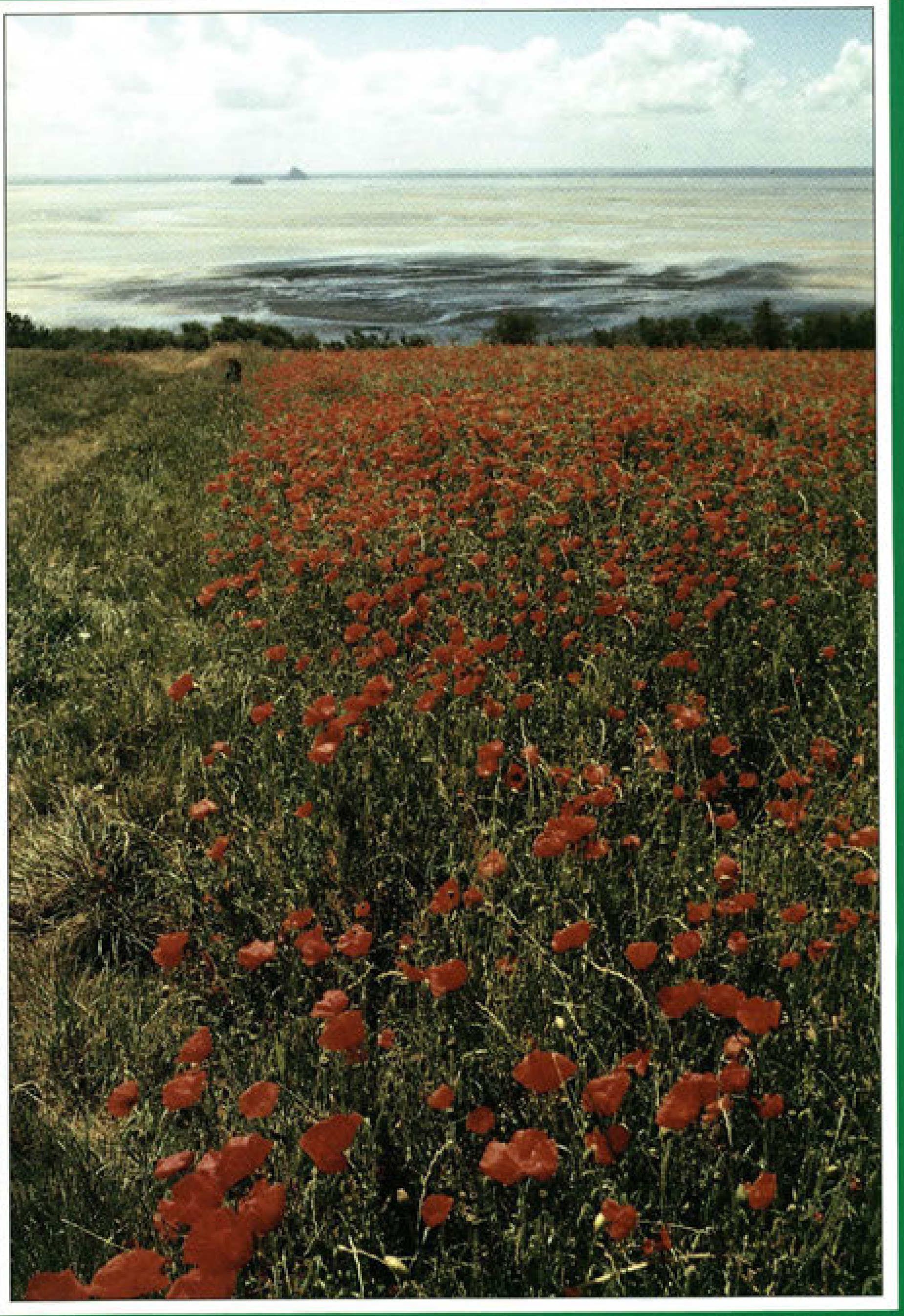
Annual Report 1989-90



THE MACAULAY LAND USE RESEARCH INSTITUTE
Craigiebuckler Aberdeen and Pentlandfield Roslin

MLURI

The Macaulay Land Use Research Institute is the only research institute in the U K specifically concerned with the study of land resources and their exploitation. Our experienced professional staff, working with extensive databases and a wide range of experimental facilities, make us a major force in the systematic development of technological approaches to the use of land in agriculture, forestry and the environment.

