970-1974 when both units were stocked wholly with South Country Cheviot ewes and when ewe pre-mating live weights increased up to 54.1 kg (Gairs, 1974), and secondly during the period 1979-1983 when both units were stocked wholly with Scottish Blackface ewes and ewe pre-mating live weights reached 58.0 kg (Gairs, 1979). Though there have been changes in cattle stocking and some increase in ewe numbers, output of lamb on the Rigg and on the Gairs has almost doubled. Lamb output from each of the units prior to their development was less than 3000 kg with stock numbers of between 130 and 140 ewes.

Though differences between the output of the two units continue to be small the study provides good evidence that the summer carrying capacity of these units with off-wintering is at least double that of year-round grazing systems of management, and that the choice of genotype is also likely to influence the output achieved.

Systems of upland sheep production (*Research objective 056*)

[TJM, RDMA, ARS, EVD, HKS]

A number of studies have been carried out during the last six years on various aspects of upland sheep production. It is now possible to draw some conclusions about the type and level of supplement necessary to achieve satisfactory levels of performance in early lactation. Information is also available on the sward conditions necessary to achieve satisfactory levels of sheep performance during the remainder of lactation and also maintain optimum levels of herbage growth and utilisation. Further information is required to clarify the position post-weaning and during the pre- and post-mating periods, but it is possible to outline the minimal sward conditions that appear to be required to sustain satisfactory levels of reproductive performance. This knowledge requires to be evaluated in whole systems of production.

The objective of the current experiment is to examine the effect of maintaining sward grazing conditions at two levels from as early as possible after lambing until weaning, on the individual performance and total output of Border Leicester × Scottish Blackface (Greyface) ewes and their lambs, and on the amount of winter fodder produced as a consequence of controlling sward conditions by closing areas for conservation. Two stocking rates (10 and 15 ewes per hectare) are included and one level of annual nitrogen application, (150 kg N per hectare) is used. The study is replicated three times. The ewes are mated in late October using Dorset Down rams, and lambing commences around 20 March.

During 1981/82 an experiment of similar design was carried out to assess the decision rules required to achieve the two levels of sward conditions required. It was also used as a means of pre-treating animals for the experiment which began in 1983, since once allocated to a treatment and replicate, the ewes remain within these until the end of the experiment, or until they are culled or cast for age at five years old. The experiment will last for a minimum period of three years.

The two sward condition treatments, which are measured in terms of herbage mass and height, are achieved by operating a series of decision rules with respect to the time at which ewes are allocated to their summer grazing area and the proportion of grazed area which is closed for conservation. Other decision rules control the amount and period during which supplementary feed is given, and the date on which ewes are removed from their grazed area and housed for the winter. Feeding is controlled during the winter in relation to ewe weight, condition score change and foetal load. Fertiliser N application is controlled by 10 cm soil temperature for the first application, and thereafter by date.

Early results suggest that delaying the stocking of pasture in spring until sward height is between 4-6 cm, as compared to stocking pastures as the ewes lamb, makes it possible to close areas for conservation earlier and to a greater extent; this ultimately results in a greater amount of winter fodder being provided. As would be expected treatments with a high, as opposed to a low, stocking rate produced less winter fodder.

Lamb live weight and lamb live-weight gain appear to be more affected by the height of the sward being grazed than by stocking rate but there is a strong suggestion that the direction of change of sward height is important. Lamb growth is less on taller swards (6 cm) which are being reduced in height than on short swards (3 cm) which are increasing in height.

The control of sward height by conservation ceases at the beginning of August. Thereafter herbage height becomes a function of stocking rate. Herbage height at mating (October 1983) averaged 3.4 cm on swards carrying 15 ewes/ha as compared to 4.7 cm for swards carrying 10 ewes/ha; this difference was significant ($p < 0.01$). Stocking rate therefore has by far the greatest effect on ewe live weight, ewe live-weight change and condition score after weaning, and this has a significant effect on reproductive performance.

In this first year of the experiment it was noted that there were substantial differences in herbage growth between replicates (fields), as evidenced by differences in the amounts of conserved forage produced. This highlights the need for much better information on the factors determining the responses to different levels and patterns of nitrogen applied to soils of different organic matter content and swards of different management history.

A management model for upland sheep production (*Research objective 059*)

[ARS, TJM]

A model, which will allow the testing of a number of decision rules by which an upland sheep system might be managed, is under construction.

The intended purpose of the model is to test the effects of such management decisions as stocking rate, maintained herbage level on grazed areas, dates of closure for forage conservation, and date of weaning on lamb growth, ewe live-weight change and the amount of herbage conserved.

The model currently consists of a number of components. A ewe lactation component deals with dry matter intake, partition of energy to live-weight change and milk production and utilisation of body reserves. A second component deals with lamb growth based on milk and dry matter intake. A third component handles herbage growth and conservation decisions. At present, the model deals only with the period from lambing to weaning at which stage conservation is usually complete and regrowths are opened for grazing. There is insufficient information at present available on which to model this phase adequately.

A new component, dealing with decisions round the mating period has been developed. This component handles herbage growth, ewe intake and changes in ewe live weight and condition. It has already been used to formulate a supplementary feeding decision rule for the upland sheep systems experiment (research objective 056). The rule is designed to provide a level of supplement to ewes around mating which is determined by herbage state and to ensure that achieved condition is maintained over the mating period.

Model the consequences of land use decisions with respect to sheep farming and forestry in hill and upland areas (*Research objective 061*)

[ARS, TJM]

The model referred to in the HFRO Biennial Report 1979-81 (pp. 122-137) has been developed to take account of areas across which it would be impossible to build roads, for example, steep slopes and bogs. A newly developed procedure searches for routes which avoid these areas. The procedure is also used to ensure that roads are properly costed against the improvement of agricultural blocks where these may be too far from access to allow cross-country haulage of fencing materials and fertilisers.

The model has been further developed so that specified landscape objectives can be achieved and incorporated into the planning phase. To meet these objectives the descriptive matrices of the model have been reduced from 10 to 2.5 ha in area. This allows a more detailed representation of the patterns produced by mixing the two land uses, sheep grazing and forestry, within the area of one farm or estate.

Examples of the landscape objectives which are incorporated include (a) a need to avoid planting areas with trees where they would mask an attractive landscape feature, or to avoid screening a more general view from a public road, (b) a need to plant trees at specific sites to act as a screen, (c) the achievement of an appropriate scale and degree of diversity in landscape.

Consideration is given to the identification of areas where intimate, mixed patterns of land use are desirable, and conversely to those areas where large scale patterns are considered to be more appropriate. The planning phase of the model is being modified to allow for land allocations to be made in such a way as to produce greater or lesser degrees of landscape diversity.

The cost of taking account of landscape requirements will be determined by the economic assessment component of the model.

Disease prevention programmes for systems of hill and upland ruminant production (*Research objective 062*)

[AW, ARF, AJM]

Introduction

The preventive veterinary programmes in the Organisation have been developed to take account of the radical changes in management that have been imposed on some flocks and herds, and the methods of preventive medicine are flexible enough to respond to the changes in the nature and patterns of disease occurrence. Specific programmes are designed for each flock and herd in relation to the characteristics of the environment and the known incidence of disease or parasitism.

Monitoring is an integral part of the concept of prevention. Routine sampling is carried out by the veterinary section. The process embraces clinical, laboratory and epidemiological diagnosis. Routine prophylactic screening is applied to introduced stock and appropriate treatments given.

The latter has been particularly important in the screening of both feral and domestic goats introduced to Glensaugh.

The procedure of monitoring checks the efficacy of programmes and detects emerging problems and indicates where investigations in greater depth are required. Some of the more important aspects dealt with are outlined.

Tick-borne diseases — Cairn (Glensaugh)
In 1981 and 1982 lamb losses due to tick-borne disease occurred in the spring on the Cairn reseeded pastures, which are enclosed with a proportion of indigenous vegetation. While these support more sheep per unit area, the indigenous vegetation provides a suitable environment for sustaining tick populations. Whilst evidence of heavy tick infestations had not occurred for many years, the influence of grouse and hares in re-introducing tick populations is always present. The losses were attributable to tick-borne fever (TBF) infection, which induces immunosuppression, in combination with infections such as pasteurella, louping-ill and tick pyaemia.

In 1982 a group of lambs were artificially infected with the strain of tick-borne fever which occurs on the Cairn; this was done soon after birth with the objective of inducing immunity prior to exposure to ticks. In that year an early tick rise occurred and lambs acquired both artificial and natural infections almost simultaneously. Lambs were lost with TBF/pasteurella, TBF/louping-ill and tick pyaemia infections and there were no differences between treatment and control groups.

In 1983 ewes were given the 'Cairn' strain of TBF pre-mating and again pre-lambing to investigate whether protection by this means was possible. Due to severe weather during lambing and consequent heavy lamb losses too few lambs from the treatment and control groups were available for valid comparison. There were practically no losses due to tick-borne disease among those lambs available for post mortem examination.

Further work will be carried out in an attempt to test the validity of controlling TBF by immunisation procedures and the possibility of immunisation against the tick itself will be studied.

Clean grazing system — Hartwood

The management objectives at Hartwood have changed from those of commercial farming to those necessary for a research station fulfilling the needs of an intensive research programme. Pasture use at an earlier stage constrained the extent to which clean grazing could become established, and some of the consequences of this have been important in assessing the progress of the clean grazing system in subsequent years. An additional constraint has been the need to provide greater flexibility in the use of sheep and pastures to meet the logistical requirements of the experimental programme. The sheep are now divided into two flocks; the first flock is on a clean grazing system and the other is accepted as being a contaminated flock, with a need for worm control based entirely on the use of anthelmintics applied routinely.

Monitoring in 1982 and 1983 demonstrated that in 1983 a breakdown occurred in the 'clean' flock where low worm egg counts were found in lambs grazing pasture designated clean but no evidence of parasitic gastro-enteritis was observed. Parasite free 'tracer' lambs used on these pastures, when slaughtered, showed that roundworm infection was low; 94% of the infection was found to be due to *Nematodirus fillicollis*. This parasite is of much lower pathogenicity than *Nematodirus battus*, but like *N. battus* can live up to two and three years on pasture.

Recent literature has reported on the persistence of roundworm larvae in the soil and also that calves can be infected to some extent with *N. battus;* pastures could therefore be recontaminated with these parasites leading to infections in lambs in the following year. While this is more important where sheep follow cattle, it is possible that such a mechanism, coupled with the persistence of *Nematodirus* species could even threaten a sheep-cattle-forage conservation rotation. Parasites clearly have a remarkable ability to survive as evidenced recently when the twice-dosing of ewes at parturition failed to control a peri-parturient infection.

The clean grazing system at Hartwood has shown that the benefits to calves are very good and there is a low parasitic contamination of lambs. Further investigations will continue.

Enteric disease of calves — Hartwood

Since the inception of the suckler cow studies a variety of agents producing enteritis have been encountered: viral, bacterial and protozoan agents have been isolated. Vaccination against rotavirus and K99 positive *E. coli* infections, in collaboration with the Moredun Institute, proved to be effective in protecting calves.

More recently, however, there has been a problem with a K99 negative *E.*

coli infection, with no evidence of viral or protozoan co-involvement. Outbreaks in the main have produced high morbidity and low mortality, but recently during a period when cross-fostering was used to establish a group of twin-reared calves enteritis became severe accompanied by a much higher level of calf-mortality. The situation will continue to be closely monitored.

Yersiniosis in deer — Glensaugh

Studies have been initiated to test a *Yersinia* autogenous vaccine prepared from the *Yersinia* strain isolated at Glensaugh, in collaboration with the Moredun Institute. *Yersiniosis* is a stress-related disease occurring at Glensaugh in young stock in the autumn and early winter.

General

Jaagsiekte is an endemic disease among the Greyface ewes at Hartwood; in order to assist the Moredun Institute in its search for a means of controlling the disease all clinical cases are removed to their laboratories and also to the MAFF Lasswade laboratory for examination and study.

An outbreak of joint-ill in lambs at Hartwood in 1983 was caused by *Streptococcus dysgalactiae* which is not the usual organism associated with this disease but may have been more prevalent due to the farm previously being stocked with dairy cattle. The focus of the initial infection was found to be centred at ear infection sites post-tagging.

It has been observed at Hartwood that despite supplying magnesium acetate in the drinking water of lactating suckler cows, serum levels can be dangerously low in wet weather, therefore magnesium rich cobs are used in the dangerous periods in spring and autumn.

Borderline plasma copper concentrations have also been observed in cows grazing certain pasture in the spring; the levels are insufficient to produce a clinical effect and are transient. This aspect will continue to be monitored closely.

Programme Unit 8

Possible role for goats in hill sheep farming systems

Introduction

The results of a small scale study conducted in 1981 on the grazing of weed-infested reseeded hill pasture and indigenous blanket bog vegetation by Anglo Nubian goats and sheep showed large differences between the grazing habits and preferences of the two species and were considered to merit further investigation. In the following year a similar study was carried out using feral goats which, it was felt, might be better suited to hill conditions than any of the more common domesticated breeds. The results confirmed the previous year's findings that indigenous hill vegetation and weed species invading reseeded pasture are more readily grazed by goats than by sheep and that, unlike sheep, goats discriminate against clover in their grazing.

It appeared from these preliminary investigations that, in certain types of hill sheep management systems, grazing by goats might be beneficial to sheep production. It was considered, however, that if goats were to find a place on some hill farms by virtue of their grazing preferences some other more tangible forms of production from the goats would also be sought. Although milk is the main goat product in this country, this form of production is likely to be too labour intensive for most hill farms. There is, however, a demand from some ethnic minority groups for substantial amounts of goat meat and it appears that this form of production warrants examination. Also, the undercoat of the feral goat is high quality cashmere and thus of considerable potential value if it can be produced in reasonable amounts and harvested economically, without harm to the animal.

A three-year research programme was initiated at Glensaugh in April 1983 to examine in greater detail the benefits which grazing by goats might have on both sown and indigenous hill pastures, and to study the production of goat meat and fibre on hill and upland sheep farms. An area of some 40 ha of hill land has been fenced to act as a grazing area for goats and a building for the in-wintering of the animals has been erected. A herd of some 200 females, comprising approximately 140 feral goats and 20 of each of the Anglo Nubian, British Saanen and Toggenburg or British Toggenburg breeds has been established. The programme is supported by two new short-term appointments.

Grazing studies on sown and indigenous hill pastures (*Research objective 063*)

[ML, SAG, AJFR, JHB]

Two experiments were conducted at Glensaugh during 1983 to examine further the grazing by goats of certain types of hill pastures.

The first experiment was concerned with the utilisation of rushes by sheep and goats grazing separately on established *Festuca rubra-Trifolium repens* pasture which had been severely invaded by the soft rush *(Juncus effusus)* and by thistles and nettles. There were two replicates of three treatments, viz. grazing by sheep or by goats with sward surface heights maintained at 3-4 cm and grazing by goats with a sward height of 5-6 cm. The 0.2 ha plots were grazed from mid-July to early September. In this experiment the sheep grazed a higher proportion of rush stems than noted in previous studies, but this was mainly confined to the stem tips and the extent of the grazing was very light. By contrast the goats on the plots at the same sward heights grazed the green rush stems very severely and within a period of two weeks very few green stems remained visible. The remaining visible green stems were virtually all grazed on both goat treatments but the mean height of the grazed stems was less on the shorter compared with the taller sward height treatments. The goats were also much more effective in grazing other invading weed species than were the sheep. Previous experiments had indicated that one of the ways in which goats might benefit sheep production is through their discrimination against clover. Estimates of clover cover on the sheep plots decreased from 21 to 7.5% over the period of the study, those on the 3-4 cm grass height goat plots remained virtually unchanged (19 and 20%), while those on the 5-6 cm grass height goat plots increased marginally (22 to 25%).

The second experiment was designed to study the effect of grazing pressure on the utilisation of grass and heather by goats grazing grass-heather mosaics. There were two replicates of three treatments, viz. 20:80 grass:heather by area grazed at either 3.7 or 14.7 goats/ha (considered to be equivalent to 2 and 8 sheep/ha respectively) and 40:60 grass:heather grazed at 14.7 goats/ha. Earlier studies had shown that the greater the amount of grass, the less the extent of the grazing of heather by sheep. In this experiment the converse was observed. At the higher stocking rate the utilisation of the current season's heather growth was 46 and 58% on the 20:80 and 40:60 grass:heather plots respectively. At the lower grazing pressure the heather utilisation was 24%. *Juncus squarrosus* was also present on these plots and at the higher stocking rate some 80% of its leaves were grazed, although at the lower stocking rate the utilisation was of the order of only 20%. The degree of heather utilisation at the high stocking rate on the 40:60 grass:heather plots would be considered to be excessive and potentially damaging to the heather. The results obtained from the other treatments and the clearly contrasting grazing preferences of sheep and goats indicate, however, that there is considerable potential for the complementary grazing of two animal species with respect to the grazing management of grass-heather mosaics.

Cashmere production in domestic and feral goats and their crosses (*Research objective 064*)

[AJFR, ML, JHB, IRW]

A small experiment with 18 castrate feral goats of mixed ages and origins was conducted over the winter of 1982-83 to study the effect of nutrition on cashmere production. Six goats were fed an approximately maintenance diet of hay from September until March (Group I), six received a mixture of hay and a concentrate based on cereals and soya bean meal at a level of approximately 1.67 × maintenance (Group II) and six were offered a mixture of hay and a concentrate diet based on cereals and fishmeal at 1.67 × maintenance (Group III). Fibre production was measured by clipping patches at intervals of 6 weeks throughout the study and by shearing the animals in April.

Evaluation of the clipped patches and of the fleeces was carried out by a specialist laboratory. The results have only recently become available and the data have not yet been examined in detail. At this stage it appears from the results of both the clipped patches and full fleeces that the higher levels of feeding were associated with increased fibre production, but because of the high variability between animals within groups the effects of nutrition are unlikely to be statistically significant. Mean weights of cashmere (with associated S.E.'s) produced by animals in Groups I, II and III were 87 (± 15.4), 106 (± 24.1) and 100 (± 18.4) g respectively. Individual animal production ranged from 31 to 209 g of cashmere and did not appear to be related to live weight, origin or age. Yields (i.e. cashmere as a percentage of total fleece) ranged from 6 to 50%.

In addition to the experimental animals some 20 other feral goats were shorn at Glensaugh. The evaluation of the fibre from these animals gave results similar to those noted above and showed the same high degree of variability. The shearing of these animals was carried out primarily to assess the feasibility of harvesting cashmere by this method, as opposed to combing and from the limited experience to date it would appear that feral goats can be shorn safely provided that they are in reasonable body condition and that they are housed and well fed for a period of about ten days after shearing.

The mean weights of cashmere production noted above are not high, and at this stage the majority of the feral animals in the herd are coloured and their fibre does not attract the highest price. However, fibre quality in terms of diameter and length is very good and the high between-animal variation in fibre production indicates that there is a very considerable scope for improvement through genetic selection. Also, the results of the limited breeding work to date indicate that the colour can be changed to white. At present prices it is estimated that a yield of 200 g of white cashmere of similar diameter to that currently being produced would give a return of about £12 per animal. In terms of stock units it is considered at present that two goats are approximately equivalent to one sheep and thus cashmere would appear to be a potentially valuable form of production meriting further serious consideration.

Services and field research stations

Glasshouses, growth rooms and microclimate

[DES]

The glasshouses have suffered from wind damage on several occasions during the past two years. The clips which hold the glass panes in position have been renewed and their number increased in a bid to lessen the problem. In addition, para web windbreak has been erected as a temporary measure while fast growing conifers, planted as a longer-term solution, establish in a position to break the force of the prevailing wind.

Usage of the glasshouses has been moderate. The growth rooms have been fully used and during the biennium the cooling system was drained, cleaned and refilled with a new, full-strength solution of glycol.

The automatic weather station at Lephinmore was dismantled prior to HFRO leaving the farm. The stations at Glensaugh and Hartwood have continued in use but there are a large number of gaps in the records due to a variety of reasons. A back-up system with traditional daily manual recording is still essential to provide data for the adequate interpretation of plant growth and performance experiments. Attempts to improve the reliability of the automatic stations continue.

Analytical services

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

In support of the research programme about 108,500 analyses were carried out during 1982 and 1983 on 61,700 samples of plant tissues, soil extracts, biological fluids, animal feeds and animal tissues. In addition, substantial numbers of samples were analysed for sulphur by X-ray fluorescence (XRFS) for Rothamsted Experimental Station and smaller numbers were analysed for Animal Diseases Research Association and Edinburgh School of Agriculture. Facilities were provided for the Animal Breeding Research Organisation to undertake analysis of plasma samples for metabolites, and uterine fluid for alkaline phosphatase and total protein.

Analytical methods

A large scale comparison of XRFS and Atomic Absorption (A/A) for chromium analysis in sheep and cattle faeces showed that XRFS gave lower values for some materials than A/A. A considerable amount of development work was carried out and the problem solved by using the Gold scatter tube line. An investigation into procedures for the assay of acetyl-coenzyme A carboxylase in sheep tissues was undertaken. A method for the determination of bicarbonate in infusates was developed. Considerable time was spent in developing a method for molybdenum in plant tissues and soil extracts using carbon furnace electrothermal atomisation.