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THE MACAULAY LAND USE RESEARCH INSTITUTE

Annual Report 1989-90

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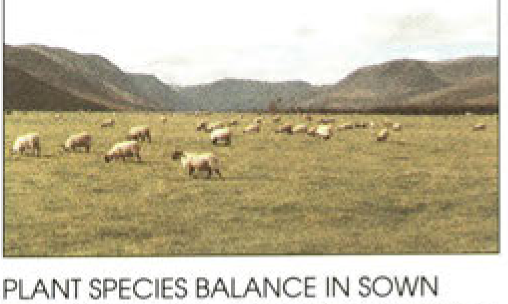

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1: LAND RESOURCES AND INFORMATION SYSTEMS

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CONTENTS

THERE HAS NEVER BEEN A TIME when the debate regarding the use of rural land has been so intense, and covering every sectoral interest. Agriculture is undergoing severe economic pressures, particularly in the livestock sector and is facing the prospect in the longer term of prices no longer being protected or supported to the same extent under CAP. The public perception of agriculture has also been damaged by ill-balanced and poorly informed presentations regarding food quality and health. Pressure on the land market, the volume of agricultural borrowing and the fact that farmers continue to leave the land are indicative of the constraints under which many farmers now operate. Nevertheless significant parts of the industry continue to respond to technological opportunities to improve the efficiency of crop, meat and milk production, to increase profitability and compete more effectively in the European, and indeed, the world market place.

New planting of forests has slowed down and the uptake by farmers and landowners of the Farm Woodland and Woodland Grant Schemes is also slow: it can be concluded that this will only be improved on the basis of perceived future beneficial investment opportunities in forestry which is dependent upon projections on market demand for timber products, by improved financial incentives from Government or as a result of diminishing agricultural fortunes.

At the same time concern for the protection and conservation of the environment is uppermost in the minds of the public. The agriculture, forestry and recreation industries are increasingly aware that their continued development must be in the context of land management policies which are environmentally sensitive. And yet it is crucial that these industries find acceptable ways of contributing to and sustaining the social and economic fabric of rural areas, and in particular, for agriculture to remain in a position whereby it can contribute to the future world demand for food as the world population continues to expand rapidly into the next century. Technological opportunities which improve the efficiency of agriculture and forestry require to be developed and applied in an appropriate context. Equally, opportunities to provide access in a controlled, and environmentally sensitive manner to facilitate the enjoyment of the countryside have to be found.

The success with which this multitude of objectives for land use can be achieved depends on our ability to analyse critically the various options and strategies based on as much 'hard' information as possible. The Institute's central role is to develop information technology and modelling systems, underpinned by the knowledge derived from relevant programmes of strategic science to do this.

This Annual Report has four articles which reflect this approach. The first article examines the factors which influence Agriculture and Land Use Change and reviews some of the prospects and opportunities for change: this is followed by a review of Geographic Information Technology as a means of objectively assessing land use options and land use planning. Two further articles deal with aspects of strategic research on animal and plant ecology which are relevant to hill and upland ecosystems. One addresses the question of how ruminants, whether they be sheep, cattle or more novel species such as deer and goats, are affected by changes in the seasonal cycle of day length in relation to reproduction, growth and the build-up and break-down of body fat, and how these interact with the digestion and metabolism of the natural food supply. The other is concerned with aspects of plant competition and the sustainability of grazed grass/clover pastures in low input and more extensive systems, and the potential for creating more diverse plant communities. The remainder of the report highlights areas of progress in the research programme as a whole.

The practical means whereby a range of land use objectives can be achieved was the subject of the 14th Macaulay Lecture given by Sir Robert Cowan, Chairman of the Highlands and Islands Development Board (pages 60-65). Sir Robert explains how the Board has tried to achieve an integrated approach to rural development in relation to 'Farming, Forestry and the Environment' in the Highlands and Islands. It is important to note Sir Robert's thesis that rural land use integration will only be successfully achieved if it involves those people who reside in rural communities and make their living off the land - the 'bottom-up' approach. Clearly the social dimension is central to almost every policy to do with land use.

During the year two substantial EEC Contracts have been awarded under the EEC programmes STEP and CAMAR, and the Institute is participating in others in collaboration with other research centres in Europe. Income from sources other than DAFS for research and consultancy has continued to grow. A Resource Consultancy Unit (RCU) which markets a range of consultancy services on land evaluation and assessment to serve farmers, foresters, estates, Regional Authorities, Government Agencies, and other public and commercial bodies is being formed which will be fully launched in April 1991.

There has been an increase in the number of visiting workers from many parts of Europe, from Japan, Sri Lanka, the Middle East, South America and Australasia. As we enter the current academic year there are twenty-five post-graduate students working in the Institute in close collaboration with both Aberdeen and Edinburgh Universities, and Universities elsewhere in the UK. Working relationships and collaborative research projects and proposals with the Scottish Universities, the Scottish Agricultural College, the Forestry Commission, the Institute of Terrestrial Ecology, the Rowett Research Institute, the Moredun Research Institute, the Scottish Crop Research Institute and the AFRC Institute of Grassland and Environmental Research, and the

Institute of Animal Physiology and Genetics Research, are a significant feature of the Institute's activities and multidisciplinary research.

The major political changes which have taken place recently in Eastern Europe have opened the door for increased collaboration. The Institute in common with its sister SARI Institutes and with SASS launched an initiative to promote a range of scientific exchanges and joint projects to be funded by international funding agencies and by the EEC. A brochure was prepared and a series of pathfinder and fact finding missions have been arranged to visit Poland, Czechoslovakia and Yugoslavia. Scientists in all these countries have responded positively to the SARI East European Initiative. Project areas of mutual interest have been identified; programmes of training visits, scientific and technical exchanges and cooperative experimental programmes for which funding can be sought are being developed.

Topics appropriate for collaboration already raised by scientists in Poland and Czechoslovakia as of importance to their countries and relevant to MLURI expertise range from grass physiology, through monitoring changes in environmentally sensitive areas, the attainment of sustainable plant production with low inputs, foraging behaviour and vegetation dynamics, land use in hill, upland and marginal land, to the use of remote sensing as an aid in land use monitoring and planning. Since all are of key importance in the programme of research commissioned by DAFS there are clearly mutual benefits to be realized in developing cooperative scientific work in these areas.

The Institute continues to review its programme of research in relation to the changing requirements of R&D funding, new opportunities and the roles of research organizations throughout the UK and Europe. Achievement of scientific excellence and the relevance of research are the criteria which will influence our programme of work and the establishment of an international reputation in four key areas. These are:-

Land use information and modelling systems, and environmental impact assessment

Acidification and pollution of soils and waters, organic matter turnover and soil mineralogy

Soil-plant relationships, including microbiological aspects and nutrient cycling.

Vegetation dynamics and foraging strategies of grazing animals.

T. J. MAXWELL, Director

Photo: Words and Pictures Aberdeen

Hugh Webster - Photography Strathpeffer

AGRICULTURE AND LAND USE CHANGE

T.J. MAXWELL

Introduction

Land use and land use change is increasingly influenced by Government and EEC policies and these policies are largely determined by the way in which economic and social issues, and environmental considerations and technology interact (Figure 1). The final outcome, however, is largely determined by the way **land owners** and those responsible for managing the land respond to these policies in the choices and decisions that they make.

In order to understand the nature of this decision-making process it is important to consider, first, the impact that economic and social policies have had on land use change; second, the implications of the increasing influence of environmental considerations on land use; third, how the hill and upland sector of agriculture might respond; and the means whereby the development of these areas can be secured.

The impact of economic and social policies

As a result of changes in the profitability of different agricultural enterprises, changes in the balance of use of land between these enterprises are inevitable; secondly, within enterprises land management practices will also respond to changes in profitability by adjustments to inputs and the adoption of new technologies. Thirdly, some forms of agricultural production may be less profitable relative to other land uses and therefore land will be removed from agricultural use altogether.

This analysis is derived from an economic view based on the assumption that the motive for farming is to maximize profits. Though farmers invariably have other motives, it is axiomatic that if they are to stay in business and remain on the land, revenues must exceed costs by a sufficient margin to justify the employment of labour and the use of capital in the farming business.

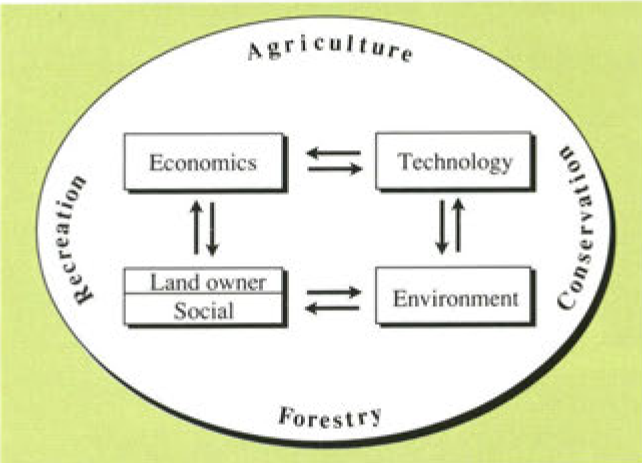

Figure 1. Land use interaction.

During the last 25 years the revenues which farmers have been able to expect have encouraged practices which have increased output to maintain income, to the point at which, for some commodities, surplus levels of production have been reached. Economic theory would suggest that surplus output would bring about a reduction in price and a fall in revenue, justifying a reduction in inputs. This would reduce output and consequently restore the balance between supply and demand and a stabilization of price. However, the sources of revenue to farmers extend beyond the market price and include significant financial support from Government. Support is used as a means of implementing strategic economic and social policies. In concert with the European Community's Common Agricultural Policy (CAP) the aim has been until relatively recently to:

1. increase agricultural production
2. guarantee regular supplies
3. ensure reasonable prices to consumers, and
4. ensure a fair standard of living for the agricultural population.