PDP 11/03 Micro-computer system

[ARS, PEM, ES]

The laboratory data capture and processing system has proved to be extremely reliable. The number of data capture points per run has been raised by a factor of 4 to 131,068 in order to allow full overnight running of gas chromatographs. A locally written peak processing module which can run simultaneously with on line data capture has been developed giving greater flexibility in the use of the whole system.

Electronics

[RAC]

The electronics laboratory and instrument workshop is now well equipped to be able to tackle the wide variety of problems presented; design and development work being the laboratory's main output, with some limited servicing.

Two projects on the automatic monitoring of feeding behaviour in ruminants have been undertaken. The first was with sheep and cattle to monitor grazing behaviour. The major part of this work involved the design and comparison of transducers strapped to the head of a grazing animal. Transducers used were accelerometers, Penning resistance bands (Penning, 1983), inertia and gravity switches, and electro myograph sensors (EMG). Recordings were made and analysed of the output of these devices together with video pictures. The Penning band gave one of the most useful records of jaw movement and the results conformed well with the other techniques.

Secondly, automatic lamb feeders have been designed with computer interfacing to give a quantitative analysis of an individual lamb's feeding behaviour and intake whilst still in a 'group' situation. The apparatus, by re-formatting computer software, can record or control milk intakes by volume or by suckling period.

Many projects now require computer based data logging. In developing a rationalised approach to data acquisition at HFRO every attempt has been made to build in flexibility so as to adapt to rapidly changing technology and faster 'system level' solutions to logging problems. The microcomputers used for logging are Epson HX-20s.

Data logging facilities have been developed for Mettler and Sartorious analytical balances and the design and construction of facilities for a computer interface for the Phillips X-ray Fluorescence Spectrometer is now complete. Various 'off the shelf' style input/output modules have also been designed to link microcomputers to transducers. These modules have been used in the lamb feeder project (above), as the basis for a solarimetric logger, and have many other possible applications.

Research into a technique for the determination of foetal number in pregnant ewes was undertaken. Real-time ultrasonic scanning provides an excellent solution (see p. 141), however at a high cost. Various other 'point source' and ECG methods were also studied as these ultimately could provide a considerably cheaper alternative to ultrasonic imaging. However considerably more signal processing research is required to make these techniques a viable alternative.

PENNING, P. D. 1983. A technique to record automatically some aspects of grazing and ruminating behaviour in sheep. *Grass and Forage Science*, **38**, 89-96.

Longer research reports

HFRO Biennial Report 1982/83 - ERRATA

p. 112 Figure 11 Key to treatments should read:

Key to treatments: ——— Complete, i.e. 5t lime/ha, 3 dressings N at 40 kg/ha, trace elements, Rhizobium and 60 kg K/ha; ▬▬▬▬ complete plus 120 kg/ha extra N (4 dressings, 40, 80, 80 and 40 kg N/ha); .... complete except no N added; - - - - - - untreated.

p. 150 Figure 20 Bog/fescue should read Agrostis/fescue.

p. 155 Table 26 Daily live-weight gain at pasture on low herbage mass with medium level of winter feeding should read 1.02, not 1.20.

p. 170 Table 28 "Improved" should read "Unimproved". 3rd column mean should read 2.8, not 3.8.

Nitrogen fixation and transfer by white clover

C. Marriott and A. Rangeley

Introduction

White clover has a dual role in hill and upland pasture systems. It provides a high quality feed and thus is important in improving the nutrition of grazing animals. It also contributes nitrogen to the system through the fixation of atmospheric nitrogen by its symbiotic partner, *Rhizobium trifolii*, and the subsequent redistribution of this fixed nitrogen through the soil/plant system. The purpose of this report is to present the progress made towards assessing the contribution of nodulated white clover to the nitrogen economy of hill and upland pastures. This contribution is determined not only by the rate at which atmospheric nitrogen is incorporated into the plant, but also by the rate at which the nitrogen becomes available throughout the soil/plant system and the extent to which it is lost from both the plants and the rooting zone of the soil. The net effect of redistribution and loss of fixed nitrogen is referred to as nitrogen transfer, and is of particular importance in low-input agricultural systems in which sward production is largely dependent on the input of nitrogen from the nodulated legume.

Clover and nitrogen fixation

Effective management of hill and upland pastures must provide adequate feed to meet the requirements of grazing animals throughout the growing season, from a stable or, if possible, improving plant/soil system. An understanding of how nitrogen fixation is affected by climatic, soil and management variables is obviously important for determining the availability and growth of herbage in these low-input systems. The seasonal profile of nitrogen fixing activity of upland white clover was investigated at Hartwood Research Station, on a site which was cut to 3.5 cm (to achieve a standing organic matter (OM) of ~ 1200 kg/ha) weekly from mid-May until mid-October to simulate continuous grazing. No fertiliser inputs were made.

Measurements of nitrogen fixing activity were made approximately every 3 weeks by performing acetylene reduction assays on the day prior to cutting. The seasonal profile obtained is shown in Figure 9 together with clover leaf dry matter data from the turves used in the assays. Clover growth resumed during March but the rapid increase in nitrogen fixation was delayed until April, by which time new nodules should have formed. The peak nitrogen fixing activity occurred during the period of vigorous growth in late spring — early summer.

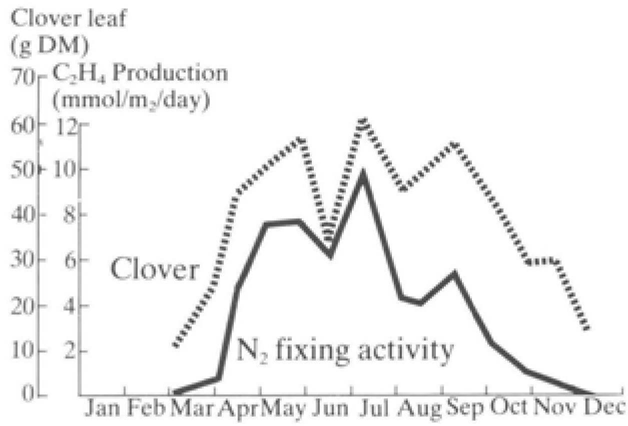

Figure 9

Seasonal profile of nitrogen fixing (acetylene reducing) activity and standing dry matter of clover leaf material.

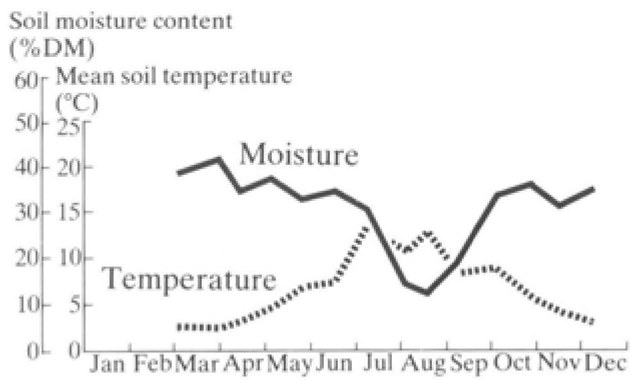

Figure 10

Seasonal profile of soil moisture content and mean 10 cm soil temperature at Hartwood.

Nitrogen fixing activity was closely correlated with clover leaf dry matter on each measurement date, except during the hot, dry conditions in summer. Figure 10 shows the seasonal values for soil temperature and soil moisture content. While little can be done to overcome the influence of climatic variables, the close relationship between leaf area index (LAI) and nitrogen fixing activity indicates that management should aim to optimise LAI, and maintain the level of clover in the sward, in order to achieve maximum levels of nitrogen fixation. In this particular sward the clover content was about 20% on a dry matter basis.

Table 14
Relationship between standing crop and nitrogen fixing activity (acetylene reduction) of grazed white clover at Glensaugh

Standing crop (kg OM/ha)	Nitrogen fixing activity (μmol $C_2H_4/m^2/h \pm SE$)	
	5 July	25 July
500	6.2± 0.8	11.2± 0.7
700	40.8± 9.1	45.8± 7.2
1700	151.3±15.9	109.6±16.6

A similar relationship between the amount of clover and nitrogen fixing activity was found on a grazed site at Glensaugh (Table 14) on swards maintained at different herbage masses (Bircham, 1981). The acetylene reduction assays were carried out over the second period of detailed measurement of sward growth and senescence. During this period clover contributed 6% of total net production in all three swards. Studies in the Grazing Ecology Department showed there was little advantage in terms of net production of herbage or in production of weaned lambs by maintaining continuously stocked swards at a herbage mass in excess of 1200-1500 kg OM per ha. In terms of nitrogen fixing activity it would be advantageous to aim for the higher level of herbage mass.

Effects of fertiliser nitrogen

During spring and autumn there is often a shortfall in pasture production compared with animal needs. This can be overcome by the use of strategic fertiliser nitrogen applications to promote grass growth. However, in the spring this can lead to a delay in clover growth and a reduction in nitrogen fixation due to competition from the associated grasses, since grass growth begins about two to three weeks earlier than clover growth. The effect of fertiliser nitrogen on nitrogen fixation was investigated on cut plots on the Cairn hill 1978 reseed at Glensaugh.

Acetylene reduction assays were carried out, prior to harvest, on plots subjected to different nutrient treatments and the results are presented in Figure 11, expressed on both an area basis and clover leaf dry weight (cut to 2 cm) basis. In all treatments peak nitrogen fixing activity occurred during the period of vigorous growth in late spring—early summer. Drought conditions over the summer caused a decline in activity and, although clover dry matter production recovered, when soil moisture content increased there was no increase in fixation. (The rainfall for June, July and August was 25 mm, 27 mm and 65 mm respectively). Acetylene reduction assays were carried out on one occasion during the following year (14.7.83) when soil moisture content was not a limiting factor (Table 15). The level of nitrogen fixing activity was similar to peak values obtained the previous year. Nitrogen fertiliser decreased nitrogen fixation mainly through a decrease in the clover content of the sward. The reduction in activity was significant during the period of maximum activity resulting in a large decrease in the seasonal input of fixed nitrogen.

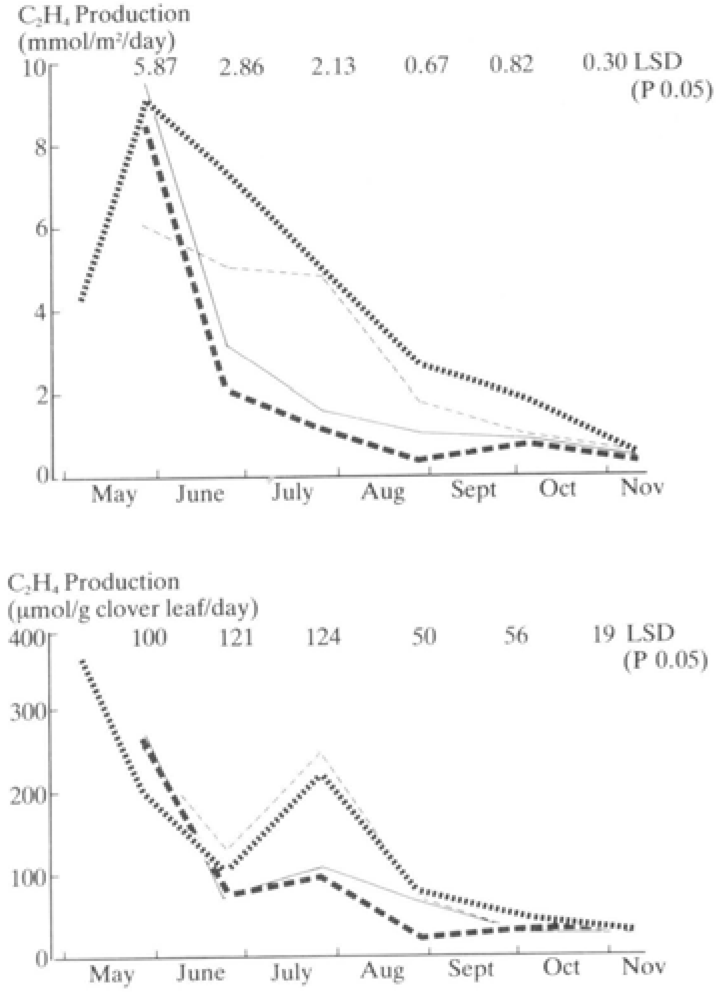

Figure 11

Nitrogen fixing (acetylene reduction) activity of white clover on Cairn Hill 1978 reseed measured in 1982, shown on an area bases (top graph) and on a clover leaf dry weight basis (bottom graph).

Key to treatments: ——— Complete, i.e. 5t lime/ha, 3 dressings N at 40 kg/ha, trace elements, Rhizobium and 60 kg K/ha; ▬ ▬ ▬ complete plus 120 kg/ha extra N (4 dressings, 40, 80, 80 and 40 kg N/ha); ········ complete except no N added; - - - - - untreated.

Table 15
Nitrogen fixing activity (acetylene reduction) of white clover on Cairn hill 1978 reseed measured 14.7.83, with % white clover content of the sward

Treatments:					
	1982	C	C	C-N	U
	1983	C-N	C	C-N	U
Nitrogen fixing activity	Area basis ($mmolC_2H_4/m^2/day$)	5.25	7.30	9.23	5.44
	Leaf dry wt. basis ($\mu molC_2H_4/g/day$)	150	118	105	110
% White Clover		13.3	14.7	34.2	17.1

Treatments: C — complete, i.e. lime 5 t/ha, 3 dressings of 40 kg N/ha, trace elements, Rhizobium, 60 kg K/ha.
C-N — complete minus nitrogen.
U — untreated.
Only one fertiliser N application (40 kg/ha) had been made in 1983 in treatment C prior to 14.7.83.

It is interesting to note that there was a poor correlation of acetylene reduction activity with nodule number ($y = 0.017x + 158.2$ $r=0.21$). The mean number of nodules per m^2 was 13,000, with a range 6,420—25,920. Nodule number was best correlated ($y = 97x + 72$ $r=0.77$) with the weight of clover shoot material (leaf + stolon). As at Hartwood, there was a positive correlation between acetylene reduction activity and clover leaf dry weight ($y = 54.1x + 88.6$ $r=0.59$). The regression analyses were performed on data from the 1983 measurement only.

Seasonal contribution of fixed nitrogen

The results from parallel ^{15}N dilution experiments at Hartwood to determine the absolute amount of nitrogen fixed are not yet available. However, using a theoretical conversion ($C_2H_2 : N_2 = 4:1$), the amounts of nitrogen fixed during the season can be estimated at about 80 kg N per ha at Hartwood and about 56 kg N per ha at Glensaugh, both somewhat lower than previous estimates for hill clover growing at Sourhope and Lephinmore (Newbould and Haystead, 1978). At Hartwood the difference might be explained by the presence of higher levels of inorganic nitrogen in the soil. In a fertiliser trial within the same field as that used for the acetylene reduction assays there was no significant increase in dry matter production between applications of 100 and 200 kg N per ha, indicating that nitrogen mineralisation was not a factor limiting production. The analysis of soil extracts for inorganic nitrogen levels (both NH_4-N and NO_3-N) will provide a clearer understanding of the interaction of inorganic nitrogen levels and nitrogen fixation. Factors other than soil nitrogen, perhaps temperature and dry soil conditions, may be responsible for the lower level of fixation at Glensaugh. A more detailed comparison of the profiles of nitrogen fixing activity at the two sites will be made when all the data have been collected.

Effects of defoliation

The effect of severe defoliation on the nitrogen fixing activity of white clover is well documented (e.g. Moustafa *et al*, 1969; Chu and Robertson, 1974; Haystead and Marriott, 1978). The defoliation studies were extended to investigate the effect of lenient defoliation on white clover growing in pots. The defoliation treatment, which could be regarded as analagous to an intermittent grazing regime, involved removal of all fully expanded leaf tissue and allowed a 21-day uninterrupted regrowth period. Defoliation caused little reduction in nitrogen fixation in plants which derived 98% of their nitrogen from fixation (determined using a ^{15}N technique). This may be attributed to the fact that the defoliation treatment caused no reduction in the capacity for regrowth, since all young leaves and growing tips remained intact. This, in addition to the long regrowth period, would minimise the period of reduced current assimilate supply and hence reduced nitrogen fixation. Obviously in the field there could be appreciable differences in nitrogen fixation and nitrogen cycling between intermittent and continuous grazing regimes, where leaf material becomes available to the animal as it enters the grazing horizon. A new leaf enters the grazing horizon every 7-10 days depending on the sward height maintained.

Transfer of fixed nitrogen

In addition to the effect on clover nitrogen fixation, climatic and management factors will also affect the processes involved in transfer of fixed nitrogen to associated grass species. A list of possible routes of transfer can be found in Haystead (1983a). In the field work done to date using a ^{15}N isotope dilution technique (McAuliffe *et al*, 1958) no account is taken of the pathway of transfer. Only the net result is measured. This technique compares the ^{15}N enrichment of non-nitrogen-fixing plants growing in a mixture with and apart from the nitrogen fixing legume. Inherent in this technique are assumptions, which are described elsewhere (Haystead, 1983a).

Table 16
N yields and ^{15}N enrichment of grass growing in a mixture with clover or in a pure stand on a deep peat site

	Regrowth period					
	8/6-21/7		21/7-29/9		29/9-1/6	
	N yield (kg/ha)	Atom % ^{15}N	N yield (kg/ha)	Atom % ^{15}N	N yield (kg/ha)	Atom % ^{15}N
Grass-pure	7.82	0.473	18.41	0.466	13.90	0.418
Grass-mixed	11.51	0.479	33.33	0.488	9.59	0.410
LSD ($P < 0.05$)	1.85	0.017	8.22	0.055	5.26	0.015

Using this technique measurements have been made throughout the growing season of nitrogen fixation, grass nitrogen yields and ^{15}N enrichments to determine at what time during the year transfer occurs. The work was carried out on two soil types — a deep peat and a non-calcareous gley. On the deep peat differences were measured in nitrogen yield and ^{15}N enrichments between grasses growing in mixed swards and in pure stands under identical fertiliser and cutting regimes (Table 16). A simple analysis may not be applicable since there is often little isotopic evidence of transfer but the grass grown with the clover has a higher yield and ^{15}N content. This could be explained if the small addition of fertiliser nitrogen was rapidly immobilised into microbial biomass in the grass only plots but in the mixed plots (where there may be a lower organic matter C:N ratio) the grass competed effectively for added mineral nitrogen. Thus the grass in the monoculture would take up less nitrogen and also less labelled nitrogen, since remineralisation is quite slow. As a result the grass from the mixed and monoculture plots could show the same ^{15}N enrichment. Clearly further work is required in more detailed studies of isotopic nitrogen transformations to clarify the differences in dynamics of nitrogen turnover in pasture soils with and without legumes. These studies would provide a means of more meaningful interpretation of net transfer data obtained in isotope dilution experiments.

During a study year in Australia, A. Haystead began experiments to investigate the mineralisation of legume residues, using isotopically labelled material (Haystead, 1983b). He followed the disappearance of ^{15}N from labelled leaf litter applied to the soil surface over a 90-day period after addition. There was a rapid decrease at first, followed by a slower release. However the true rate of nitrogen loss may have been overestimated since it was possible that loss could have arisen from relocation of surface litter in the pasture. In an experiment where *Pinus radiata* seedlings were grown in soil amended with legume residues either with nitrogen, as ammonium nitrate or urea, or without there was little difference between the rates of decomposition in nitrogen treated or control plants. A preliminary analysis of the leaf material indicated a low level of incorporation of legume residue nitrogen, 2% of plant nitrogen being derived from decomposing plant material. Clearly this is an area where much work is required, especially in studies of the soil microbial biomass, to understand the factors affecting the mineralisation of organic matter.

Table 17
Effect of mycorrhizal infection of clover and grass plants on transfer of labelled nitrogen to the grass

	Impermeable barrier		60 μm mesh	
	+M	−M	+M	−M
% N grass	1.92	2.02	1.93	1.99
Atom % ^{15}N grass	0.398a	0.387a	0.571b	0.411b

a. Mean of 3 determinations on material from 3 separate plants. The measured ^{15}N abundances are significantly ($P < 0.01$) greater than natural abundance of grass grown in the same medium.

b. Mean of 9 determinations on separate plants. Both values are significantly greater than natural abundance ($P < 0.01$) and significantly different from each other.

Studies of individual pathways involved in the transfer of fixed nitrogen have concentrated on two specific areas, namely the role of vesicular arbuscular mycorrhizal (VAM) fungi and the possibility of canopy ammonia transfer. Mycorrhizal infection studies have shown the involvement of the fungi in phosphorus nutrition (Sanders and Tinker, 1971) and recently it has been shown that phosphorus can travel through direct hyphal connections between plants (Heap and Newman, 1980). Preliminary experiments were set up to investigate the possible mediation of VAM fungi in nitrogen transfer, using a technique where ^{15}N labelled nitrogen was applied to the legume plant. Data are presented (Table 17) from an experiment with Wimmera ryegrass and subterranean clover, inoculated with *Glomus* spp. Transfer was increased in the inoculated pots and since it occurred in pots with the 60μm mesh barrier it could have been due to hyphal transport. Similar experiments with perennial ryegrass and white clover showed the same response. Further technique development is required before a quantitative assessment can be made, but it obviously has implications in the recycling of nitrogen in mixed swards.