In general the CAP has achieved its objectives by guaranteeing minimum prices, and providing grants. Consequently, farmers have often increased output because they have farmed land which, in a free market economy, they would not have found profitable to farm. Equally, some have found it profitable to farm their limited land resources more intensively. Farm price support through CAP has raised both the extensive and intensive margins of land use.

However, the CAP has also brought problems, of which surplus output is the most important. While improvements in technology have been a major force in the creation of these surpluses, the improvements would not have been so readily adopted had it not been for the price support received through the CAP. Consequently the principle aim of the policy is now the stabilization of production and the limitation of budget cost. The objective is to attain this within a framework which calls for economic development in depressed areas and has due regard for social and enviromental factors.

Perhaps the most significant changes in land use in the hills and uplands have been brought about, until recently, by the way in which Government have balanced their support policies as between agriculture and forestry and the extent to which planning guidelines have protected agricultural land from both urban and forestry development. During the last 30 years, most afforestation has taken place on land which has become less economic to farm in the hill and upland areas of Scotland, with a more modest expansion in Wales and northern England. Just over 10% of land is now in forests. To an extent, the rates of afforestation have reflected the economic fortunes of the hill farming sector in relation to the introduction of the various policy instruments to encourage investment in forestry. The fiscal advantages to high tax payers, who found it financially rewarding to make long-term investments in forestry, however, were removed by the Chancellor in his 1988 Budget. The expectation is that the Government's planting targets of 33,000ha per annum will now be more difficult to achieve despite the introduction of new grant-aided planting schemes: these being the Woodland Grant Scheme and Farm Woodland Scheme. The schemes were designed to be attractive to owner-occupiers. Both schemes have the potential to encourage a greater degree of integration of agriculture and forestry activities. The Farm Woodland Scheme is designed to encourage the planting of arable and improved grassland, with planting grants being paid by the Commission under the Woodland Grant Scheme and agricultural income foregone is compensated until the likely time of the first returns from timber appear. However, the uptake of these schemes so far has been very modest. Planting is being done for a variety of reasons, the most popular being for landscape, amenity, conservation, sport and game. It is notable that the production of timber appears to be of less importance.

It is difficult to assess what the future rate of transfer of land from agriculture to forestry is likely to be. As in the past much will depend upon the balance the Government chooses to adopt in its support policy for each of the industries. If a significant amount of land is to come out of agriculture and still be used in the production of a tangible product, then of these options forestry must rate quite highly. The support for a continued expansion of forestry rests on the current high import bill for wood products (£7.0 billion) and the strategic view that a greater degree of self-sufficiency is a prudent policy for the future.

However, Government and EEC economic and social aims for agriculture still appear to be oriented towards maintaining the stability of rural populations. Until recently these aims have largely been achieved through the support of production objectives but during the last six years the CAP has been increasingly designed to bring production levels down. This has been done by setting production limits (e.g. quotas), reducing support prices, often in association with stabilization arrangements and developing incentives to take land out of agriculture, for example 'set-aside' and the Farm Woodland Scheme. The free-marketeers will continue to argue for further reductions in price support, believing that this would enable agriculture in the future to compete more effectively in a world market: by reducing support, agriculture would be encouraged to use its resources, including land, more efficiently and reduce its unit costs. In Europe as a whole, the political price for such a policy would be high, since it would inevitably lead to an exodus of people from rural areas. European policies are therefore likely to be more measured; certainly they will be concerned to reduce budget costs which support excess production: but policy makers will wish to find ways of diverting the consequent savings into other kinds of support like the Farm Diversification Scheme and the anticipated Extensification Schemes in order to secure the viability of rural areas.

Land use and the environment

While much of the rationale for change in the CAP is based on the need to contain its budget, the recent political willingness to bring about change has been as much influenced by the environmental as by the economic issues which have to be addressed.

Until relatively recently financial support has been such as to encourage the adoption of methods which have aimed to maximize the output of crops, milk, meat and other livestock products. Hedges have been removed, wetlands drained, herbicides and pesticides have been used extensively, and increased amounts of fertilizers, in particular nitrogen, have been applied. Many of these practices have had a significant effect on landscape and reduced the diversity of wildlife in our countryside and polluted streams and rivers. Higher stocking rates in some hill and upland areas have damaged indigenous vegetation and destroyed moorland habitats for wildlife.

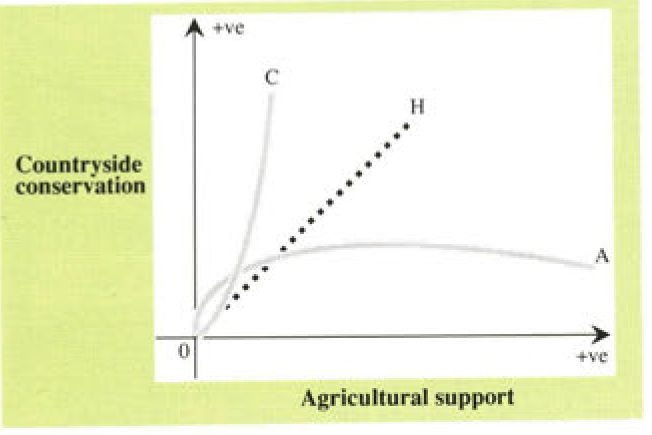

Figure 2. Policy instruments and competing objectives (adapted from Josling, 1969).

The relationships described by Josling (1969), Figure 2, provide a useful framework in which to consider the competing objectives between agriculture and countryside conservation. Progress towards support of countryside conservation is measured on the vertical axis while the support for the agricultural industry is on the horizontal axis. The curves OC and OA represent different policy instruments which influence the two objectives. Up to a certain point policy A, which is the kind of policy represented by deficiency payments, is illustrated as having beneficial effects on preserving the countryside as well as supporting agriculture - excessive support ultimately leads to environmental degradation. Policy C represents a deliberately 'green' policy, for example, paying for hedgerows and dry stone walls and penalizing intensive agriculture.

The extremes of these relationships clearly imply that agriculture and the natural environment are in conflict. But this ignores the possibility of a symbiosis between agriculture and the environment and the possibility of joint production of both agricultural goods and environmental goods and services (Harvey and Whitby, 1988). The challenge is to design a policy instrument which would produce a course lying between A and C, i.e. H.

Many of the policy instruments more recently introduced for agriculture and forestry require specific management protocols to be followed in order to safeguard the environment. At one extreme there are Sites of Special Scientific Interest (SSSIs) for which the Nature Conservancy Council (NCC) is responsible and specific management agreements have to be adhered to, while at the other extreme there are the effective voluntary efforts of individuals who are guided by bodies like the Farm and Wildlife Advisory Groups. More recently the introduction by the Agricultural Departments of the Farm and Conservation Grant Scheme which encourages positive environmental investment, and the Environmentally Sensitive Areas (ESAs) where farmers volunteer to manage their resources according to specific protocols and are paid to do so, are examples of a direct way of managing the countryside to achieve both agricultural and conservation objectives.

Several important questions arise out of all of this. First, are the costs involved and the constraints placed on agriculture and forestry justified by the benefits achieved? As yet no entirely satisfactory way of answering this question in economic terms has been developed because many of the benefits are intangible. It is possible to calculate the cost of pollution but it is proving difficult to find ways of putting a quantitative value on a landscape or on wildlife diversity.

The responsibility for land use ultimately rests with the land owner or his tenant: their livelihood depends upon the decisions they make about what crops to grow, how they manage them, what livestock to keep and the stocking rate and so on. Society is prepared to pay for the food he produces and the timber that he grows. But he is also responsible for creating much of our landscape, habitats for wildlife, and contributes to the general amenity of the countryside which is enjoyed by those who seek the recreation that it offers. The question that remains of course is should society pay for this?

While a precedent has already been set, the extent to which economic incentives can continue to be used to achieve a balance between agriculture, forestry, conservation and recreational objectives will require careful handling. There seems little doubt that European Policy development will be based on such a mechanism to secure its environmental objectives and at the same time secure its social objectives for rural communities. But will society, in times of economic difficulty, be prepared to support such policies? While compensatory and direct payments in relation to the Wildlife and Countryside Act and the creation of the ESAs have their place, are these the appropriate mechanisms in the long term to bring about a widespread acceptance of what constitutes environmentally sensitive land use? The latter requires policies and management strategies which sustain the use of the primary resources of soil and water on which plants, animals, fish and ultimately man depend. Such policies and strategies are not only designed to meet his nutritional and habitat needs, but also the cultural, aesthetic and intrinsic needs, which together determine the overall quality of life. These are vexed issues which society and its policy makers will have to tackle in the years ahead.

Never has there been a greater need for research and technological development to ensure that agriculture can continue to respond to an increasing world demand for food at less cost and do so with a greater degree of environmental sensitivity. Yet this is at a time when R&D funding is being seriously eroded. There continues to be a need to provide basic information about the land resources themselves and there is a need to know a good deal more about the physical, biological and ecological processes that either naturally or through their management bring about change. Equally it is imperative that the socio-economic consequences are investigated and understood.