Table 18
^{15}N abundance of bean *(Vicia faba)* and corn *(Zea mays)* shoots, grown with separate roots and enclosed shoots[1]

	Atom % ^{15}N				
Harvest[2]:	1		2		3
Bean	11.724	ns	13.163	*	9.124
Corn	0.368	*	0.392	**	0.471

ns — non-significant difference; * $p < 0.05$; ** $p < 0.01$.

[1] The plants were grown in assemblies in which the shoots from the two separate plants were enclosed within a polythene bag — without allowing direct leaf contact. The bean root system was fed with $(^{15}NH_4)_2SO_4$.

[2] 10-day interval between harvests.

The possible role of aerial transfer of ammonia in nitrogen transfer from a legume to an associated grass species was investigated. A preliminary experiment with *Vicia faba* and *Zea mays* had shown that gaseous transfer of ammonia could occur, particularly when the legume started to senesce (Table 18). To give some indication of the significance of such transfer in a field situation simulated sward experiments were set up. There was experimental evidence that transfer had occurred and was greatest in the sward subjected to the lax cutting regime. About 1.5% of the grass nitrogen was obtained via gaseous ammonia transfer from the legume. This amount is relatively small, but in field situations where there are urine patches in a leafy sward the transfer may be much greater. However, under higher grazing pressures much of the volatilised ammonia may be lost.

Conclusion

The work presented describing the contribution of white clover in terms of nitrogen fixation and transfer shows that further attention needs to be focussed on the effect of management practices and climatic variables in different soil types. Since in the short-term the greatest increase in pasture production in the uplands will come from the strategic use of nitrogen fertiliser rather than from biologically fixed nitrogen it is of particular importance to understand how the legume responds to such practices. More quantitative data is required for the individual pathways of nitrogen transfer to grass, e.g. via the animal, plant senescence and decay, and gaseous transfer, in both hill and upland situations. Against this background of information it is hoped to be able to create a predictive model to assess the response of these components of the nitrogen cycle to particular management strategies.

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Grazing management and pasture production: the importance of sward morphological adaptations and canopy photosynthesis

S. A. Grant and J. King

Introduction

In a previous review paper, research work on grazing management at HFRO was discussed mainly in relation to pasture utilisation and animal production (Hodgson and Maxwell, 1981). Hodgson and Maxwell illustrated the grazing system as a flow of organic matter into the sward, from the sward to the animal, and ultimately into the animal product. They stressed the dynamic nature of grazing systems and the need to consider the systems not just in terms of flow but in terms of populations of plants and animals and the way in which they interact. In this report we consider more fully the influence of grazing management on pasture production.

In grazing systems the measure of herbage production which matters is the amount of herbage utilised by the grazing animals. Managements which aim to maximise pasture growth rate can be inefficient in terms of utilised herbage, as has been amply demonstrated in studies on continuously stocked pastures (Bircham and Hodgson, 1983; Grant *et al*, 1983). In these studies tissue flow techniques, which involve detailed measurements of the rates of growth and senescence loss per tiller and of adjustments in tiller population densities, were used to investigate the relationships between maintained, steady state sward conditions, and rates of growth, utilised production and senescence loss per unit area. Growth rate was shown to have a curvilinear relationship with increasing sward height and mass, and senescence loss a linear relationship. Utilised production was little affected within the height range 2.5-6 cm but declined considerably below 2.5 cm because of the steep fall in growth rate on very short swards. Above 6 cm it declined gently because of increasingly ineffective utilisation and the consequent high rates of loss to senescence.

Well-grazed short vegetative swards develop high population densities of small tillers while taller swards develop lower population densities of larger tillers. This differentiation occurs in response to competition between tillers for light. In vegetative swards which have had time to reach equilibrium with the defoliation regime and the level of incident light, the relationship between tiller weight and population density conforms to the -3/2 self-thinning law of Yoda *et al* (1963). Very short over-grazed swards, however, do not conform to the rule and have fewer tillers than would be expected because of frequent uprooting and possibly also a depressed rate of tiller formation.

In practice tiller population densities are continually adjusting. The herbage mass in relation to the seasonal variation of incoming radiation determines the potential tiller density and factors which influence growth rate such as temperature, moisture and nutrients influence the rate at which the swards adapt. Tiller densities in early spring are usually low as a result of low winter light levels and low temperature. The seasonal increase in level of incoming radiation up to midsummer offers scope for tiller density increase. This period overlaps the main reproductive phase when tillering rates tend to be slow because of apical dominance effects and swards maintained at different heights may show a similar order of increase in tiller number up to the summer solstice. Tillering is rapid after the main reproductive phase and, as at this time light levels are falling after the solstice, it is not long before limiting conditions are produced and tiller populations differentiate according to the differences in sward height or mass which are maintained.

Differences in sward morphology which result from differences in management can have an important effect on growth rate by influencing the ability of the sward to produce new leaf area. For example when tall swards are grazed down to a leafless stubble, not only is the tiller density low and the area of leaf on each tiller small, but the new leaf produced is erect so that light interception is low. As a result, growth rate for a time is slow. On the other hand when stock are removed from a sward which has developed a high tiller density and a prostrate growth form under continuous stocking, an enhanced rate of growth might be expected because of rapid expansion of young leaves from many tillers which are disposed at an angle which maximises light interception.

Recent studies have investigated the effect of change in management (from continuously stocked hard grazed to laxly grazed and vice versa) and have compared continuously stocked swards with both the grazing down and regrowth phases of intermittently grazed swards. The results of these studies will be outlined firstly in terms of tissue flows, i.e. the rates of adjustment in tiller size and production per tiller and in tiller population densities, and secondly in terms of the pasture considered as an area of leaf surface, i.e. in terms of the photosynthetic efficiency of the canopy.

Growth per tiller and tiller populations

The effects of change in herbage height and mass on growth and senescence rates per tiller and on tiller populations under continuous stocking have been studied in two experiments. The first (Bircham and Hodgson, 1984) was conducted in autumn and measurements were made over a 2-week period starting 4 weeks after the management change was initiated. The highest rates of growth and senescence were obtained on

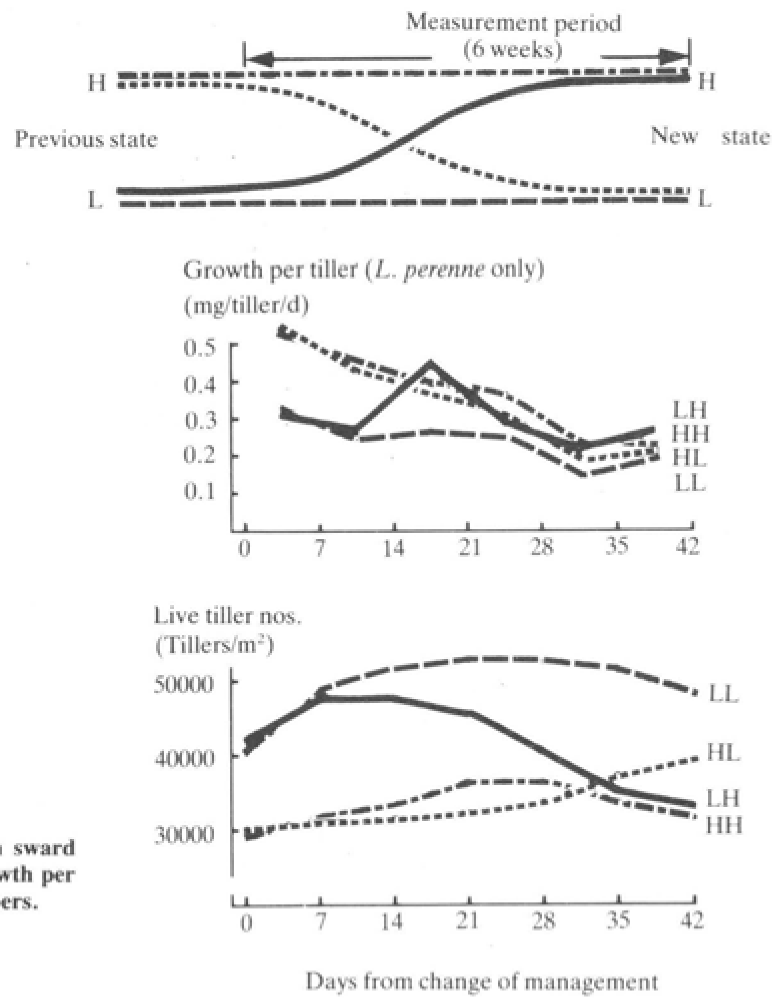

Figure 12

Effects of change in sward management on growth per tiller and tiller numbers.

previously short swards where herbage had been allowed to accumulate (LH) whereas the lowest rates occurred on previously laxly grazed swards which were subsequently grazed short (HL). Swards maintained short (LL) or tall (HH) had intermediate growth rates. Utilised production was similar on LL, HH and LH treatments but was reduced in the HL sward.

In the second experiment, conducted in late spring - early summer (Grant and Barthram, unpublished), measurements were made during 6 weeks and began immediately the management change was introduced. The changes with time for growth rate per tiller (*L. perenne*) and tiller population density (all tillers) are shown in Figure 12. Comparing HL with HH swards, growth per tiller was only slightly reduced by the change from lax to close continuous grazing. There was an initial reduction in tiller numbers before the numbers began to rise 5 weeks after the change. On swards where the herbage was allowed to accumulate (LH) growth rate per tiller increased rapidly and was similar to those of HH swards (maintained tall) after 2 weeks; the associated decline in tiller numbers was relatively slow and it was 5 weeks before density had fallen to similar levels as on the HH swards. This time lag between adjustments in production per tiller and adjustments in tiller population density provides a mechanism by which

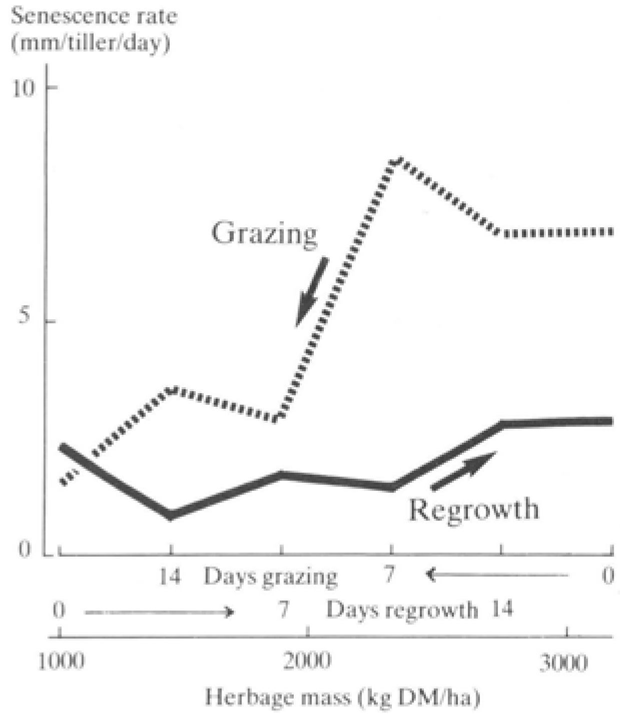

Figure 13

Senescence rate per tiller for swards regrowing or being grazed down over 21 days.

gross production per unit area on LH swards can be temporarily increased compared with the HH swards (cf above). Increase in senescence loss per tiller is not as immediate as increase in growth rate and is delayed until the new leaves, produced during herbage accumulation, reach the normal age for senescence to begin. Thus before senescence increases there is a delay of about three leaf appearance intervals (which is about three weeks in summer), during which there is a transient improvement in net herbage production. This effect is also seen during the regrowth phase on intermittently grazed swards and is illustrated in Figure 13. Senescence loss per tiller remained low during an 18-day regrowth period but was high during the subsequent period of grazing down, and diminished as the herbage mass was reduced.

The pasture considered as an area of leaf surface

Pasture growth rate depends on the rate at which carbohydrates are formed by the plant and therefore on the rate of photosynthesis and respiration.

The leaf surface area of a pasture may be anything from one to over six times the area of the ground on which it is growing. This relationship is usually termed the leaf area index (LAI). The leaf canopy intercepts light and by photosynthesis accumulates carbon in the form of simple carbohydrates. After respiratory losses have taken place the carbon appears as root and shoot growth. The rate of canopy photosynthesis is therefore a useful measure of growth rate. It is a function of LAI and of the incident light intensity. However, it is also influenced by a number of factors which can be affected by grazing, and this provides a means by which grazing management can affect growth rate.

For swards grazed intermittently as in a rotational system, considerable differences in net canopy photosynthesis and therefore in growth rate, arise from the grazing process itself (King *et al*, 1984). In Figure 14 curves (b) and (c) represent the regrowth and grazing phases of a rotationally grazed sward. It is apparent that photosynthetic rate per unit of LAI of the canopy while it is being grazed down (curve (c)) is less than that of the regrowing canopy (curve (b)). That is to say, at any value of LAI the pasture grows more rapidly during regrowth than while it is being grazed. The overall reduction in terms of carbon accumulated is about 22% and appears to be due to two factors; the removal of young photosynthetically efficient leaves by grazing, leaving mainly older inefficient leaves; and the disturbance of the canopy by treading which affects light interception and adversely affects the rate of photosynthesis (Leafe *et al*, 1974).

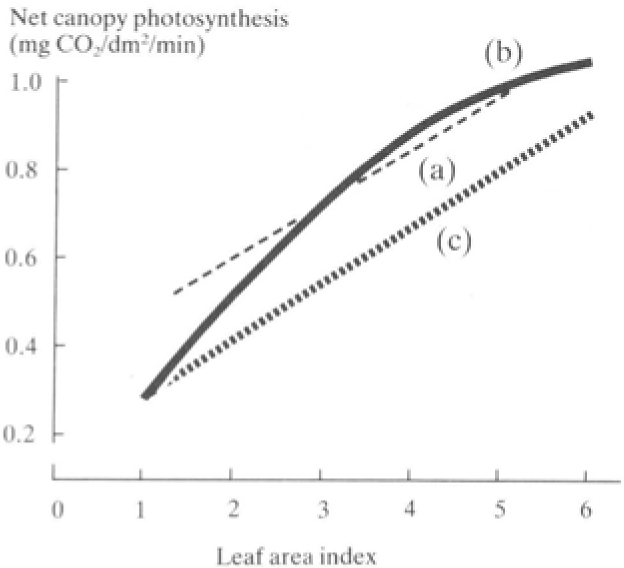

Figure 14

Relationship between the rate of net canopy photosynthesis and leaf area index for rotationally grazed swards in the regrowth (b) and grazing (c) phases and for continuously stocked pastures (a).

Major differences also arise between continuously and rotationally grazed pastures which can be seen by comparing curves (a), (b) and (c) in Figure 14. For continuously stocked pastures maintained in a steady state the relationship between photosynthetic rate LAI over the range LAI 2 to 4.5 (curve (a)) is represented by a straight line, which gives a rate of photosynthesis significantly higher than that for the grazing phase of the rotational swards (curve (c)). Over a wider range of LAI extending down to LAI 1 or less the relationship for the continuously stocked pastures would be curvilinear passing close to zero (Parsons *et al*, 1983a).

It is evident from Figure 14 that below LAI 3 the photosynthetic rate of the continuously grazed swards (curve (a)) exceeds that of the rotational swards (b) and (c) and above LAI 3.5 is slightly less than that of the regrowing canopy (curve (b)). The difference at low LAI is attributable to high light interception by the continuously stocked sward, due to high tiller density and a prostrate growth form with more horizontally disposed leaves, and also to the high photosynthetic potential of the leaves. This is a result of their development in a high light environment unshaded by other leaves (Woledge, 1978; Parsons *et al*, 1983a). In contrast the rotationally grazed sward below LAI 3 is of low tiller density with, in the grazing phase, many leaves of low photosynthetic efficiency, and in the regrowth phase, an erect growth form with low light interception.

At the other end of the LAI range, about LAI 4-5, the small difference between curves (b) and (a) is attributable to the fact that the regrowing swards (b) are ungrazed while the continuously stocked swards (curve (a)) are subject to a low grazing pressure. This depresses the photosynthetic rate relative to that of the undisturbed regrowing canopy, but not as much as occurs when this canopy is subject to a high grazing pressure as in a rotational system (curve (c)).

Productivity of grazing systems

The relationship between the rates of growth and senescence and between the rate of photosynthesis and LAI which have been discussed have implications for the productivity of grazing systems. Comparing continuously and rotationally stocked pastures it can be seen from Figure 14 that below LAI 3 the former is potentially more productive in the same LAI range. Above LAI 3 their potential is similar to that of the regrowth phase of a rotational system but greater than that of the grazing phase which has a consistently low potential. For this reason grazing periods in rotational systems should be as short as possible. For both kinds of pasture maximum utilisation is only achieved if the rate of senescence loss is kept low relative to growth rate. On continuously stocked pastures the optimum balance of growth and senescence is obtained near LAI 3 whereas on rotational swards senescence loss is least when the total length of the rotational cycles does not exceed three leaf appearance intervals. The length of this period varies with season but is about 21 days when grass is actively growing in summer. When the net productivity of these two systems is compared there appears to be little to choose between them (Parsons *et al*, 1983b).

An attempt to increase production by combining the advantages of both systems has recently been made at HFRO. The objective was to allow the amount of leaf to increase periodically as in a rotational system but at the same time to retain the high tiller density, high light interception and high photosynthetic potential of a continuously stocked pasture.

The method was to alternate spells of continuous stocking during which the sward was maintained close to LAI 3 (sward height about 3.5 cm), with periods of herbage accumulation over about 2.5 leaf appearance intervals (17 days) followed by 3 days grazing back to LAI 3. Herbage accumulation was achieved by removing either half or all of the animals during the accumulation periods. Both continuously stocked and intermittently grazed pastures were provided as controls.

Growth rate per tiller (mg/tiller/d) increased steadily with time during herbage accumulation, being on average 30-50% higher after two leaf appearance intervals on plots where animals were removed when compared with the continuously stocked controls. Rates of senescence remained low so that utilised production could be increased. After return to continuous stocking, growth rates per tiller were either better than or similar to those of the controls while senescence losses were similar on both treatment and control plots. Tiller populations were reduced by 18-22% during the accumulation phase in comparison with the controls; earlier in the season this was manifest as a smaller rate of increase in numbers and later on as a decline. Table 19 shows the pattern on treatments where the animals were removed. After the periods of herbage accumulation it was necessary to maintain continuous stocking for four leaf appearance intervals for tiller numbers to build up to match those of the continuously stocked controls. At the close of the experiment in October tiller populations were 44100/m^2 on the continuously stocked controls as compared with only 23300/m^2 on the intermittently grazed control swards.

Table 19
Changes in tiller populations during herbage accumulation (all stock removed) and on continuously stocked control plots maintained at 3.5 cm as affected by season

	Tiller no./m^2 Accumulation period Start	Close	Percentage
First accumulation period (June/July)			
Plots released from grazing	23500	33515	+42.6
Continuously stocked controls	25680	42700	+66.3
Second accumulation period (August)			
Plots released from grazing	47750	40870	−14.4
Continuously stocked controls	49300	49975	+ 1.0
Third accumulation period (September)			
Plots released from grazing	44340	37070	−16.4
Continuously stocked controls	51590	45520	−11.8

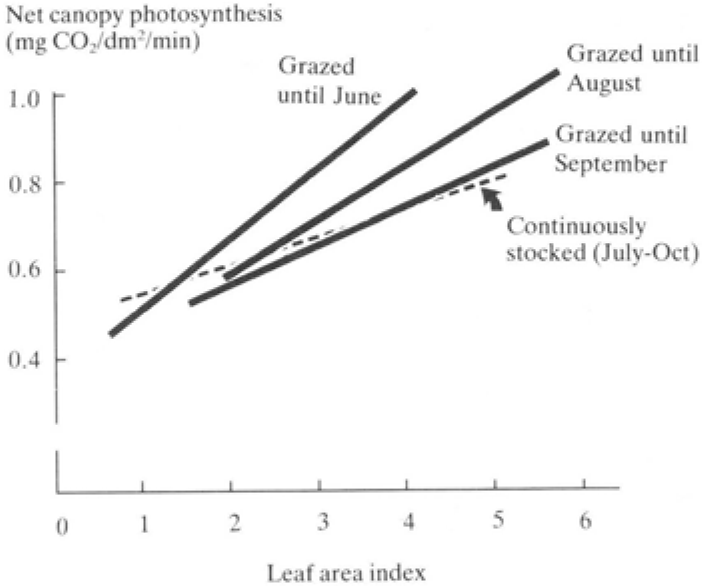

Figure 15

Relationship between the rate of net canopy photosynthesis and leaf area index for grass swards regrowing following the removal of sheep after a period of continuous grazing at three dates in June, August and September respectively and for a continuously stocked pasture between July and October.

Measurements of net canopy photosynthesis were made during three periods when herbage was allowed to accumulate both after halving the stocking rate and after removing the sheep altogether. Similar measurements were made on the continuously stocked swards maintained at an appropriate range of LAI values. Some of the results are shown in Figure 15. The photosynthetic rate during the first (June) and second (August) periods of accumulation increased rapidly as LAI increased and over much of the LAI range was considerably greater than that of the continuously stocked control sward. However, the photosynthetic rate during the third accumulation period (September) was similar to that of the controls. The reasons for these differences are not yet known, but it is evident that it is possible under some conditions to combine high photosynthetic potential with high LAI. These improvements in photosynthetic potential were obtained when the swards were released from grazing. They were much less marked when herbage accumulation took place as a result of a 50 per cent reduction in stocking rate. This suggests that fluctuations in herbage height of set stocked swards as, for example, when growth rate exceeds consumption, are likely to affect the photosynthetic rate only because of the changes in LAI. The photosynthetic rate, at a given leaf area, will be the same as that indicated by the relationship for the continuously stocked swards (fig. 15), that is to say, there will be no increase in photosynthetic efficiency.