Impact of technology - hills and uplands

Agriculture is of course of particular importance to the hills and upland which, in Scotland, constitute the largest agricultural sector in land use terms. Research continues to be necessary to provide information which will allow the traditional sheep and cattle enterprises to operate with a greater degree of efficiency across a range of inputs, to support agricultural incomes and employment and potentially reduce the need for financial support. For example, there is a continuing need to improve the

	Weight of animal weaned (kg/ha)			Area closed for 1st silage cut (%)			
	Sheep		Cattle	Sheep		Cattle	Cattle turnout date
	Cheviot	Beulah		Cheviot	Beulah		
1985	630	635	538	38	33	50	16 May
1986	663	640	542	4	0	56	26 May
1987	618	609	582	42	42	18	8 May

Sheep : 20 ewes/ha, 1.2 lambs/ewe, 200 kgN/ha/annum
Cattle : 2.5 cows & calves/ha, 250kgN/ha/annum

Table 1. Output and proportion of area closed.

establishment and utilization of grass/clover pastures and the operation of efficient extensive pastoral agriculture. The sustainability of plant growth will increasingly have to depend upon the natural availability of nutrients from the soil, leguminous plants, and those minimal inputs of fertilizer which can be economically and environmentally justified.

The biology of hill and upland soils is influenced by high acidity and low temperature resulting in a relatively low level of microbiological activity and a low rate of organic matter turnover. It is of fundamental importance that there is a continued and sustained effort to elucidate and quantify the background processes and pool sizes which determine acidification on the one hand and the availability of nutrients on the other, so that more precise predictions can be made about the level of plant growth and range of vegetation mix which is likely to occur in the changing circumstances of the future. Further, with a continuing increase in atmospheric CO_2 concentration and a potential consequential rise in temperature, a knowledge of these processes is a prerequisite to research which aims to predict the future implications of climatic change for agriculture, forestry and the ecology of hill and upland resources.

As new technologies emerge and environmental objectives become more precisely defined there will be a need to investigate the input:output relationships of these pasture-based traditional and novel livestock systems managed at different intensities. On sown upland pasture, for example, it is possible to show that across a range of inputs there is the potential to achieve a consistent level of animal performance (Table 1) and choose a stocking rate which balances winter forage supply with summer grazing requirements (Figure 3). This kind of information allows on the one hand a critical assessment as to the level of inputs, e.g. fertilizer and bought–in feed, needed to sustain an economically viable agriculture, and on the other hand provides an assessment of the cost of meeting environmental objectives. Mathematical models of these systems provide greater scope for investigating an extended range of input:output relationships.

In relation to indigenous hill vegetation it has been possible also to characterize the potential outputs that can be achieved from hill sheep systems using a range of inputs (Table 2), (Sibbald, 1990).

On the better hill farms improved income levels can be generated by introducing grazing control and it may be possible on these holdings to generate enough income to undertake land improvement. But on poorer hill farms which are predominantly found in the north and west of Scotland and encompass the Crofting Counties where land improvement is still supported by grants, significant increases in incomes are possible but more difficult to achieve. These farms are the most vulnerable from an

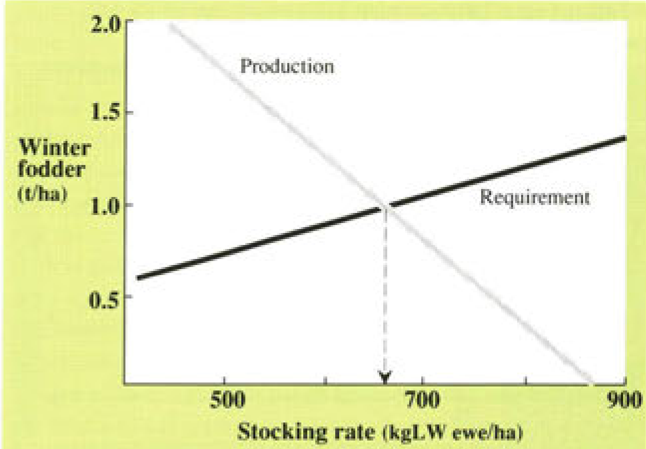

Figure 3. Optimum stocking rate in relation to winter fodder production and requirement.

economic point of view and the land is not ideal for forestry either. Yet the presence of sheep and cattle in these areas contributes to the conservation of the vegetation mix which is a vital part of the landscape.Without livestock the character of the landscapes would change dramatically.

Towards rural development

Ever since the World Commission on Environment and Development (WCED) published its report *Our Common Future* in 1987 the idea of 'sustainable development' has become central to any debate which aims to find a balance between economic and environmental objectives. Pearce *et al.* (1988) have suggested that sustainable development 'involves devising a social and economic system which ensures that real economies rise, educational standards increase, that the health of a nation improves and the general quality of life is advanced'. The WCED defines the concept as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.

It is not that long ago when University Departments of Agriculture taught courses in animal and crop husbandry. The word 'husbandry' has all the connotations of sustainability; it implies that production should take place with a proper regard for the conservation of resources for further use. For the practical land manager, 'husbandry' conveys most meaningfully that which has to be achieved to secure the long–term future of our primary resources of soil and water and other features of the countryside which together contribute to the overall quality of rural life.

In the hill farming areas and in terms of conservation, there is a strong desire to protect wildlife habitats and the visual amenity inherent in the vistas and visions presented by expanses of indigenous vegetation maintained in their current state of low fertility. Open hill landscapes that have evolved through time as a consequence of varying degrees of agricultural activity are highly valued. For agriculture it is important to understand the impact of grazing on plants. It is necessary to evolve a management regime which secures their continued presence, productivity and contribution to the nutrition of the animal populations utilizing them. Thus, though different emphasis may be placed on management strategies for conservation and productive agriculture, ultimately the objective in both cases must be the definition of a management regime which attains a sustainable balance between the plant species in particular communities, and between the plant and animal populations in a particular locality, (Hodgson, 1985).

A useful way forward in developing management systems to meet conservation, amenity and agricultural goals is to use acquired knowledge to develop computer models. A good example of this approach is a model which has been developed in the Institute to predict the consequences of grazing sheep on the vegetation dynamics of heather moorland. The model describes the effects of sheep stocking rate and burning regimes on the productivity of both heather and sheep (Sibbald *et al.*, 1988). It has been used already in a practical way by NCC officials in setting stocking rates in the north of England. It is currently being enlarged to take account of the seasonality of grazing different plant communities and the impact of other herbivores such as red deer on these communities (Armstrong, 1990). This is the kind of approach which requires to be extended to other important indigenous communities.

Models are also a useful means of assessing the potential of new approaches to land use and assessing the potential for change. For example, on the basis of present support policies for forestry and agriculture a modelling analysis of the potential for change in land use carried out by the Institute and the College suggests that it is the upland type of farm which has the potential to be attractive for afforestation (Crabtree and Macmillan, 1989). This also implies that farm forestry investment would be very worthwhile in these areas. Equally, the potential for agroforestry or more correctly silvopastoralism in which grazing animals make use of pastures grazing between widely spaced trees may also be relevant for this type of land. A preliminary modelling study has indicated the way in which agricultural income might be exchanged for forestry income over the lifetime of such a project (Sibbald *et al.*, 1989). This proposition is now undergoing field testing and validation at a number of sites in the UK. The impact of such change in land use on the visual and amenity aspects of the environment and the effects on wildlife, water balance and nutrient outflows are the subjects of current research by a number of groups throughout the country.

Techniques are being developed in the Institute for handling the information required to make some of these impact assessments. Current work is aimed at developing the capability for the visualization of different planting schemes. Digital terrain models can be combined with terrain cover data for visual impact analysis. Information of this kind can be used to identify areas of focal points of potential recreational value, and the intervisibility of planting from designated viewpoints or access routes can also be examined (Miller and Morrice, 1990). The technique is being further developed to investigate where atmospheric deposition of air pollutants may occur. Environmental assessment provides a series of options on which informed decisions can be made with regard to planting proposals.

Farm code	Dominant sward species	Subjective assessment: A/F area	Subjective assessment: Extent of inputs	Total weight of lamb weaned (kg/ha/annum): Trad.	Total weight of lamb weaned (kg/ha/annum): Impr.
Farm 21	Cv, Tc, Er spp		*	3.5	7.3
Lephinmore	Cv, Et, Ev, Ea, Tc		**	17.2	23.8
Glensaugh	Cv		***	17.9	34.1
Farm 03	Cv, Tc, Er spp, Mc, A/F	***	*	17.9	49.1
-Farm 10	A/F, Mc, J spp	*****	**	62.1	70.1
Sourhope	A/F, Ns, Mc	****	***	27.5	76.5

Cv - *Calluna vulgaris*; Tc - *Trichophorum cespitosum*; Er spp - *Erica species*; Et - *Erica tetralix*; Ev - *Eriophorum vaginatium*; Ea - *Eriophorum angustifolium*; Mc - *Molinia caerulea*; A/F - *Agrostis/Festuca*; J spp - *Juncus species*; Ns - *Nardus stricta*

Table 2. The potential physical production from farm improved management systems, of a range of resource type ranked in order of lamb output per hectare (Sibbald, 1990).