Management implications

Clearly there are advantages to be gained by occasional release of continuously stocked swards from grazing but it is too early to say whether such a management practice when incorporated into a year round grazing system offers potential for increased herbage production and utilisation over the season as a whole. However, separate management guidelines for continuously and rotationally grazed swards can be given on the basis of present knowledge. It is safe to say that the maximum rate of utilised herbage production from swards continuously stocked by sheep is likely to be obtained when herbage height is maintained close to 3.5 cm (approximately equivalent to LAI 3) but will not be greatly reduced by variations between 2.5 and 6 cm. For rotational swards in a vegetative state, the precise combination of regrowth and grazing periods which maximises utilised production has not yet been worked out. However, it can be said that an efficient system should have the shortest possible grazing period and a cycling time of not more than three leaf appearance intervals. In summer this will be about 21 days extending to 27 or 30 days at each end of the season.

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Manipulation of ovulation rate and lambing rate in the ewe

R. G. Gunn and S. M. Rhind

Introduction

Lambing rate in the ewe, i.e. the number of lambs born and reared per ewe mated, is the key to profitable systems of sheep production. It is important, however, that the number born bears some relationship to the number that can be effectively reared and there is little advantage to be gained in producing more than a particular system can sensibly sustain in both nutritional and environmental terms. The objective of our programme of research into reproduction is therefore to determine how to control lambing rate at any chosen level so that it may be manipulated accordingly. Since, in practice, the rate is largely under nutritional control, it is necessary first to consider how this operates.

Nutritional control

The reproductive performance of ewes is determined by nutritional effects which apply days, weeks, months or even years earlier. The longer term effects appear to originate during the first 18 months of life and those animals which have been severely undernourished early in life and which have a reduced mature body size have been shown to have a reduced reproductive potential (Gunn, 1977) (Table 20).

Table 20
Live weights and lambing rates of Scottish Blackface ewes with different histories

Level of nutrition		Live weight (kg)		Mean lambing% over 5 years
0-12 months	12-78 months	12 months	54 months	
High	High	38.5	65.7	170
Low	High	27.5	60.1	140
High	Low	38.7	53.1	124
Low	Low	27.2	46.3	118

In the mature animal, severe undernutrition in spring and summer, for reasons such as drought, can reduce the ovulation rate of ewes in the subsequent breeding season some 4 to 6 months later, even when the ewes have recovered body condition and have a normal intake (Fletcher, 1974). Such a result may be caused by a reduction in the number of primordial follicles activated in the ovary.

Both body condition and intake can influence ovulation rate (Gunn, 1983). Body condition is a consequence of food intake over several weeks or months and may be described as having a medium-term nutritional effect. The level of food intake in the days prior to mating may be described as having a short-term nutritional effect. While the response is, to some extent, dependent on breed, in general, ovulation rate increases with increasing body condition (Fig. 16), probably through its effect in determining the number of follicles actively growing in the 20-30 days before mating. Effects of body condition and intake are frequently confounded but, at a certain intermediate range of body conditions, the level of intake may also influence ovulation rate, probably by affecting the proportion of growing follicles which rupture. So, to increase ovulation rate, it is necessary not only to provide a high level of intake at mating but also to raise the level of body condition prior to mating and during the 4-6 months before that.

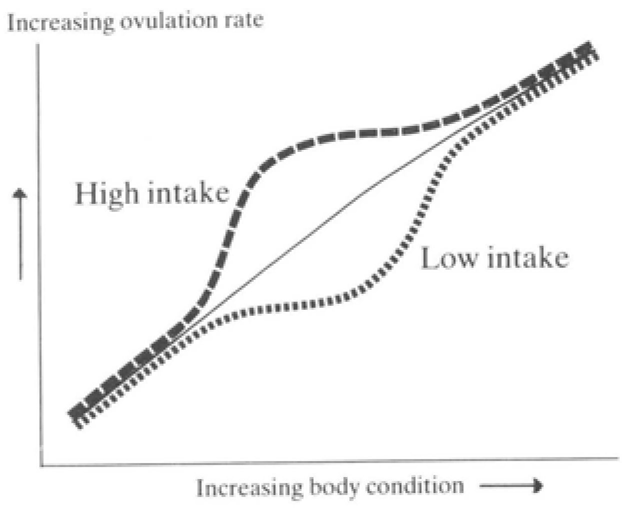

Figure 16

The effect of body condition and level of intake at mating on ovulation rate.

Such advice must, however, be interpreted with caution, since the effects of condition and intake are not necessarily additive and may influence embryo mortality differently from ovulation rate, depending on the condition level, so that the final lambing rate could bear little relationship to the original ovulation rate. For example, studies have shown quite different patterns of response according to the level of condition at 5 weeks before mating, when ewes were subsequently grazed on high quality pasture of adequate amount to ensure condition was at least maintained over the mating period (Table 21).

Table 21
Reproductive performance of North Country Cheviot ewes in different body conditions at 5 weeks before mating

Condition score 5 weeks before mating (mean)	Mean condition score at mating	Ovulation rate	Litter size	Lambing rate	Proportion lambing
⩾3(3.07)	3.11	2.23	1.58	1.26	0.80
2.5/2.75(2.64)	2.92	2.21	1.70	1.50	0.88
⩽2.25(2.10)	2.64	1.87	1.55	1.26	0.81

The intermediate condition ewes had as high an ovulation rate as the fat ewes which failed to maintain as high a litter size or lambing rate, presumably through having a higher embryo mortality rate, and did little better than the lean ewes, in spite of still being fatter and heavier at mating. There is also evidence that failure to maintain body condition over mating, brought about by a decline in nutrient intake, will lead to a depression in lambing rate, irrespective of the level of condition. For the best chance of achieving a high level of lamb production, ewes should be in rising condition prior to mating, a score of between 2.5 and 3 at mating and maintained or slightly increased in condition over the mating period. Too low or too high a condition level and any loss in condition will have adverse effects on response.

Nutritional effects are therefore clearly important in the control of reproductive performance but to really understand why and to assist in improving the level of control, it is necessary to understand the endocrine mechanisms through which body condition and intake mediate their effects.

Endocrine mechanisms

Two hormones, luteinizing hormone (LH) and follicle stimulating hormone (FSH) are considered to be essential for the growth and development of follicles. A third hormone, prolactin, may also be directly involved, although its role is unclear, while several other hormones are secondarily involved.

Circulating levels of LH, FSH and prolactin have been investigated in ewes in similar body condition at the time of mating but which were on either high or low food intakes (approx. 3.0 and 0.8 kg dry matter (DM)/day) for a month before mating. The ewes of the high and low intake groups had mean ovulation rates of 1.95 and 1.40 ($P < 0.01$), respectively, and mean litter sizes of 1.75 and 1.00 ($P < 0.001$), respectively. The numbers of large follicles (> 4 mm diameter) present 3 weeks after mating was similar for ewes of the two groups. There was no difference with intake in the pattern of hormone secretion on day 11 during the luteal phase (days 2-14 after oestrus onset) of the cycle preceding mating. Neither were there any significant differences with intake in mean LH or FSH concentrations in the subsequent follicular phase (2-3 days prior to next ovulation), but LH pulse rate and mean prolactin concentration were both significantly lower during the 48-25 hour period prior to the preovulatory LH surge in ewes on the low pre-mating intake (LH: 0.09 vs. 0.22 pulses/hour, $P < 0.05$; prolactin: 6.94 vs. 13.11 ng/ml, $P < 0{\cdot}01$).

In another experiment, hormone profiles were investigated at the same stages of the cycle in ewes which had similar food intakes but were in either moderately good (score 2.75) or poor body condition (score 1.75). These animals had mean ovulation rates of 1.8 and 0.9 ($P < 0{\cdot}05$), respectively. The number of large follicles present at slaughter was also greater in ewes in good condition (3.1 vs. 1.7; $P < 0.1$). Mean LH concentrations and pulse frequencies during both luteal and follicular phases were unaffected by condition, while FSH levels were higher in animals in good condition at both phases of the cycle (luteal: 71.7 vs. 54.3 ng/ml; $P < 0{\cdot}05$; follicular: 43.1 vs. 34.0 ng/ml; $P < 0{\cdot}1$). The mean prolactin values showed a similar trend (luteal: 12.1 vs. 3.0 ng/ml; $P < 0.001$; follicular: 31.0 vs. 11.9 ng/ml; $P < 0{\cdot}05$).

These results suggest that effects of body condition and food intake on ovulation rate are mediated through different endocrine mechanisms. Differences in body condition apparently affect FSH and prolactin levels in the weeks before mating and these are associated with differences in the number of large follicles. Such follicles are likely to be the ones that have the potential to grow and rupture in response to the preovulatory changes in LH, FSH and prolactin. Level of intake, on the other hand, does not appear to affect the number of large follicles that develop but the recorded differences in hormone profiles in the preovulatory period were associated with different ovulation rates. This suggests that, while intake did not affect the number of large follicles, the proportion induced to rupture may have been increased at higher intakes.

It has long been recognised that the reproductive performance of very fat ewes is lower than might be expected, particularly in view of the relationship between ovulation rate and condition score. The ovulation rates and numbers of embryos present at 4 weeks after mating of ewes in moderately fat (score 2.75) or very fat (> score 3.25) body condition at mating in one experiment designed to study this are shown in Table 22.

Table 22
Reproductive performance of Greyface ewes in moderately fat or very fat body condition at mating

Mean condition score	2.74	3.35
No. of ewes	19	20
No. barren i) with no oestrus	0	4
ii) mated but not pregnant	4	5
Mean ovulation rate	2.33	3.36
Mean potential litter size	1.80	2.00
Mean potential lambing rate (lambs/ewe put to ram)	1.42	1.10

These results show clearly that barrenness and embryo mortality were substantially increased in the very fat ewes. The endocrine status of these ewes is currently being investigated.

Manipulation of reproductive performance by pasture management

In step with our improved understanding of the nutritional effects influencing ovulation and lambing rates and the endocrine mechanisms through which they are mediated, work has started to determine how best to control changes in body condition and intake by positive manipulation of sown pasture sward conditions during late summer and autumn.

The differences in response according to body condition at 5 weeks before mating, illustrated in Table 21, may be partially explained in terms of voluntary intake of pasture, the fat ewes eating very much less than the intermediate and lean ewes in the week prior to mating (Table 23).

Table 23
Dry matter intake at mating of North Country Cheviot ewes in different body conditions at 5 weeks before mating

Condition score at 5 weeks before mating	DM intake at mating (g/day)	
	/head	/kg LW
⩾3	1021	14.0
2.5/2.75	1162	16.7
⩽2.25	1282	19.8

With this information, it should be possible to manipulate reproductive performance by management of pasture resources to ensure that animals have an appropriate condition and intake at mating and to maintain these over the 4 weeks after mating.

The most difficult aspect of pasture and its management in the autumn period is the determination of how much is actually there and the extent to which it will effect changes in the animal's condition. For any particular response, the aim is to be able to describe the pasture conditions in terms that are easily understood and are repeatable in any year on any farm and pasture. The simplest measure of pasture amount is that of its height. However, its effect, in terms of animal response, is not independent of pasture management and species composition. Previous pasture management will largely determine its density in terms of the number of plants per unit area. Swards grazed intensively by sheep will usually have tiller populations in excess of 40,000 per m^2. Previously conserved areas or cattle grazed swards will have tiller populations often less than half that number. Such different swards are also likely to lead to different qualities of ingested herbage when grazed in the autumn. For these reasons, it is important that any recommendations as to the height of sward required for a particular animal response have to take previous pasture management into account.

Two other very important aspects of pasture management to be considered are stocking rate and change in pasture growth rate. The relationship between these is the basis for regulation of animal response. The decline in growth rate is difficult to predict but an estimate can be made by comparing herbage heights at different times under one stocking rate, which can then be adjusted to enable enough pasture to persist throughout mating. With high amounts of pasture and a high growth rate there may be no problem and stocking rate can be left at the same level. The accumulation of too much pasture is, however, counterproductive, since rot and senescence set in at the base of deep swards of more than 10 cm height at this wet time of year and the quality of the herbage declines rapidly. Consequently, an increase in stocking rate by a reduction in area may be a more efficient way of using the pasture and would provide surplus for use by other classes of stock. Greater difficulty will arise with low amounts of pasture and a low growth rate. Such conditions will almost certainly require a reduction in stocking rate if body condition is to be maintained for 4 weeks after mating. A stocking rate reduction requires an increase in the area of pasture on offer and a flexible approach to the timing of disposal of late-finishing lambs or the early housing of calves. An alternative would be to provide supplementary food when the pasture alone is unable to maintain ewe body condition at the level achieved by the time of mating.

It is possible to make some tentative recommendations, based on our limited experimentation, regarding the stocking rates that may be used in the late summer and early autumn in relation to the amount of grass available.

For a dense, previously sheep-grazed, sward, a pasture height in late August of some 3-6 cm will carry 15 upland crossbred ewes per ha as long as the herbage continues to grow. This stocking rate should be adjusted upwards only if the ewes are in fat condition (> score 3). By mid-September, in preparation for mating, a final stocking rate will need to be decided upon. The choice will depend on ewe condition, pasture height and estimated rate of herbage growth. Some guidance on the rate of growth can be obtained from the change in pasture height during the previous period but it must be remembered that herbage growth is likely to cease in mid-October. At 15 ewes per ha, a pasture height of some 5-6 cm will be required. At lower heights than this, stocking rate will need to be reduced. If, during the mating period from October onwards, the pasture height falls to less than 3-4 cm, then our calculations would suggest that supplementary feeding will be required if body condition is to be maintained over the first 4 weeks of pregnancy.

For more open swards, e.g. after conservation or cattle grazing, the pasture heights suggested above would have to be increased by a further 2-3 cm and supplementary feeding would have to be introduced when height falls below 4-5 cm.

Clearly, more work is needed to achieve greater objectivity in describing sward requirements for a variety of circumstances and environments. Only then will we be able to manipulate reproductive performance by pasture management in a predictable way.

Manipulation of reproductive performance by immunological techniques

Manipulation, however, need not be solely by natural means using pasture management, it may also be possible to manipulate reproductive performance by artificial means through chemical or immunological manipulation of the endocrine status of the ewe. Work in various parts of the world in the last decade has shown that active or passive immunisation of ewes against one or more steroid hormones induces a higher mean ovulation rate and litter size than in control animals, with less variation than in animals treated with pregnant mare's serum (PMS).

Recent work in this Organisation has shown that the reproductive performance of Scottish Blackface ewes can be improved by passive immunisation without inducing abnormally high ovulation rates or litter sizes in individual animals. However, the magnitude of the response was

Table 24
Reproductive performance of Scottish Blackface ewes passively immunised against testosterone

Condition score at mating:	≤2		2.25/2.5		2.75/3	
Group:	Anti-T	Control	Anti-T	Control	Anti-T	Control
No. of ewes	19	21	18	16	13	13
No. non-pregnant	3 (15.9%)	5 (23.8%)	0	1 (6.3%)	0	0
Mean ovulation rate (1st cycle)	1.67	1.07	2.35	1.69	2.42	2.08
Lambs present at slaughter:						
—per ewe pregnant (2 cycles)	1.50	1.06	1.83	1.43	2.00	1.83
—per ewe put to ram (2 cycles)	1.26	0.81	1.83	1.25	1.85	1.69

found to depend on the body condition of the ewes at mating (Table 24), the greatest improvements being obtained in ewes in poor or moderate condition.

The nutritional consequences in mid- and late pregnancy and during lactation arising from multiple pregnancy in ewes in relatively poor condition at mating are not known but are likely to have important implications for the management of pasture and other feed resources. The technique may provide opportunities for the reallocation of feed resources away from the pre-mating period and into other parts of the animal reproductive cycle, introducing greater flexibility of management.

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The determination of foetal number in pregnant ewes

A. J. F. Russel and I. R. White

One of the major constraints to the application in practice of the results of research on the nutrition of the pregnant ewe is the inability to determine foetal numbers at some stage prior to the last 6-8 weeks of gestation. Over the years a variety of approaches to this problem, including the use of concentrations of a number of blood metabolites and hormones, have been examined. For various reasons, not the least of which is their inability to provide an immediate result, these have been found to be unsatisfactory. Radiological techniques have been used successfully for experimental purposes, but are not considered to have application commercially.

More recently attention has turned to the use of ultrasonic techniques and two main approaches have been examined. The first is based on the detection of foetal heartbeats or other signals using the Doppler and similar principles of this type. This approach is probably satisfactory for the diagnosis of pregnancy but it is considered not to be sufficiently accurate or rapid for the determination of foetal number.

The second approach is the use of real-time ultrasonic scanning. This technique involves the examination of an area of the ewe's abdomen immediately in front of the udder and from which the wool has been removed. A linear-assay transducer emitting a beam of ultrasound approximately 10 cm wide and penetrating the abdomen to a depth of some 20 cm is used to visualise the tissues beneath the shorn area. The reflected ultrasound is processed electronically to give a real-time or 'live' image which is portrayed on a screen and from which it is possible to examine the uterus and its contents to diagnose pregnancy and count foetal numbers. This can be done with a high degree of accuracy at any stage between 50 and 100 days of gestation.

The use of the technique in sheep was pioneered in Australia by Dr D. G. Fowler of the New South Wales Department of Agriculture who spent six weeks with the Organisation in 1983 as a visiting worker. During that time trials were conducted to examine the use of the technique under United Kingdom conditions and the opportunity was also taken to train a previously inexperienced operator.

After a short period of instruction on the use of the instrument and the interpretation of real-time images the trainee operator scanned a total of 566 ewes of different breeds and at different stages of gestation over a period of five days. Sixty-two non-pregnant ewes were all correctly identified. Over the five days the accuracy with which ewes were classified as carrying either no foetuses, one foetus, or more than one foetus improved from 81 to 100%. The accuracy of the more difficult problem of determining multiples as either twins or triplets increased from 69 to 100%.

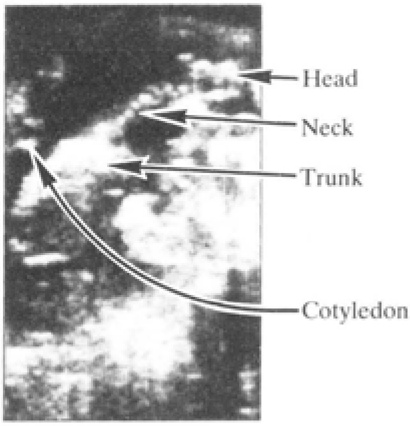
In a flock of 287 Scottish Halfbred ewes scanned by Dr Fowler, 28 non-pregnant, 49 single-bearing and 138 twin-bearing ewes were all correctly identified. Of the 71 ewes which produced triplets, 68 were identified correctly and 3 were wrongly classified as carrying twins. One set of quadruplets was wrongly classified as triplets. Thus, 283 of 287 ewes were correctly diagnosed, giving an accuracy of determination of actual foetal numbers of 98.6%. The accuracy of classification according to non-pregnant, single- and multiple-bearing ewes was 100%.

From the studies carried out to date it is considered that the technique offers a safe and practicable means of diagnosing pregnancy and determining foetal numbers in ewes between 50 and 100 days of gestation. Accuracies of diagnosis of pregnancy of more than 99%, of differentiation of barren, single- and multiple-bearing ewes of 98%, and of determination of actual foetal number of 97% can be achieved in practice at a scanning rate of considerably more than one ewe per minute.

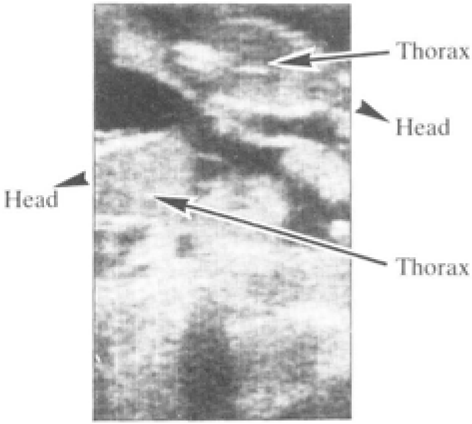
A considerable interest in the use of the technique in commercial flocks has been shown by the industry and the Organisation has been involved in a programme of training operators who, it is estimated, have scanned more than 80,000 ewes this year.

The major limiting factors in the use of the technique at present are the rate at which ewes can be prepared and presented for scanning and the high labour requirement for handling the animals. The Organisation is currently engaged in collaborative work with the Scottish Institute of Agricultural Engineering and with a commercial firm to develop specialised handling equipment which will reduce the labour requirement and make the operation easier and more efficient.

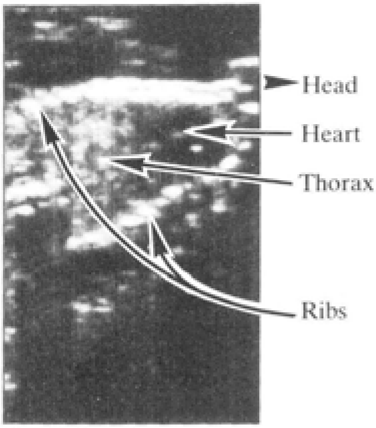
Other uses of the real-time ultrasonic scanning instrument have been examined. These have included the *in vivo* estimation of subcutaneous fat



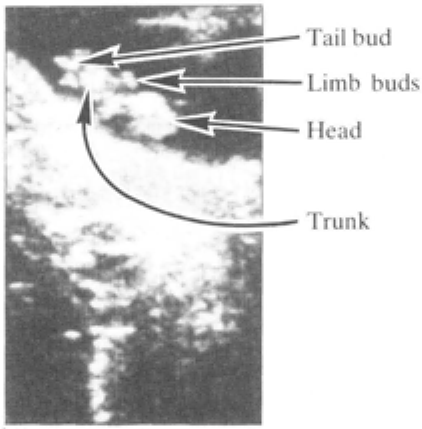
Single sheep foetus
aged 60 days



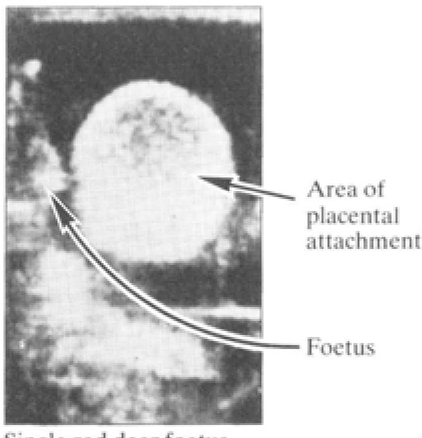
Twin sheep foetuses
aged 65 days



Single sheep foetus
aged 101 days



Single cattle foetus aged
approximately 45 days



Single red deer foetus
aged approximately 45 days

Figure 17

Photographs taken from real-time ultrasonic scanner screen. The movement seen in 'live' real-time images is an invaluable aid to interpretation and is, of course, lost in still photographs.

depth in sheep and cattle as indices of carcass and whole body composition. It is considered that the instrument, which was not designed for this specific purpose, is not well suited to this particular application. Its use in diagnosing pregnancy and determining foetal numbers in other species of livestock has also been investigated. The same equipment can be used successfully for these purposes in goats, and indeed in this species it is likely to be particularly useful in detecting false pregnancies which have hitherto been difficult to diagnose. With specially designed intrarectal transducers the instrument has also been used to diagnose pregnancy in beef cows and red deer. Data being collected from measurements made on real-time images from pregnant beef cows indicate that the technique can also be used to age foetuses over a period from 6 to 18 or 20 weeks of gestation with accuracies of the order of 4-7 days.

The nutrition and growth of lambs

J. M. Doney

Introduction

Lamb growth rates depend on the level of nutrition provided throughout the whole growing period from birth to slaughter. Land resources and marketing opportunities may lead to a range of systems producing a suitable carcass at an early age (14-20 weeks), an intermediate age (6-8 months) or, following a slower growth and a store period, at 10-12 months of age. The choice of system will be affected by the breed or cross of the lamb itself and by associated development in body conformation. Nutritional resources of the system include those available to the ewe during the whole of the lactation period.

The lactation period is subject to manipulation. Systems of early weaning (0-6 weeks) may be adopted in situations where ewe's milk has a high alternative value, where climatic conditions lead to a serious deficit of pasture during the lactation period, where intensive feeding of the lamb is economically practicable or where more than one lamb crop per year is produced. In hill and upland pasture-based systems natural suckling, with once-yearly lambing, provides the most useful economic exploitation of the resources. Our studies have been restricted to such a system.

The 'normal' lactation period continues for 14-18 weeks, by the end of which time a proportion of lambs may be ready for slaughter although, more commonly, a further finishing period will be required. The nutritional development of the lamb can be considered in three phases: early lactation (4-5 weeks) when the lamb is entirely dependent on milk provided by its dam; mid- and late lactation when milk intake declines as herbage intake increases and after weaning when the lamb becomes entirely dependent on solid food.

Milk production

Lamb growth depends closely on milk supply (Fig. 18) so considerable attention has been given to the factors affecting milk production and to the possibilities of its increase by realistic management control (e.g. Doney and Munro, 1962; Peart, 1967; 1970a; Doney, 1982).

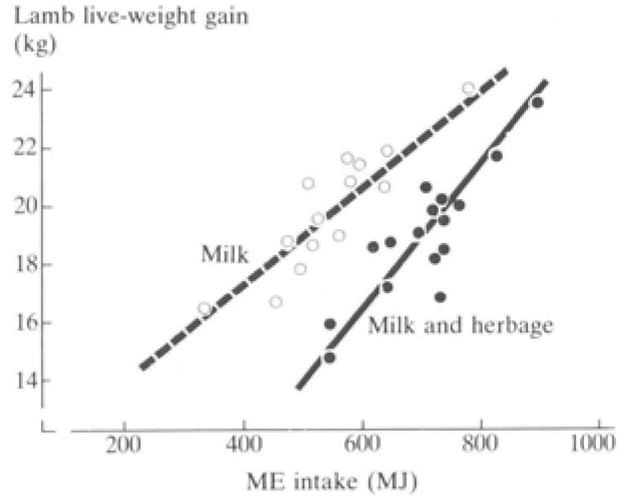


Figure 18

Relationship between lamb live-weight gain and ME intake from days 22 to 85 of lactation.

Low nutrition and poor body condition of the ewe prior to lambing have been found to depress subsequent milk production when nutrition in lactation is restricted but, otherwise, to have little significant effect (Peart, 1970b; Maxwell *et al*, 1979; Doney *et al*, 1981). The importance of adequate levels of nutrition in lactation, especially during the early stage, has long been recognized (Peart, 1970b; 1982). More recently attention has been given to the management of pasture to achieve this adequate level of nutrition and to the tactical provision of supplementary food where herbage availability or quality limits milk production (Doney *et al*, 1981; Milne *et al*, 1981; Doney, 1982; Milne *et al*, 1982). Sown pastures can provide a better milk supply than unimproved hill swards (Doney *et al*, 1983). Herbage mass and height is also of critical importance; in a well-established ryegrass/white clover sward a height of 4-5 cm has been shown to be necessary. Below this, whether due to season or over-utilisation, milk production is reduced and some form of supplementation is recommended (Milne *et al*, 1981).

The shape of the lactation curve has been studied. Peart (1970b) found that in early lactation the level of milk production is directly affected by nutrition, but from about 6 weeks it falls rapidly irrespective of food availability. Attempts to prevent or reduce the rate of decline by nutrition or pasture management were unsuccessful. Since both level of milk production and the pattern of lactation are known to be influenced by genotype a series of studies using crossbred ewes derived from a 'dairy' breed were initiated (Ĺouda and Doney, 1976; Doney and Peart, 1976; Doney *et al*, 1979; Peart *et al*, 1979). These studies have shown that higher levels of milk production can be sustained by such crossbred ewes in later stages of lactation and that, because of differences in voluntary food intake patterns, differences may be increased when the nutritional provision is improved (Doney *et al*, 1983).

Milk production by the ewe, irrespective of nutritional provision, responds to differences in demand by lambs. The effect of twin-suckling is well known but even genetic differences in suckled lambs can stimulate different responses (Peart, Doney and Macdonald, 1975). In a lamb cross-over study with pure Scottish Blackface (BF) and East Friesland × BF ewes it was found that the intrinsic lamb demand could have a significant effect during the first phase but that, subsequently, the ewes regulated production independently of the lambs (Doney, Peart and Smith, 1981). During the first 6 weeks pure BF lambs extracted more milk from crossbred dams than from dams of their own breed but, conversely, crossbred lambs were able to extract more milk from BF dams than could the pure BF lambs themselves.

The sustained lactation character may be of considerable value in a number of lamb production systems. However its exploitation is constrained by the lack of response to nutrition in most of the breeds examined. Studies have recently been initiated on endocrine patterns related to differences in lactation curves, especially after peak production has been reached (Bass *et al*, 1984). In the long-term it is hoped that these studies will lead to the possibility to modify lactation pattern by endocrinal manipulation (e.g. immunisation or hormone supplementation). At present there are clear indications of distinct differences in endocrine profiles associated with genotype, milk yield and litter size (Rhind *et al*, unpublished).

Intake of milk and herbage by lambs

Differences in milk intake during early lactation (phase 1) have been indicated in the previous section. Up to the limit of maternal potential it has been shown that the lamb's own demand, perhaps genetically determined, can influence its intake. In almost all cases where more than a single lamb is reared, however, the ewe's ability to produce milk will be the major limiting factor. The effect of nutritional depression of birth weight was studied by (Peart 1970b) by a cross-over approach. Subsequent observations have confirmed that, within normal limits, birth weight has little effect on subsequent demand.

Lambs begin to eat a measurable amount of solid food from around 4 weeks of age, with some variation associated with the amount of milk consumed. Beyond this age in mid- and late lactation, phase 2, intake of solid food increases and, eventually, milk supply declines. In common with other workers, it has been found that the rate of increase and the absolute amount eaten depends on the characteristics of the solid food (Doney and Peart, 1976) and that there is a negative relationship between herbage and milk intake (Doney *et al*, 1984). However, a higher level of herbage intake does not compensate for a lower level of milk (Fig. 19) emphasising the potential benefits of a more sustained lactation pattern. During phase 2 suckled lambs are perforce grazing the same pasture as their dams and there may be competition for a limited resource between lambs and ewes. Furthermore the sward characteristics and composition which have been found to be optimum for grazing by ewes may not be identical with those suitable for lambs. In order to develop a critical experimental approach to the further study of the relationship between milk and herbage intake in different pasture conditions a study of the validity of using artificially-reared lambs at pasture has been carried out (Zygoyiannis *et al*, 1982; Doney *et al*, 1984). Although the approach is valid there are associated problems, mainly in relation to labour requirements, which limit its usefulness. Preliminary studies on the development of an electronically controlled individual system for milk feeding of grazing lambs have been initiated (Curtis and Smith, unpublished).

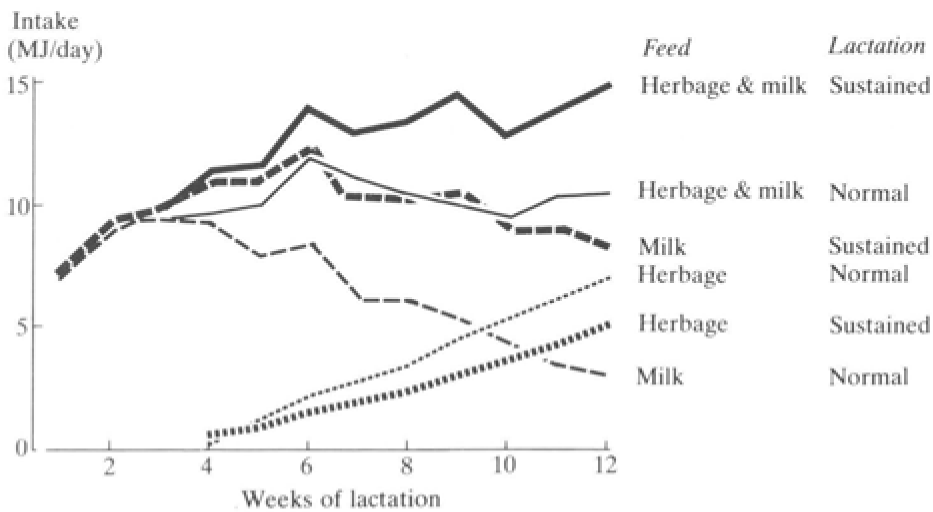


Figure 19

Intake of milk, herbage or milk and herbage in lambs with sustained or normal lactation.

Post-weaning

Normally after an abrupt weaning, the lamb is dependent on solid food alone. By the end of the traditional suckling period (about 16 weeks) milk already forms a low proportion of the diet but the greater the extent to which lactation is sustained the greater will be the sudden fall in intake. In the study illustrated in Fig. 19 the lambs with access to a sustained lactation were consuming some 20% less herbage than those with a normal lactation at weaning (12 weeks in this case). The lambs continued to graze the same ryegrass/clover pasture after removal of the dams. Within 2 weeks the difference in herbage intake had been eliminated and, by 4 weeks, the sustained lactation lambs were apparently consuming more food. The development of post-weaning intake may be dependent on many factors — live weight achieved, total intake and relative proportions of milk and herbage before weaning, alimentary tract development, sward or alternative feed characteristics, genotype and/or growth potential and, perhaps, even season of year. Further investigations are required since post-weaning food intake is critical for the choice of a finishing system.

Lamb growth

Within breed, lamb growth rate is closely related to intake; indeed the indications from many of our studies suggest that between-breed differences may be largely dependent on intake differences. During the first phase growth is closely related to amount of milk consumed, neither breed nor birth weight having much independent effect. In the second phase growth is still closely related to milk consumption and, as was shown in Fig. 18, milk intake in mid- and late lactation is as effective a determinant of gain as is total energy intake from milk and herbage together. As a consequence of the variation in nutritional resource available to the lamb either directly as solid food or, indirectly through the ewe's milk production, the patterns of pre-weaning live-weight gain can vary very considerably. Some of these patterns, illustrating the effects of both lactation pattern and sward type, are shown in Fig. 20.

Weight and body composition at weaning are important determinants of subsequent finishing systems. In some cases lambs may be suitable for slaughter at this stage. Others require further and different feeding regimes to finish. Studies with Scottish Blackface lambs have indicated that live weight at weaning is a critical factor in the determination of a suitable subsequent procedure. Body composition change during growth is also important in determining the suitability of diet composition, particularly during the finishing period, and assessing the optimum point of finish.

Work has begun to characterise the relationship between live weight and body composition and the influence of diet composition in the important breeds and crossbreeds used in the hills and uplands of the UK.

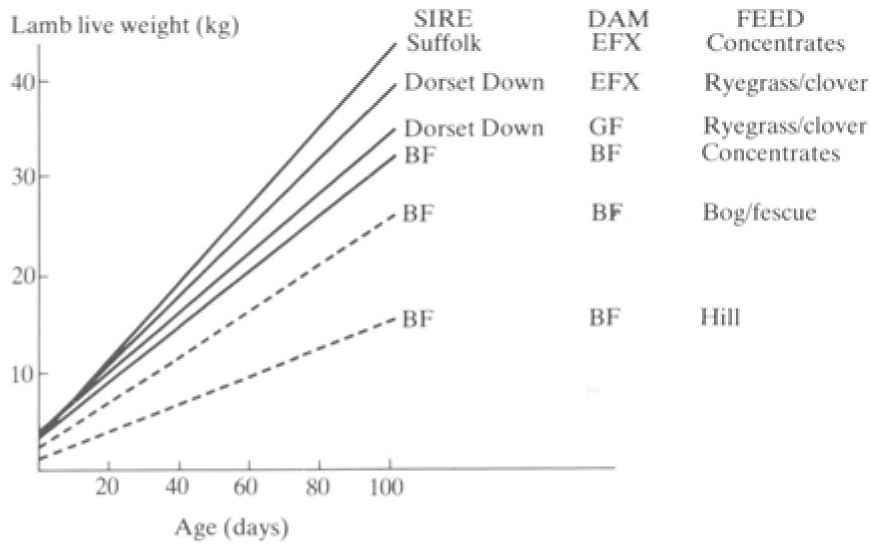


Figure 20

Patterns of lamb live-weight gain (single lambs — solid lines; twin lambs — dotted lines; EFX = East Friesland Cross; GF = Greyface; BF = Scottish Blackface)

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Nutrition and performance of weaned suckled calves

I. A. Wright, A. J. F. Russel and E. A. Hunter (AFRUS)

In 1981 the Organisation's beef cattle research programme, which until then had been concerned only with the suckler cow and the beef calf to the point of weaning, was extended to include work on the weaned suckled calf. This was prompted by considerations of the relative inflexibility of certain systems of beef cattle management in which suckled calves are traditionally sold at fixed times regardless of financial returns.

The problem is perhaps most evident in spring-calving hill suckler cow enterprises in which calves are doubly penalised in the autumn sales because of a low weight *per se* and because this class of animal attracts a low price per unit weight. The limited supplies of conserved fodder in this type of enterprise are all required for the winter feeding of the cow herd and consequently the calves have to be sold without regard to price. In these situations summer grazing is generally not limited in quantity, although herbage quality may not be of the highest order, and if calves could be overwintered on a moderate level of feeding it is probable that a reasonable level of performance could be achieved during the following grazing season. This might allow the calves to be sold more advantageously at about 18 months of age. Such a system would almost certainly require some reduction in cow numbers to make provision for the wintering of the calves, but calculations based on empirical estimates of likely performance indicate that such a strategy merits more detailed examination. These considerations and calculations also highlight the paucity of quantitative information on which to base predictions of the performance at pasture of weaned suckled calves.

It was against this background that work was initiated at Glensaugh to examine the factors influencing production from weaned beef calves. Sixty-four individual standings in the Glensaugh cattle shed were modified to suit the needs of silage-fed weaned calves. The weaned calf programme makes use of an assured supply of Charolais-cross calves of known nutritional history from Blue-Grey and Hereford × Friesian cows in the November-December and March-April calving herds at Hartwood.

The principal objective of this work is to gain an understanding of the relationship between levels of performance imposed over winter by different feeding regimes and those at pasture during the following grazing season, and to examine the extent to which this relationship is influenced by both animal factors, such as genotype, sex, age and previous nutritional history, and pasture factors, such as herbage mass or sward height.

To date one experiment, extending over two years and involving a total of 119 weaned calves, has been completed. Results from the first year are now available and preliminary examination of the data from the second year indicates that these are likely to confirm the tentative conclusions drawn from the first part of this experiment.

In the first year 36 heifer and 24 steer Charolais-cross calves, balanced for genotype of dam and age, were allocated to three feeding treatments designed to achieve different rates of live-weight gain over winter. All animals were offered 16 kg silage and quantities of mineralised barley according to treatment group and live weight. The feeding treatments were effective in creating distinctly different rates of live-weight gain over winter (Table 25). At turnout in mid-May the three treatment groups were different not only in live weight but also in degree of fatness as assessed both by subjective assessment of body condition and by objective measurements of fat cover over the ribs made ultrasonically using the Scanogram (Table 25).

Table 25
Performance over winter of weaned suckled calves offered 16 kg silage/day and varying quantities of barley

	Level of winter feeding			Significance of difference
	Low	Medium	High	
Mean barley intake (kg/day)	1.2	2.1	2.9	***
Initial live weight (kg)	279	279	286	NS
Live weight at turnout (kg)	325	367	406	***
Daily live-weight gain (kg)	0.31	0.58	0.79	***
Condition score at turnout	2.57	2.78	2.90	***
Scanogram measurement at turnout (cm^2)	2.55	4.03	4.27	***

*** $p < 0.001$.

From turnout until mid-August, when the study had to be terminated because of drought, the animals were grazed on ryegrass swards managed to maintain two levels of herbage mass. Initially the higher herbage mass was in excess of 3000 kg dry matter (DM)/ha (more than 10 cm sward surface height) and fell during the course of the experiment to 1500 kg DM/ha (3.5 cm); the low herbage mass was maintained around 1800 kg DM/ha (4 cm) for most of the experiment but later also fell to 1500 kg DM/ha (3.5 cm).

Performance at pasture was inversely related to rate of live-weight gain over winter (Table 26), those on the lowest level of winter feeding gaining most and those on the highest level gaining least. This relationship was evident at both levels of herbage mass. It was not possible in this part of the experiment to estimate herbage intake in all animals and these were made only in those of the higher herbage mass. These estimates (Table 26) also show an inverse relationship between level of winter feeding and voluntary intake at pasture, and it is reasonable to assume that differences in summer live-weight gain were attributable, at least in part, to the differences in herbage intake. In the lower herbage mass it would be expected that voluntary intake would be limited by the amount of herbage available, and indeed the highly significant difference in live-weight gain between the animals on the two herbage masses suggests that this was so (Table 26). It is therefore of particular interest to note that effects of winter feeding on performance at pasture were still evident in animals on the lower herbage mass, suggesting differences in intake in a situation where maximum voluntary intakes could not be expressed.

Table 26
Effects of level of winter feeding and herbage mass on performance of weaned suckled calves at pasture

	Level of winter feeding				Significance of difference
	Low	Medium	High	Mean	
Daily live-weight gain at pasture (kg)					
High herbage mass	1.35	1.23	1.19	1.26	***
Low herbage mass	1.10	1.20	0.87	1.00	
Mean	1.23	1.12	1.03		**
Herbage intake (high herbage mass only) (g OM/kg)	17.7	16.2	15.9		*
Final live weight (kg)	420	440	464		***
Final condition score	2.76	2.91	2.92		*
Final Scanogram measurement (cm^2)	3.20	4.52	4.21		**

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

The relatively short duration of the grazing season in this particular year constrained the opportunities for animals on the lowest level of winter feeding to overcome fully, during their time at pasture, their weight disadvantage at turnout. By the end of the experiment in mid-August they were still lighter and less fat, as judged by condition score and Scanogram measurement, than those on the highest level of winter feeding (Table 26).

The observation of an inverse relationship between rates of live-weight gain during periods of restricted winter feeding and summer grazing is not new, and indeed is the basis of what has generally been termed 'compensatory growth.' The results of this part of the experiment, and particularly those relating to the indices of body composition and to herbage intake, allow the formulation of a hypothesis that compensatory growth can be explained, at least in part, in terms of an inverse relationship between body fat and voluntary food intake. Supporting evidence for this comes from earlier studies with lactating suckler cows in which an inverse relationship between body condition at turnout and herbage intake during the grazing season has been demonstrated. The results available to date from the weaned calf studies cannot, however, provide direct evidence to allow a more detailed examination of the hypothesis. All that can be claimed at this stage is that the effects of the different feeding levels during winter most probably created differences in body composition, and that rate of live-weight gain at pasture was associated with differences in intake which in turn appear to be related to body composition.

Food intake is not the only factor determining animal performance and it is unlikely that the so called "compensatory growth" observed in this study can be wholly attributed to effects of body compositon on herbage intake. Results from work on mature cows has shown that body composition also has a major effect on the composition of tissue gain or loss (Wright and Russel, unpublished) such that, for example, 1 kg of gain in lean animals contains more protein and water and less fat than 1 kg of gain in fatter animals. This in turn will affect rate of live-weight change.

In the experiment discussed here effects of both age and sex on performance at pasture were observed (Table 27). Superficially these effects appear at least to be consistent with the hypothesis that differences in performance at pasture are explicable in terms of an effect of body composition on herbage intake; the supposedly leaner animals (i.e. the March-April born calves and the steers) gained weight more rapidly than those assumed to be fatter (i.e. the November-December born animals and the heifers). Consideration of the limited data on herbage intake, however, indicates that these age and sex effects are more likely to be due to an influence of body composition on the composition of tissue gain. This interpretation must be regarded as tentative for the time being, but the results from the second year of the experiment, in which estimates of herbage intake were obtained from animals grazing both levels of herbage mass, will be examined to obtain further information on this point.

Table 27
Efects of age and sex on performance of weaned suckled calves at pasture

	Mean live-weight gain (kg/day)	Significance of difference
Season of birth		
November-December	1.06	*
March-April	1.19	
Sex		
Heifers	1.03	**
Steers	1.20	

* $p < 0.05$; ** $p < 0.01$.

Some of the animals used in this experiment have been finished and slaughtered from pasture and others have been retained for indoor finishing. The results will also be examined in terms of the combinations of levels of winter feeding and herbage allowances likely to be required for different classes of weaned stock to allow them to be finished, or at least brought to certain predetermined weights, within the resources of many typical beef production systems. Of particular importance in this respect is the identification of factors constraining the general inverse relationship between levels of winter and summer performance.

An experiment currently in progress complements that described above. This work is designed to examine the effects on performance in spring-born calves of level of nutrition prior to weaning, when offered restricted quantities of barley and *ad libitum* silage during winter.

In future studies it is planned to relate the indices of body composition used to date to directly-measured body composition to allow examination in more detail of the postulated central role of body composition in this work. To obtain the desired level of understanding of factors affecting the performance of beef calves it will be necessary to attempt to separate the effects of body composition on intake and on composition of tissue gain.

In the two years to date the grazing component of this work has been conducted on sown swards of relatively high quality. There is a need for the work to be extended to other types of vegetation and particularly to hill pastures where quality rather than quantity is likely to be the main limitation to weaned calf production.

Progress in research on red deer farming

W. Hamilton, J. A. Milne and T. J. Maxwell

The principle objectives of research on the red deer have been to identify the problems associated with the application of traditional animal husbandry techniques to the farming of the red deer and to ascertain the feasibility of farming the animal in practical and economic terms in hill and upland environments.

Domestication

The herd was founded in 1970 at Glensaugh with artificially-reared calves. Strong healthy calves which weighed at least 30 kg at 12 weeks could be reared (Blaxter *et al*, 1974). These calves become very tame and were easily trained. As adult hinds, they were amenable to handling on the extensive hill areas and could be gathered into the handling pens with ease. Provided that calves born to the initial hand-reared stock were handled with their dams until weaning, hand-fed during their first winter and thereafter gathered at monthy intervals, the second generation stock could be managed, although not as easily as artificially-reared stock. This was particularly so at calving and during the summer months when the hinds had calves at foot. Later direct comparisons were made between artificially-reared and second generation stock using a technique for measuring the relative docility of the stock. Naturally-reared stock were less docile than hand-reared stock. Further trials showed that with a frequency of handling of four times a year, September (weaning), December (post-rut), March and May (calving) it was possible to handle a separate herd of second generation stock adequately. On some kinds of terrains collie dogs can be used to gather naturally-reared deer although mixed populations of artificially- and naturally-reared deer present difficulties. In fenced fields handling deer is a much simpler matter regardless of the origins of the stock.

Reproductive performance

Hind live weight at the rut in October is of crucial importance to the subsequent production performance of the animal. There are positive relationships between live weight of the hind at the rut and calving probability, calf birth weight and calf growth rate (Hamilton and Blaxter, 1980). Hind live weight has to be in excess of 80 kg to achieve a calving probability of greater than 0.9 and the probability of a hind which weighs less than 52 kg calving successfully is nil. An increase in hind live weight from 60 to 80 kg results in an increase of 1 kg in the birth weight of the calf and an increase in growth rate of about 12%. Calf mortality is related to birth weight, being 100% for calves weighing 4 kg or less and 5% for those between 7-8 kg. Mortality rises to 13% for calves with a birth weight of 8-9 kg and is up to 28% for calves weighing over 9 kg. Hind live weight at the rut is also related to time of calving; small hinds calve later than large hinds so that for each additional 4 kg of live weight, calving is one day earlier. Earlier calves enjoy a longer growing season and are heavier at weaning in September.

These results have a direct implication for the rearing of hind calf replacements and indeed there is evidence to suggest that the nutrition of hind calves during their first winter and subsequent summer has proved to have a considerable effect on their future productive performance. Hind calves require to be reared on a plane of nutrition which allows them to reach a live weight of 75 kg at the age of 16 months if they are subsequently to breed successfully.

Red deer stags reared on hill pastures are fertile at 16 months and have bred hinds successfully but they can be slow to take an interest in hinds and can sometimes fail to mate. In a hill environment 2-year-old stags will successfully mate 10 to 15 hinds while a 3-year-old will mate 20 to 25 hinds. At 4 years of age stags are fully mature and a single stag at Glensaugh has mated 28 hinds so that they all calved within a 20-day period (Hamilton and Blaxter, 1980).

Stags perform well singly and when in consort with other stags in the same enclosure, provided that there is sufficient space to allow the rutting stag groups to keep apart and that the stags are of similar live weight, age and close together in the dominance order.

The lifetime reproductive performance of red deer has yet to be established but there appears to be no deterioration in performance up to 10 calf crops. The calf birth weights of hinds bearing their 10th calf crop were 8.5 kg for stags and 7.7 kg for hinds and all 42 hinds of this age group produced calves. Only two hinds have lost incisor teeth. The incidence of 'broken mouths' in deer appears to be due to accidental damage rather than genuine wear or incisor loss as the problem is understood in sheep.

The state of the molar teeth cannot be examined with ease. These could well be the key to longevity and performance in hill deer stocks.

Lactation and calf growth

As with hill sheep, hill vegetation limits the lactation performance of hinds (see fig. 21) and reduces calf growth rates by 40% in comparison to upland swards. Calf growth rates from June to September on a mixed heather:*Agrostis*/*Festuca* hill sward were 257 g/d and on an upland predominantly perennial ryegrass sward maintained at a herbage mass of 2000 kg DM/ha were 369 g/day (Loudon, Darroch and Milne, 1984). Calf growth rates on hill grazings over the 6 year period 1973-78 were found to vary with season and ranged from 236 to 288 g/d (Blaxter and Hamilton, 1980).

The potential for growth during the autumn appears to be high since stag calves weaned in September and offered a barley-based concentrate *ad libitum* can attain growth rates of 200-300 g/d. Calves weaned in mid-September onto an upland sward, however, grew at only 130 g/d though some were affected by a stress-related disease, Yersiniosis (Loudon and Milne, 1984).

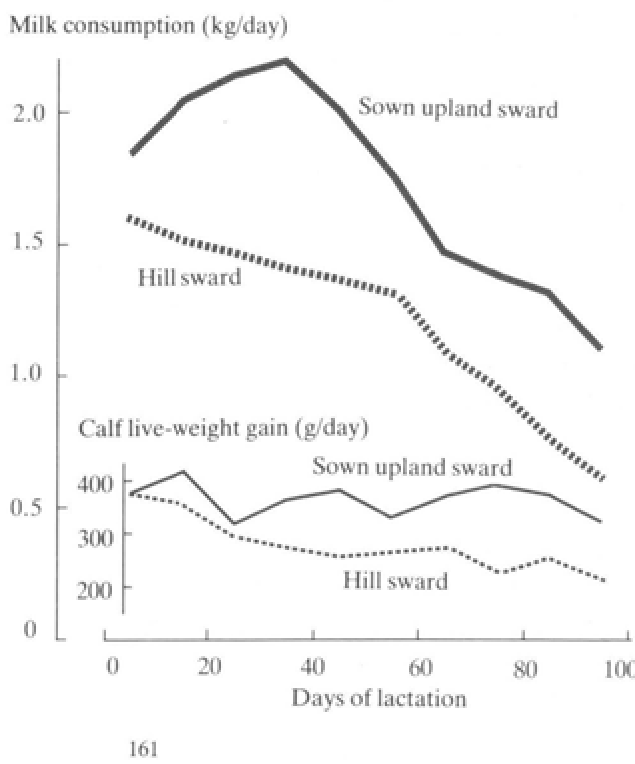

Figure 21

Performance of red deer during lactation on contrasting swards

Some information has been obtained on the performance of calves which have been weaned at a later date. Stag calves left with their dams during the rut on the hill in October and November grew at only 120 g/d. In conditions of bad weather, growth rates were as low as 50 g/day. On upland swards milk yields at weaning have been found to be of the order of 1 kg/d, suggesting that there may be advantages to calf growth rate in this environment in delaying weaning until later in the rut. A delayed weaning however may influence reproductive performance adversely particularly in relation to date of calving, since suckling frequency during lactation has been shown to delay rebreeding after weaning (Loudon, McNeilly and Milne, 1984). This will delay calving the following year and, since date of calving is of crucial importance to the live weight of the calf at weaning, the effects may be far reaching. Further research is required to establish the appropriate system of management for calves in the late summer and autumn.

Calf performance from weaning to slaughter

The present system of finishing calves for slaughter is to house the calves in the autumn and feed either hay or silage with a concentrate supplement and in May turn out to grass to achieve a live weight of 80 kg at 16 months. It is, however, difficult to achieve consistently high growth rates during the winter. A period of inappetence occurs in January and February and calf growth rates are at most 100 g/d during this period. The cost of winter feed therefore tends to be high relative to the live weight gain achieved and the price of the end-product. Consequently the role of compensatory growth in the summer following low levels of winter feed has been investigated.

It was found that compensatory growth resulted in an additional 5 kg of live-weight gain during the summer in animals given a low level of winter feed compared with those animals that had received a high plane of nutrition in winter. The calves given the high plane of nutrition in winter were 10-15 kg heavier at turnout in May. Summer growth rates ranged from 100 to 200 g/d, depending upon winter treatment and calendar month and were achieved on upland swards maintained at 2000 kg DM/ha during the summer. The stocking rate was 25 calves per hectare and the sward received 35 kg of N in each of 3 applications over the summer period. The strategy to be adopted for managing calves to slaughter can be assessed from this data, and from a knowledge of the relative costs of winter feeding and summer grazing and the price of the end-product.

Systems of deer farming

Red deer performance and output from the use of hill resources will depend upon stocking rate and the long-term stability of such systems, which in turn depends upon the effect of grazing on plant productivity. This aspect has been investigated at Glensaugh on heather-dominant moorland (Grant, Hamilton and Souter, 1981). The effect of grazing by red deer on the productivity of heather appears to be similar to that of sheep grazing although deer are able to graze stands which sheep would not be able to penetrate. At stocking rates of 1 to 2.5 hind equivalents/ha heather utilisation levels ranged from 25 to 60% of the current season's shoot production. Old heather was less able to withstand grazing than was young heather, and heather cover was reduced at stocking rates consistently above two hinds per ha. Thus it is possible from this information to determine the stocking rates that are likely to be appropriate for systems of hill deer farming predominantly based on dry heather moorland. Stocking rates of 1 hind equivalent/ha would appear to be consistent with the maintenance of the character of the sward and the provision of an adequate pasture for the animal. However this has yet to be tested critically in practical systems.

Since 1979 the possibility of farming the red deer more intensively on upland sown pasture has been explored. It was recognised that the economics would depend not only upon high levels of animal performance but also on having low winter feed costs. The study therefore was essentially concerned with comparing two different wintering systems, one including a hill outrun on which hinds would be mated and then wintered, and the other where hinds were wintered in a paddock of approximately 3 ha and where they were fed a controlled ration of hay and concentrates. These latter hinds were mated on the sown pasture area. Each of the herds comprised 34 hinds having access to 3.4 ha of permanent sown pasture.

Hind live weight at the rut was 88 and 89 kg in 1980 and 1981 respectively. Live-weight loss in winter was controlled where necessary in both herds by feeding additional hay and concentrate as required to achieve a live weight of 80 kg by the end of March. Reproductive performance differed between the two herds. The weaning percentages of the hill wintered calves were 82 and 73 in the 2 years while those of the paddock wintered calves were 88 and 100 respectively. The lower weaning percentages of the hill wintered group were mainly due to losses at and around calving. The reasons for these losses cannot be adequately explained, though they may be linked to a significantly earlier calving date.

The growth rates of the calves tended to be greater from the hinds wintered on the hill. From birth to weaning, growth rates for both systems were around 300 g/d. The output per unit area from the hill wintered hinds was 326 and 321 kg calf live weight/ha of sown pasture at weaning in 1981 and 1982, whereas the paddock wintered hinds produced 299 and 386 kg calf live weight/ha in the two years respectively.

The average cost of wintering the hinds over the two years on the hill was £6.69 whereas on the enclosed area the average cost of wintering was £22.35. The hill wintered stock provided a better economic return than hinds wintered on the enclosure. The returns from the sale of venison would have to increase very considerably relative to winter feed costs to overcome the higher costs of winter feeding on the latter system.

At the levels of nitrogen application and pasture production achieved the performance of the calves in terms of output/ha at a stocking rate of 10 hinds/ha equated with the output obtained from similar stocking rates of sheep on the same area.

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Review articles

Trace element research: copper deficiencies in grazed hill pastures

C. C. Evans

Introduction

It has been established that trace element deficiencies can occur in sheep which graze some hill pastures. Cobalt and copper deficiencies have been increasingly demonstrated in sheep when confined to improved reseeded pastures. Until recently, experimental work in HFRO has concentrated upon methods of diagnosis and quantifying the effects of deficiencies upon animal health and productivity, together with the development of prophylactic procedures suitable for hill farming systems.

Cobalt deficiencies are quite common in Scotland and remedial treatments are necessary in many areas and on many soils. Studies into diagnostic procedures (Russel *et al,* 1975) and prophylaxis (Whitelaw and Russel, 1979) have been undertaken at the HFRO. However, since 1976 priority has been given to studies into copper deficiencies in sheep since it became apparent that sheep, and particularly young growing lambs, soon became copper deficient when introduced to reseeded pastures at Sourhope. In contrast, sheep grazing unimproved pasture remained copper sufficient (Whitelaw *et al,* 1979). A direct link therefore had been established between hill land improvement and copper deficiency in sheep. It should be noted however that there was no evidence of copper deficiency in the plants growing in the grazed improved swards.

Experiments commenced in 1976 at Sourhope in order to evaluate the effect of this copper deficiency and particularly its effect on young growing lambs, as it was considered that lambs would be most seriously affected between birth and weaning. In an experiment with twin Scottish Blackface lambs it was found that hypocupraemia developed quickly post-partum on the reseeded pastures of the Alderhope production unit (Whitelaw *et al,* 1979). Retardation of growth rate, skeletal fragility with osteoporosis, increased mortality and changes in the structure and growth of wool were all implicated in evidence of a severe hypocuprosis. Lambs which were given copper supplements or which grazed unimproved pasture showed no symptoms of copper deficiency. Although the ewes also became hypocupraemic no adverse effects in this or subsequent experiments could be demonstrated.

The incidence of swayback (enzootic ataxia) in lambs may be greatly increased by grazing reseeded pastures. In an experiment carried out at House o' Muir, lambs born to ewes which had been overwintered on reseeded pasture showed a high incidence of swayback of almost 50% (Whitelaw *et al,* 1982). In contrast there were no cases of swayback in lambs from ewes which received copper therapy during pregnancy.

Growth retardation in yearling calves has also been demonstrated when they grazed reseeded pasture after weaning both at Sourhope and on a commercial farm in Fife (Whitelaw, personal communication).

The results from these experiments with both sheep and cattle have shown unequivocally that copper deficiencies can result from grazing reseeded pastures. Furthermore the degree of deficiency would appear to be potentially high and may lead to serious production penalties unless remedial treatments are undertaken.

Initial investigations into the uptake of trace elements by pasture herbages were limited in extent with the purpose of providing the necessary supporting data for that aspect of the animal research programme concerned with copper deficiency. During the past two years this area of the Organisation's research programme has been expanded, with a remit to provide a greater understanding of those factors within the plant/soil complex which influence the trace element composition of grazed herbage, and to include assessments of the efficacy of applying copper to the soil as a remedial treatment for animal deficiencies.

Hill land improvement and trace element uptake by hill pastures

The improvement of indigenous hill pastures as a means of increasing animal production and farm profitability is now well established in British agriculture. Sheep production systems which incorporate the utilisation of improved areas of pasture have been developed at HFRO (Eadie, 1971, 1978; Armstrong *et al,* 1978). In these 'two-pasture' systems the improved areas are strategically grazed at nutritionally demanding periods in the annual cycle of production. These are primarily during lactation, when preference is given to ewes with twin lambs, and over the pre-mating and mating period.

The basic aim of pasture improvement is to upgrade or replace swards of low dry matter (DM) production and often of poor quality with swards of significantly higher DM production and of greater nutritive value for the grazing animal. A range of techniques can be used to achieve improvements. They include the provision of fencing alone, which enables some control of grazing, the application of lime, fertilisers and seeds with or without soil cultivations and the removal or suppression of the indigenous plant species. Dry matter production as a result of complete reseeding can be rapidly increased from approximately 1300 kg/ha to 4000 kg/ha on blanket bog soils and from 3000 kg/ha to 6000 kg/ha for the more naturally fertile brown earths (Newbould, 1979). The most commonly introduced plant species are based upon a mixture of perennial ryegrass *(Lolium perenne)* and white clover *(Trifolium repens)*. Small proportions of timothy *(Phleum pratense)*, cocksfoot *(Dactylis glomerata)* or red fescue *(Festuca rubra)* also may be included depending upon soil and environmental conditions. Copper deficiencies have been observed as a consequence of complete reseeding and only this type of improvement will be considered here.

Initial assessments of the changes in trace element concentration of herbages when unimproved hill grazings were reseeded commenced in 1976. Both reseeded and contiguous unimproved hill swards were sampled at random points over selected areas of the Alderhope unit at Sourhope. In subsequent years these pastures were sampled at least three times during the period of lactation between May and August/September. Pastures at the three other HFRO research stations were also sampled at least once during this time. The soils of these pastures are of diverse type and vary from a freely drained brown earth at House o' Muir to deep peat at Lephinmore. The Alderhope area of Sourhope is primarily a freely drained peaty podzol while the Birnie area of Glensaugh is a freely drained mineral podzol.

Initially copper estimations were made on the herbage samples but subsequently both molybdenum and sulphur analyses were included as it had become widely accepted that together dietary molybdenum and sulphur could reduce copper absorption in ruminants. It should be noted that sulphur does not occur in plant tissue at trace concentrations but is in effect a macro-nutrient. The results shown in Table 28 exemplify the differences which were found in the reseeded and indigenous herbages respectively. A number of features are readily apparent. Firstly, the copper concentrations in many reseed samples were similar or even higher than those from the unimproved vegetation (Table 28). This implied that the copper deficiency in the grazing animals was not due primarily to low herbage copper concentrations as no symptoms of deficiency could be found in animals which only grazed the unimproved pastures.

Table 28
Trace element concentrations (sulphur (S), copper (Cu) and molybdenum (Mo)) in herbage from reseeded and improved hill pastures

Location	Sampling date	Reseeded pastures S (%DM)	Reseeded pastures Cu (μg/g DM)	Reseeded pastures Mo (μg/g DM)	Improved pastures S (%DM)	Improved pastures Cu (μg/g DM)	Improved pastures Mo (μg/g DM)
Sourhope	6.8.76	0.43	6.1	2.9	0.20	5.2	0.7
(Alderhope)	29.5.79	0.52	6.3	3.9	0.18	6.8	0.9
	18.7.79	0.26	4.5	2.3	0.18	5.5	0.8
	1.9.79	0.32	4.0	4.0	0.17	4.8	0.9
	29.5.80	0.34	2.9	2.0	0.19	6.3	0.8
	9.7.80	0.30	3.1	2.5	0.18	5.5	0.7
	3.9.80	0.34	3.4	2.7	0.17	5.0	0.9
Glensaugh (Birnie)	23.8.77	0.28	9.2	3.5	0.18	7.8	0.7
House o' Muir	27.5.81	0.33	8.4	1.9	0.18	7.5	1.0
Lephinmore (Low End)	15.1.82	0.24	5.9	1.8	0.14	5.7	0.5
Mean		0.34	5.4	3.8	0.18	6.0	0.8
Standard error		0.028	0.73	0.27	0.005	0.35	0.05

The low copper levels in the reseed samples from Sourhope in 1980 may have reflected high pasture growth rates due to untypically high rainfall during the spring and summer of that year. Drought conditions are quite common during spring and early summer in the eastern side of the Southern Uplands of Scotland and soil water deficits may restrict pasture growth in many years. It is probable that on soils with marginal or low available copper however, increases in pasture production of the order brought about by reseeding can readily lead to depressed herbage copper concentrations through a dilution effect.

At all locations, and on all dates (Sourhope), the concentrations of molybdenum (0.5-1.0 μg/g) were considered normal for indigenous herbages. They were significantly enhanced in all reseeded herbages with a mean concentration of 2.8 μg/g, i.e. an increase of 3.5 times when compared with the mean level in the unimproved pastures. The pH values of the improved soils were not excessively high as only sufficient lime was applied to enable the satisfactory establishment and growth of white clover and introduced grasses. This was confirmed by soil pH measurements which indicated that the pH of these reseeds did not exceed 6.0.

The reseeded herbages also consistently showed higher sulphur concentrations with a maximum value of 0.52% in May 1979 at Sourhope. The sulphur levels in the indigenous vegetation, which were fairly constant at 0.17-0.20%, were 1.5-2.5 times lower than equivalent sulphur levels in the reseeds. Lower concentrations of sulphur were found for both indigenous and reseeded pastures from the Lephinmore deep peat but even here the concentration in the reseeded pasture was greater. These elevated sulphur concentrations may reflect increased mineralisation rates of soil sulphur as a result of both the soil cultivations used during the improvement process as well as to increased soil pH.

The 1979 and 1980 data from Sourhope for the reseeded vegetation suggest that both inter- and intra-annual variations exist in the concentrations of all these nutrients. There was a consistent decline in copper concentration during 1979 whereas in 1980 there was a tendency for it to increase. In both years, but particularly in 1979, lower sulphur concentrations were found in the July harvest than in either May or September. These may have been simply dilution effects due to higher pasture growth rates in July. A similar trend can be observed in the 1979 molybdenum concentrations but in 1980 a steady increase during the growing season was found. The magnitude, nature and significance of these variations have not been investigated in regularly defoliated pasture species in the hill environment and such studies would now appear to merit serious consideration.

The nutritional availability of copper to grazing ruminants

The absorption of copper from animal feeds may be adversely influenced by numerous dietary components (see, for example, Owen, 1982), although only the influence of zinc, iron, molybdenum and sulphur would appear to be potentially relevant to the grazing of hill pastures. Increases in zinc and iron concentrations in herbages as a result of reseeding, are unlikely to be significant. Indeed some reduction in zinc and iron uptake after reseeding could be anticipated although no assessment of this has been made. However it is known that plant uptake of both elements is inversely related to the pH of the soils and in general, therefore, liming would tend to reduce plant tissue concentrations. Nevertheless, soil, as a source of readily available iron to grazing animals, can be ingested in significant quantities at certain times of the year, particularly during autumn. It has been shown that soil ingestion can impair copper absorption, but no assessment of its significance in the grazing of hill swards has yet been made.

Since it was revealed that dietary molybdenum and sulphur could markedly impair the copper metabolism of sheep (Dick, 1956), much work has been carried out in order to understand fully both the metabolic mechanisms involved and the nutritional significance of the antagonism. Although these mechanisms remain imperfectly understood much progress has been made, and it is now known that the ruminal formation of unabsorbed copper thiomolybdate complexes is strongly implicated.

Using a copper repletion technique with Scottish Blackface sheep, which grazed summer pastures varying in the herbage concentrations of molybdenum and sulphur, a relationship between the absorbability of copper (in the animal) and the concentrations of ingested pasture molybdenum and sulphur has been reported (Suttle, 1983). This relationship is described by equation (2).

$$\text{(2)} \qquad \text{Cu absorption (\%)} = 5.72 - 1.279\text{S} - 2.785 \log_e \text{Mo} + 0.227\ \text{Mo} \times \text{S}$$

where S and Mo are the sulphur and molybdenum herbage concentrations in g and mg/kg DM respectively.

Equation (2) has been applied to the concentrations of molybdenum, sulphur and copper shown previously in Table 28 which refers to reseeded and improved herbages. The copper absorption (%) (A_{Cu}) and the concentration of copper absorbed from the grazed herbage (D_{Cu}), as µg Cu/g dry matter (DM), are shown in Table 29 and clearly indicate the wide disparity between the two sources of herbage.

The A_{Cu} values in the reseeded herbages were all low at 1.4% or less, except in herbage from the Lephinmore deep peat (2%), whereas those of the indigenous herbages were 3.8% or higher. Mean A_{Cu} and D_{Cu} values of the reseeded herbages were only about 20% of those found in the indigenous swards. The D_{Cu} figures when converted to daily copper intakes (D_{Cu} × kg/day DM Intake — not shown) and, compared with published requirements (Agricultural Research Council, 1980), indicate that the reseeded herbage provided only 25% or less of the net copper requirements for satisfactory performance of growing lambs (Lephinmore — about 50%), whereas the unimproved pastures provided a sufficiency for most classes of ruminant livestock. The reseeded pastures did not provide sufficient absorbable copper for adult Scottish Blackface sheep.

This would be most significant in pregnancy and particularly during the last 6-7 weeks, when ewes have a high copper requirement as have their foetuses, if swayback is to be avoided subsequently.

Table 29
Calculated coefficients of copper absorption (A_{Cu}) and concentration of absorbed dietary copper (D_{Cu}) in sheep which grazed either reseeded or unimproved hill pastures

Location	Sampling date	Reseeded A_{Cu} (%)	Reseeded D_{Cu} (µg/g DM)	Unimproved A_{Cu} (%)	Unimproved D_{Cu} (µg/g DM)
Sourhope (Alderhope)	6.8.76	—	—	4.5	0.23
	29.5.79	—	—	4.1	0.28
	18.7.79	1.4	0.064	4.4	0.24
	1.9.79	0.7	0.027	4.2	0.20
	29.5.80	1.0	0.028	4.3	0.27
	9.7.80	1.0	0.032	4.7	0.26
	3.9.80	0.7	0.023	4.2	0.21
Glensaugh (Birnie)	23.8.77	0.4	0.035	3.8	0.29
House o' Muir	27.5.81	1.1	0.095	4.7	0.37
Lephinmore (Low End)	15.9.82	2.0	0.120	6.0	0.34

Quantitative assessments of copper absorption of the type described above provide a context in which soil/plant interactions, and consequent trace element levels in pasture herbages, may be considered directly in relation to the nutritional needs of grazing animals.

The influence of lime and fertilisers on concentrations of copper, molybdenum and sulphur in plants

A number of glasshouse experiments have been instituted as a preliminary examination of the uptake of copper, molybdenum and sulphur by both S23 perennial ryegrass and S184 white clover in response to the application of lime and fertilisers to acidic hill soils. Initially the Sourhope peaty podzol was used, as herbage from this soil had induced copper deficiencies in sheep at Sourhope due to elevated molybdenum and sulphur levels following reseeding. A later experiment included a brown earth from House o' Muir for comparative purposes. Treatments included applications of commercial NPK fertiliser (15:15:21), basic slag (as a source of phosphorus) and lime. A copper addition was made in one experiment only. Treatments were applied to the soil surface at rates proportional to those typically used under field conditions. Concurrently a further series of glasshouse experiments were initiated to investigate the interactions of a much wider range of soils and plant growth, in order to identify, and measure the effect of, the primary factors which affect plant trace element uptake. This work is being carried out under an AFRC studentship by Miss R. M. Paynter. None of the above experimental work has been concluded and therefore the results from the preliminary experiments which are referred to below are, as yet, unpublished.

Copper uptake

Higher concentrations of copper were found in white clover than in perennial ryegrass for most treatments, as would be expected. In one experiment for example, in the lime-only treatment, the copper concentration in perennial ryegrass was 5.5 μg/g compared to 8.1 μg/g in white clover. However the treatments which produced the greatest growth rates, reduced copper concentrations in both species to similar low levels of about 2.7 μg/g. All treatments tended to depress the copper concentration in both species with the exception of the lime-only treatment which had little effect. These responses could be accounted for by dilution effects due to greatly stimulated growth rates. In addition it is probable that the availability of soil copper (not measured directly) may have been marginal at these elevated growth rates. This postulate was supported by responses to the application of copper which produced small but significant increases of growth rate in both perennial ryegrass and white clover. The effect of copper application was to increase tissue copper concentrations in both species, but to a much greater extent in white clover than in perennial ryegrass. Copper levels in response to copper fertilisation of the soil confirmed those reported in the literature (e.g. Reith, 1975). Concentrations in perennial ryegrass ranged from 6.0-9.2 μg/g and in white clover from 8.8-17.7 μg/g, depending upon the main fertiliser treatment. If increases in copper concentrations of this magnitude could be achieved under field conditions, most induced copper deficiencies would still not be fully ameliorated, but the rate of depletion of copper reserves would be reduced and the onset of hypocupraemia delayed in grazing livestock.

Molybdenum uptake

Consistently higher molybdenum concentrations were found in perennial ryegrass than in white clover in all equivalent treatments. For example, in the lime-only treatment 2.7 μg/g Mo/g was found in perennial ryegrass but only 1.6 μg Mo/g was recorded in white clover. While NPK reduced molybdenum concentrations, both slag, and particularly lime, produced increases as would have been expected. The relationship between plant tissue concentrations of molybdenum and soil pH was confirmed. However, variable responses were observed in both plant species and soil type as the concentrations of molybdenum in perennial ryegrass were greater when grown in the peaty podzol, whereas in white clover molybdenum levels were greater in the brown earth. Further information on the nature of these interactions is still required.

Sulphur uptake

The concentrations of sulphur were about twice as high in perennial ryegrass as those found in white clover. For example, in one experiment the mean concentration of all treatments was 0.52% sulphur in perennial ryegrass compared to 0.26% in white clover. In perennial ryegrass essentially similar sulphur levels were obtained on both soils, whereas for white clover consistently higher levels of sulphur were found on the brown earth than on the peaty podzol. Increasing the rate of lime application from the equivalent of 2,500 kg/ha to 10,000 kg/ha did not influence the concentration of sulphur in white clover on either soil nor that of perennial ryegrass on the brown earth. However on the peaty podzol the sulphur concentration was significantly greater at the highest rate of lime (0.72%) than at the lower lime level (0.59%). Application of NPK consistently reduced the concentration of sulphur of both species, whereas there were no similarly consistent responses to the application of phosphatic fertiliser. Here sulphur concentrations were apparently dependent upon complex interactions between soil type, plant species, lime and phosphorus application. Many of these responses could be attributed in part to the relative balance between increasing uptake of sulphur, as a result of increasing soil mineralisation rates, and the depression of sulphur concentration due to increased growth rates (dilution effect). It is apparent that herbage sulphur levels are controlled by a complex of interrelating factors. The floristic composition of the sward and factors relating to the soil such as liming and fertiliser applications as well as its structure were shown to be of importance.

These preliminary glasshouse experiments, although incomplete, have identified some of the factors which can influence the copper, molybdenum and sulphur concentrations in the two plant species most commonly used in the reseeding of hill pasture. They have shown, at least in a glasshouse environment and in the two soils examined, that manipulations of the fertiliser, lime and copper status of the soils can give rise to large variations in the uptake of these three nutrients, and that the two plant species respond in markedly different ways. For example the higher levels of copper and the lower concentrations of molybdenum and sulphur, together with the greater response to applied copper, in white clover could be of considerable significance in terms of animal nutrition. Any conclusions however must remain provisional until responses and sources of variability are examined under field conditions. It is of importance therefore that field investigations are now carried out to determine the influence of factors such as sward components, the trace element status and structure of soil, plant growth rates and the effects these have on the uptake of copper, molybdenum and sulphur and also on the absorption of copper in the grazing animal.

Reconnaissance survey of reseeded hill pastures

As was shown previously, induced copper deficiencies in sheep and cattle could occur when some reseeded hill pastures were grazed. This condition was primarily due to increases in the concentrations of molybdenum and sulphur in grazed reseeded herbages and, furthermore, it occurred in pastures growing on quite different soil types. Extrapolation of this limited amount of data to the wider perspective of hill land improvement was felt to be unsatisfactory and unjustified, even though the data suggested the probability that induced copper deficiency is a frequent occurrence in hill reseeds. Nevertheless its extent was not known, nor was there available relevant data on which to base an assessment. Consequently, in the autumn of 1982 a relatively small reconnaissance survey of reseeded hill pastures was undertaken in collaboration with the three Scottish Colleges of Agriculture and the AFRC Unit of Statistics with the assistance of the Soil Survey of Scotland and DAFS Agricultural Inspectorate.

The reconnaissance survey, which was carried out in August and September, involved sampling the herbage and soil of 90 reseeded swards throughout the whole of mainland Scotland with equal numbers from each of the three College areas. Reseeds from the HFRO research stations were resampled mainly as a basis for comparison. Sites were chosen primarily according to soil type, with drainage status and age since sowing as secondary determinants. Herbage samples have been analysed for copper, molybdenum and sulphur concentrations, and A_{Cu} and D_{Cu} values have been computed using equation (2) (Suttle, 1983). As the statistical analyses remain incomplete few conclusions can be drawn at present.

A provisional examination of the D_{Cu} results indicates that a substantial majority of the sites (75%) could induce copper deficiency in grazing livestock. The degree of any such deficiency and responses to prophylactic treatment are obviously related to many factors. For example, in addition to the absorbable copper in the grazed herbage, the length of time animals are confined to the reseed, the copper status of the stock prior to confinement, and the age and physiological state of the animals will all be important. However about 50% of the sites yielded herbage with D_{Cu} values of 0.05-0.10 μg/g DM which were similar to levels measured in reseeds in which growth retardation has occurred in young growing lambs (Whitelaw *et al*, 1979). These results clearly suggest therefore that the depletion of the copper status of grazing livestock may be widespread as a result of grazing hill reseeds. Under certain conditions of pasture and grazing management symptoms of copper deficiency may be expected on a majority of recently reseeded pastures, unless remedial treatments are made.

A secondary objective of the survey was an attempt to identify some of the main soil/plant factors which control the trace element content of hill pastures. Variables which have been measured include age since sowing, drainage conditions, floristic composition, soil pH and organic matter content. However, any assessment of these must await completion of statistical analyses presently in progress. In addition it was hoped that the survey would help in the location of sites which would be suitable for further experimental work. Sites with diverse soil, climate and trace element status have now been identified.

The results of the survey can only refer to the time at which the samples were collected and under the conditions which then obtained. These are, however, of such a nature as to reinforce the view expressed earlier, that information is now required concerning the temporal variability of trace element uptake on both a seasonal and year-to-year basis.

Further studies

Improved methods of animal prophylaxis have been developed from recent work, including that carried out at HFRO (Whitelaw *et al*, 1980). Nevertheless it is clearly important to determine the scope for minimising the occurrence of the problem by more fully understanding the processes which influence the uptake of the relevant trace elements by plants and determine their concentrations in grazed herbage.

It has been widely reported that the concentration of copper, molybdenum and also sulphur in plant tissue can vary during the course of the growing season. This is in part a response to the state of maturity of the plant controlled by internal physiological mechanisms, as well as a response to changes in the availability of these nutrients in the soil. However there is little information on their uptake from cultivated hill soils in Scotland by regularly defoliated herbage species kept in a continual state of juvenile vegetative growth by grazing. The results of the reconnaissance survey strongly indicate that during the late summer and early autumn period the potential for molybdenum- and sulphur-induced copper deficiency in grazing ruminants is widespread in reseeded hill pastures. Analysis of pasture herbages from Sourhope suggested that seasonal and between-year variations of copper, molybdenum and sulphur occurred, with a tendency for concentrations to be lower in midsummer than earlier or later but that the pattern in the following year was rather different. As sheep production in the hills is based on an annual cycle of pasture production and utilisation it would seem appropriate for information on the variability of trace element uptake by pasture herbages throughout this cycle to be obtained. This work can only be carried out in studies under field conditions. Factors which have been found to influence the concentration of these trace elements in herbage should also be measured, including sward growth rate. This is a measurement of some importance, as annual herbage DM production is largely confined to the three or four summer months when rapidly growing swards may exhibit reduced levels of trace elements due to dilution effects. It may be anticipated that these effects will be greater on soils with low or marginal supplies of available trace elements.

The floristic composition of the sward is also likely to be influential in controlling herbage trace element concentrations. As the glasshouse experiments showed, white clover, when grown separately from any companion grass, consistently contained higher copper and lower molybdenum and sulphur tissue concentrations than was found in perennial ryegrass under the same growing conditions. These findings now require testing in mixed grass-clover swards in the field. If confirmed in the field these results could have some influence on the management of reseeded pastures, with respect to fertiliser applications and the manipulation of sward conditions to optimise the clover content.

Soil type and in particular the soil trace element content and its drainage status will affect herbage concentrations of many trace elements including molybdenum, and possibly copper. It will be necessary to examine trace element uptake by herbages on a number of sites with varying soil properties. A multi-site approach will also allow an examination of relationships between the trace element content of herbage and indices of the trace element status of the soil.

Responses to the application of copper in raising herbage copper levels has been reported to be modest, particularly when significant proportions of perennial ryegrass are present (Burridge, Reith and Berrow, 1983).

Nevertheless responses to copper application in certain soils of inherently low copper status or during periods of rapid herbage growth could be significant in animal nutrition terms, particularly in swards with significant proportions of clover.

Active consideration is currently being given to the design of field experiments to study the determinants of trace element concentrations in pasture herbages and their interrelationships. The results will be assessed with reference to the absorbability of dietary copper in grazing livestock.

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Evolution of research on the grazing ruminant

J. A. Milne

The purpose of this essay is to argue that in the conduct of research on the grazing ruminant now and in the near future there is one approach that will provide the greatest insight, the most rapid progress in our understanding and allow new findings to be incorporated into systems of production effectively.

In the past, the several approaches adopted have been constrained not only by the level of specialist knowledge and the techniques of measurement that were available at the time but also by the narrow view that was taken of how grazing management should be studied. The synthesis of current knowledge and new techniques with a more holistic view of the study of systems of grazing management now provides a basis for the further evolution of research on the grazing ruminant. It is this thesis about how grazing research should be conducted that will be developed.

Although it is not difficult to understand why scientists should be interested in the methodology of research, why should the beneficiaries of applied research on the meat-producing grazing ruminant be concerned about the methods used in that research? The livestock adviser, the commercial company introducing a new product for the market and the ultimate user, the farmer, assess the value of a new grazing system, a feed supplement or veterinary product in terms of economic benefit or other criteria, such as increased efficiency of output compatible with public acceptability. However they also require more information than for example, whether one grazing system is better than another by 10%, or whether a particular feed supplement will reduce input costs by 20% for the same level of output. They need to make judgements about the confidence that can be placed in the soundness of the conclusions of the research and in its width of application. They also extrapolate from the circumstances of the experiments to the often differing circumstances of individual farms. This requires an understanding of the biological principles involved.

This is particularly true of the sector of the farming industry that relies on grazed herbage to provide nutrients for much of the year for ruminant livestock. This sector is located in widely differing physical environments and it utilises a range of breeds and crosses and management regimes. For example, in sheep systems the physical environment can range from heather hills at altitudes of 500m with an annual rainfall of 200cm, short-growing seasons of 150 days and with poor soils of impeded drainage, which are difficult to improve, through intermediate upland swards, where the same limitations exist in varying degrees, to lowland swards where summer moisture deficit may limit output. A similar variation exists in the number of sheep breeds and crosses and in systems of management. Thus for application to this sector of the farming industry the limits of a research finding must be known. The old adage that no two farms are the same is never nearer the truth than in hill or upland areas where most meat-producing ruminants are based.

Confidence in the soundness of research findings is also important because of the conservative rate at which changes in management practices take place. A mis-applied research finding can be expensive to individual farmers especially in extensive systems of production where it may have long-lasting deleterious effects on sward and stock performance. This concern is likely to continue and indeed may become more important in the future as the cost of inputs relative to the price of outputs may become more volatile and less predictable, possibly encouraging more rapid changes in production methods and systems.

Commercial companies wishing to market a new product also have to assess the soundness and width of application of the conclusions of research, since they do not wish to invest in products which have too narrow an application or too limited a time-span of use within grazing systems. Commercial companies also use some financial measure of return on investment in research and development for which a discussion of the methodology of research has implications. It is thus of importance not only to the scientist but to the beneficiaries of research to understand the implications of using one approach rather than another.

Historical development of research methods

Agricultural research has its early roots in the classical experiments measuring yield responses to fertiliser applications. Grazing experimentation, at a much later date, followed the same approach of measuring responses initially in milk production and later in live-weight and carcass gain to variations in stocking rate, fertiliser rate or grass species. These experiments grew in size and complexity after 1945 as it was recognised that they were a valuable means of predicting benefits from apparently simple manipulations. Because of constraints related to the cost and availability of land and animals, response experiments of this type never reached the scale in the UK of those mounted in the USA and Australasia in the 1950s and 60s. However limitations to this approach became apparent. Interactions between treatments could not be understood because of the complexity of the interface between the grass plant, its growth, defoliation and regrowth on the one hand, and the intake of herbage by the animal and its conversion into animal products on the other.

Over the same period of time a completely different approach to research on the ruminant developed from the disciplines of biochemistry, physiology and nutrition. This led to a growth of indoor experimentation which allowed control over many of the interacting variables and also enabled measurements of biochemical and physiological parameters to be made. Application of these findings could be made to the housed ruminant such as the dairy cow or the beef animal in winter. In an effort to simulate grazing conditions, fresh or frozen cut herbage was given indoors, mainly to wether sheep, to determine nutritive value in terms of voluntary intake, digestibility and metabolisable energy (ME) value of herbage likely to be ingested by the grazing ruminant. Further advances in our understanding of ruminant digestion allowed more precise measurements to be made of the nutrients absorbed from the digestive tract. The use of isotopic tracers to measure aspects of metabolism of the ruminant further reinforced the need to conduct experiments under controlled conditions indoors. Extrapolations were made from these indoor studies to the grazing animal with some success, in that results from comparative experiments indoors could be expected to give the same response ranking in a grazing context. However where voluntary intake is important, as is the case with the grazing animal in all circumstances, this imposes constraints on the quantification of the nutrients that can be obtained by the grazing ruminant, because of the difficulty of simulating voluntary intake in indoor experiments. From the point of view of advancing understanding of grazing ruminants, whilst indoor-based research has contributed substantially to progress, it has had perforce to ignore issues which are not amenable to indoor study, and some of these are of great importance.

Arising out of a realisation of the complexity of the grazing situation, and stimulated by the interest of some ecologists in a systems approach to understanding the biology of natural systems, a further development in research on the grazing ruminant has taken place in the past 15 years.

Complex systems can be modelled as a series of states and rates. Mathematical relationships governing the different rates can be postulated, and computer simulations developed which enable the researcher to explore the interactive nature of the system under investigation. This approach is clearly of great potential value in the study of grazing systems. Progress is being made but the approach has led to a requirement for an understanding of the important rate processes in these models, many of which can only be quantified through experimentation at a level not previously considered possible with the grazing ruminant. Application of the systems approach to practical management systems, in which hypothesis and model-building is followed by physically testing the system, has also identified areas of knowledge which were inadequate and has thus in turn stimulated new areas of research.

This short historical perspective has had the aim of emphasising the main thrusts in research associated with the grazing ruminant. New approaches to research develop from previous work and the knowledge accumulated from it. However new approaches in applied research also reflect the times in which they are conceived both in terms of technical innovation and the circumstances of the industry for which the research is conducted. The synthesis of these elements into a new approach to research on the grazing ruminant will now be considered.

Advances in techniques

Advances in science are often associated with the application of a new technique from another scientific discipline to an area which has stubbornly refused to yield answers. The development of the electron microscope or X-ray crystallography, for example, enabled limitations to biochemical understanding to be removed and stimulated a new flow of knowledge. In grazing research I have suggested that similar limitations have occurred where animal production response experimentation foundered on complexities that the prevailing methodologies could not unravel. Similarly, the understanding of ruminant digestion and physiology obtained from indoor studies has been sometimes difficult to apply in the grazing context, where measurements which can be made relatively simply indoors cannot be envisaged outdoors. The modelling approach too is about to reach a stage where the hypotheses erected within such models require testing and where a more detailed understanding of mechanisms and processes underlying grazing and the responses of grazing animals needs experimental amplification.

The techniques developed some 25 years ago for measuring herbage intake based on the measurement of faecal output and some index of indigestibility (see Langlands (1975)) allowed some advances to be made, particularly in relating attributes of the sward to herbage intake which are impossible to establish by indoor experimentation. A crucial set of relationships exists between herbage mass, sward height and density and herbage intake which are central to modelling approaches. These relationships have now been established in general terms although their quantification remains inadequate in many respects. The measurement of herbage intake also allows the measurement of digestible OM intakes to be made and metabolisable energy intakes to be predicted. These have provided a level of understanding which has lent confidence to animal production measurements from the grazing animal. Thus this technique has provided an interpretation of production responses and has allowed a first step in the development of models of the interactions between the grazing animal and pasture. However the technique has deficiencies in that relatively steady states of pasture are required for periods of 5-10 days to allow measurements of faecal output to be made. Important changes in swards can take place or may be caused by management practices over much shorter periods than can be measured by this technique. Indeed, it could be argued that such a technique which initially has assisted progress needs now to be replaced by better techniques if further advances in our understanding are to be made.

Furthermore when supplements are given at pasture, the indigestibility factors for herbage and supplement are assumed to be independent of one another, an assumption which is usually untenable. Also where pastures contain more than one plant species and these are widely dispersed within the sward as is the case with most hill pastures, it is difficult to obtain estimates of the indigestibility factor. The technique also provides no direct information on the amounts of protein being absorbed by the grazing animal. The burgeoning growth of knowledge of N digestion in the ruminant has underlined the need to make measurements of this aspect and has highlighted a further limitation to the usefulness of the technique.

Although the measurement of herbage intake by the faecal output/ indigestibility factor method is still an important part of many experimental studies, other methods are now being explored. Herbage intake is controlled by a number of factors. These include the physiological state of the animal, for example as demonstrated by the expansion in appetite that takes place in lactation, factors controlling satiety by physical distention of the gut or which are related to the energy concentration of the diet, and factors associated with the ingestive behaviour of the animal. Variables important in this latter aspect are the time spent grazing, the rate of biting and the amount consumed in each bite. It was recognised that, if the relationships between the grazing animal and pasture were to be understood, studies of the grazing process in which herbage intake is broken down into its behavioural component factors were required (see Hodgson, 1977). However, the tedious and expensive methods of continuous observation, which are required to obtain an understanding of behavioural influences on herbage intake, have limited progress.

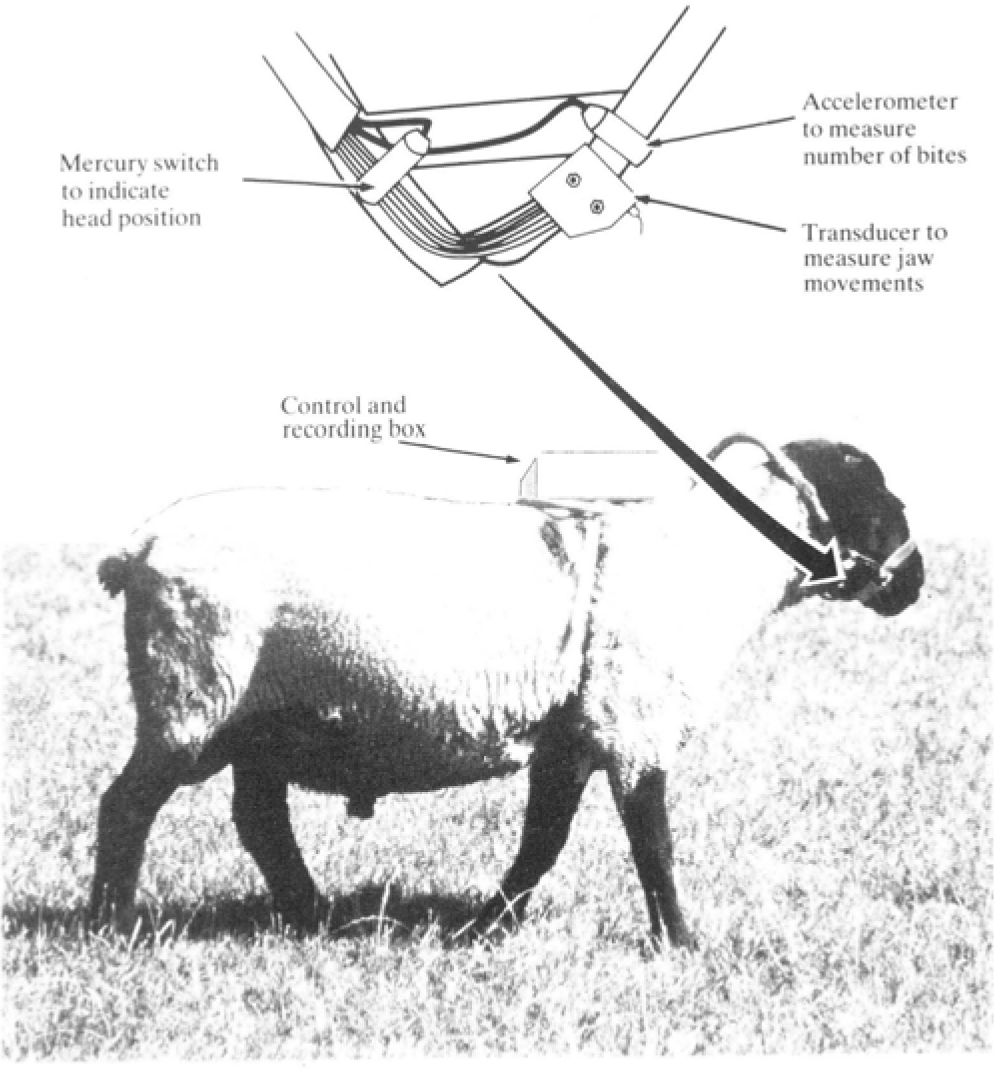

Figure 22

Equipment for the automatic recording of ingestive behaviour in sheep.

Advances in transducer and microprocessor technology are now being harnessed to provide equipment which allows continuous measurement over long periods of time of such aspects of grazing behaviour as grazing time, rate of biting, jaw movements associated with prehension of herbage and its ingestion and rumination (Chambers *et al*, 1981; Penning, 1983). An example of such equipment is shown in Figure 22. These techniques should allow an increase in our understanding of the grazing process in the next few years through aiding the development of grazing behavioural models relating sward structure to intake. These behavioural methods could also have a central role in developing an alternative method of measuring herbage intake in that the product of the total number of bites taken by an animal in any time interval and the mean amount consumed per bite describes herbage intake. Advances in electronic technology have also enabled the design of telemetry systems to pinpoint the location of animals whilst grazing. This, along with grazing behaviour measurements, could allow the development of methods of exploring the social and motivational priorities which must also influence herbage intake in flocking and herding ruminants. It will also be possible using similar hardware to monitor physiological processes such as heart rate or body temperature of the grazing ruminant which can be related to grazing behaviour.

Herbage intake, even with knowledge of the predicted digestibility of the diet, is still a crude measure of the nutrient intake of the grazing animal. Energy substrates that are absorbed as a result of rumen fermentation are not indicated, microbial protein production and the amount of protein that is potentially available for absorption are not known. This is particularly important when supplements are being offered to the grazing animal, since the interaction between herbage and supplement in the rumen is not only important directly in terms of rumen fermentation and nutrients absorbed but also as it has an effect on the substitution rate of supplement for herbage intake. For example the composition of the supplement has been shown in indoor studies in some instances to increase the voluntary intake of poor quality hill vegetation and in others to produce a substitution rate of 0.6 i.e. the addition of 1 g of supplement reducing herbage intake by 0.6 g. In grazing studies substitution rates of almost 1.0 have been obtained with high quality spring grass when a cereal-based supplement was offered and changes in ruminal ammonia concentrations and volatile fatty acid proportions have been observed.

Our awareness of these crucial issues has been heightened by improved understanding of ruminant digestion such that it is the nutrients absorbed which are now used as the basis on which to predict production responses. Equipment for the infusion of digesta markers first developed in Australia (Corbett *et al*, 1976) now enables the measurements of nutrients that can be absorbed by the grazing animal, and this approach is currently being used in cattle studies at the Grassland Research Institute (Evans *et al*, 1981) and with sheep at HFRO. The equipment in use at HFRO is

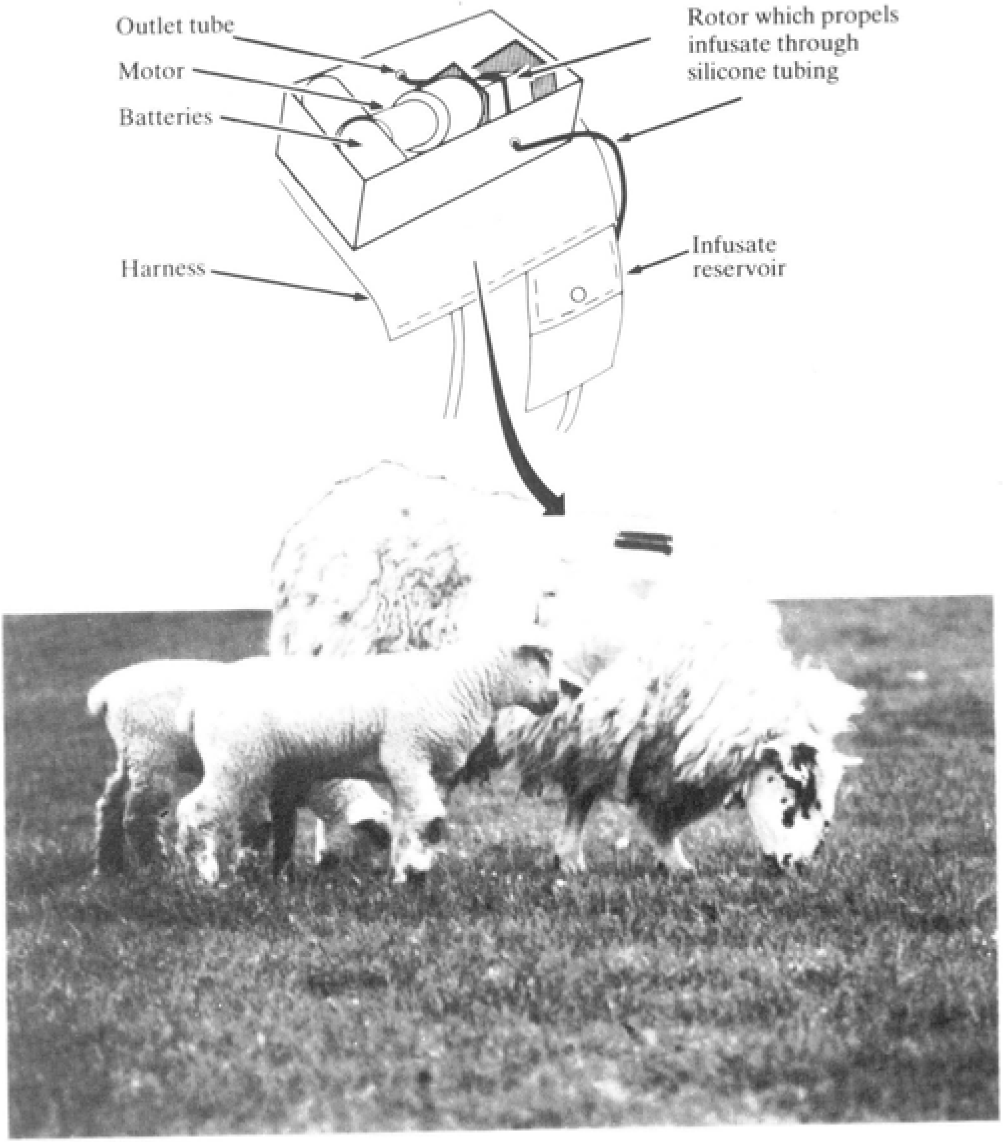

Figure 23

Portable infusion pump to allow measurements to be made of digesta flow in the grazing sheep.

illustrated in Figure 23. Measurement of substitution rate still poses problems but new approaches currently under investigation hold out promise in this regard (Mayes and Lamb, 1984).

The same infusion equipment has also been adapted to measure aspects of the metabolism of the grazing sheep using isotopic tracers. The ewe has to call upon her fat tissues at various stages of her annual reproductive cycle and a knowledge of her metabolism at those times is important in supplying the correct nutrient provision. Until recently the metabolism of the grazing animal has not been studied because of technique limitations, but it will now be possible to assess differences between the metabolism of housed and grazing ruminants. By modification of the same equipment it should be possible to obtain blood and rumen samples automatically throughout a 24 h period. This will aid nutritional and metabolic understanding and may also be useful, for example, in furthering our knowledge of the hormonal control of reproduction of the grazing ruminant.

It is thus argued that the application of electronic and micro-processor technology to the study of the grazing ruminant has created the means of developing our understanding at a level of biological organisation that was not possible before. From this greater understanding, animal production experimentation can be interpreted with a greater certainty about both the conclusions drawn and the extent of their possible application.

An example of such an approach is in the study of the supplementation of the crossbred ewe in early lactation when herbage supply limits ewe milk yield and lamb growth rate. Research conducted indoors had demonstrated a positive relationship between non-ammonia-N (NAN) passing the abomasum, a measure of protein supply to the ewe, and milk yield. This suggested that a supplement with a rumen undegradable source of protein might be beneficial. From animal production experiments at HFRO where lamb growth rates and ewe live-weight changes were measured and in which, by the nature of this type of experimentation, only a small number of treatments, i.e. supplements differing in amount and composition, can be tested, relatively small benefits in lamb live-weight gain were observed when this type of supplement was given. These benefits in lamb live weight were subsequently lost by weaning (see Table 30). These results on their own are difficult to interpret and thus to apply to the range of lambing dates and environmental and sward conditions that exist in upland Britain. Why did the supplement with a rumen degradable source of protein not produce much higher lamb growth rates than a simple supplement, such as molassed sugar beet pulp? Was it because the simple energy supplement allowed the effective use of the high levels of nitrogen in spring grass? How was the substitution rate of supplement for herbage influenced? What levels of energy substrate and protein were potentially available for absorption? By measuring the microbial protein production rate in the rumen and the amount of NAN passing the abomasum it can be seen from Table 30 that the molassed sugar beet pulp supplement, which is low in protein, increased the amount of microbial protein produced in the rumen and the amount of NAN passing the abomasum. This suggests that, indeed, more effective use of the nitrogen in spring grass was being obtained. The results from the amount of NAN passing the abomasum also give an explanation for the responses obtained in ewe milk yields and lamb live-weight gains.

Table 30
Animal production and interpretative data from an experiment conducted on Greyface ewes grazing spring pasture and given supplements

	No supplement	Molassed sugar beet pulp (600 g/d)	Protein† supplement (600 g/d)	SE of mean
Lamb live-weight gain whilst supplements were given to ewes (g/d)	254	308	331	12.5
Live weight of lambs at weaning (kg)	28.4	30.2	29.5	0.62
Microbial protein production in rumen (g N/d)	41	47	53	4.5
NAN flow at abomasum (g/d)	44	55	69	4.3

† Supplement contained 50% molassed sugar beet pulp and 50% formaldehyde-treated soyabean meal (Dove, Milne, Lamb and McCormack, unpublished data).

It can be seen that with a small number of similar experiments our level of understanding will be increased such that a greater certainty of application of research findings can be achieved. Such an approach also has the advantage that only small numbers of sheep and areas of land are required, although skilled staff and modern laboratory facilities are necessary.

Current approaches

The example given above illustrates how nutritional problems in animal production can be solved by a combination of animal production measurements, such as lamb growth rate, and results obtained from the development of new methods of measuring, for example, microbial protein production rate in the rumen and the amount of NAN passing the abomasum in the grazing animal. Other examples from the current HFRO research programme where a similar approach is being adopted are in studies on the nutrition of the ewe in late pregnancy and over the mating period and in describing the nutritive value of grazed forage crops. At the interface of the sward and the animal the study of how grazing behaviour and sward structure interact to influence herbage intake is also being investigated at the same level of detail to aid interpretation of animal production measurements. Thus one way in which an approach can be considered to have evolved is through the integration of animal production measurements, which provide evidence for the precision of a response to a given manipulation, and interpretative measurements made on the grazing animal to provide knowledge of the robustness and width of application of the findings.

These findings need to be incorporated into practical grazing systems which must be based on sound quantitative understanding. The method by which this understanding is used to design systems is through the development of what it is hoped will be comparatively simple models and decision rules. Systems experimentation then tests the decision rules in such a way as to identify the successful ones and expose those which are inadequate. Thus simple models built up using the data obtained from the techniques discussed above can be tested in a range of management systems to examine their soundness and be accepted or refined by further experimentation. Thus another aspect of the evolution of an approach is the way in which simple sub-models derived from data based on the developing techniques of measurement become an essential part of a systems investigation leading to the production of tested whole grazing systems.

A grazing system can be considered as a physical representation of a model which could, in theory, be equally well described by a computer programme. Computer models which simulate the digestion process in the ruminant with some success have already been developed (Black *et al*, 1981). Similarly, sub-models of herbage intake and pasture growth and defoliation are under development. At present these are predominantly used by scientists to aid their thinking. These models have been based mainly on findings from indoor experiments, although interpretative data obtained from measurements made with the grazing animal are now being collected and used more widely. As a consequence these models are likely to improve considerably in the next five years. A further stage will be to aggregate the sub-models to form computer models of grazing systems. Although such whole system models are a medium-term objective and a major impediment remains the difficulty of adequately modelling the responses of animals to sward conditions and the responses of swards to defoliation, they are now seen to be realisable.

An approach to grazing research has thus developed where measurements made with the grazing animal of mechanisms and processes can be used to aid interpretation of animal production experiments, to develop decision rules for grazing systems and to assist in the building of computer models. In the longer term these models should evolve to such an extent that they can be used in a predictive manner to assess, for example, the outcome of a change in stocking rate or supplementary feed input on lamb output and ewe performance from a grazing system.

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