There is also a need to develop techniques to investigate changes in land use at the regional and national scale to link physical resource evaluation with socio-economic and environmental impact assessment. Such investigations can lead to the formulation of indicative strategies for forestry, agriculture, recreational development and so on. The use of geographic, knowledge-based and spatial-inductive models are important developments. These techniques have the potential to be used as a part of the policy formulation process.

Using this approach, for example, my colleagues, using a series of biological, environmental and economic analyses interpreted through a geographic information system have assessed the potential extent and future afforestation in Grampian Region, for Sitka spruce. Land can be analysed to identify the main areas of opportunity for new planting and areas where there are sensitive issues (for example landscape and conservation) to be considered (Aspinall, 1989).

The map output of where changes may be expected to occur can also be used as an input to analyse the possible impact of change on wildlife distribution. For example the location of expected changes as a consequence of afforestation can be used to identify areas which may become more suitable for red deer and other wildlife species. These few examples demonstrate ways in which our knowledge and understanding can be used effectively to provide greater objectivity to land use decision-making on the farm and at the much larger scale of the district and region.In Scotland much of our land area is already used for a multiplicity of purposes (for example agriculture and forestry, alongside recreation and sport, and conservation). Mechanisms have to be found whereby decisions about the management of such land can be made with the greatest degree of objectivity, and through active participation and collaboration by those with a justifiable interest. There has to be a realization that what can be achieved overall, indeed globally, depends crucially on what can be achieved at the scale of the farm, forest, nature reserve or national park. At this level, the use of expert systems, modelling and goal programming supported by the necessary biological, ecological and sociological research are a means by which national approach to land management and policy development can evolve.

At the larger scale geographic information systems and the use of knowledge-based, inductive and spatial modelling procedures can provide a strategic framework in which the outcome of the integration of potential land uses at the smaller scale can be examined. Thus the impact of land use change within districts, regions and at a national level can be assessed with increasing objectivity and policies and planning implemented in ways whereby rural development that meets the needs of the present without compromising irrevocably the needs of the future can be made possible.

(Parts of this article formed the basis of a paper presented to the Royal Society of Edinburgh in May, 1990).

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GEOGRAPHIC INFORMATION SYSTEMS: A NEW TOOL FOR RURAL LAND USE PLANNING

R. J. Aspinall, D. R. Miller and R.V. Birnie

Introduction

The use and management of rural resources has become a key issue with increasing demands from agriculture, forestry, and conservation as well as for housing and other urban and industrial uses. The reconciliation of conflicts between these demands can involve a wide range of individuals and agencies and many of the solutions are provided through decisions taken as a result of planning and management procedures operating at national, regional and more local levels. The planning process, however, tends to operate sectorally, reflecting the nature of existing land use interests.

This article explains how a Geographic Information System (GIS) is being developed at the Macaulay Land Use Research Institute for application in land use planning. The GIS is used to monitor land use changes, assess impacts of changes, predict the location and extent of possible future changes, their likely impact, and evaluate the consequences of a variety of policy options. The examples presented illustrate the variety and potential for these applications of geographic information system-based techniques and the support which this tool can provide for decision-making. Planning is interpreted in its widest sense and includes both established planning activity, as carried out by a regional or district council for example, and individual decision-making as it affects the management and use of resources.

The rural planning context

The planning system in Britain is dominantly urban in its origins and direction with attention focussed on development control. Although the Scott Report (1942) argued for a system of planning controls which protected the agricultural use of the countryside, and the Town and Countryside Acts place a system of development plans and controls on land use, the focus of these systems is narrow and the major rural land uses of agriculture and forestry are outside this system (Mather, 1986). The reasons for this stem largely from the political and economic conditions of post-war Britain. The Scott Report argued that land should remain in agriculture except where an alternative use could be shown to be of greater benefit to the nation. Agricultural use was also assumed to be benign and that a healthy countryside was an automatic consequence of a prosperous agriculture (Mather, 1986).

At present, therefore, there is no coherent framework for rural land use planning, major rural land uses requiring no planning permission and being able to respond relatively freely to 'market forces'. In practice, however, both agriculture and forestry are subject to sectoral planning influences. For many years UK agricultural policy has been designed to support and increase production; more recently, with surplus in many areas of agricultural production, production-directed incentives are being replaced by a range of policy instruments designed to curb growth in commodity supply and increase environmental benefit.

There is also some evidence to support the idea that increasing awareness exists of the need for goals to be explicit in land use policy. Land use planning is beginning to reflect this change in attitude towards an approach based on multilateral consensus. For example, regional authorities in Scotland are being encouraged to produce 'Indicative Forestry Strategies' (SDD, 1990); these adopt the aims of the Woodland Grant Scheme both to create 'multi-purpose' forestry and achieve the annual tree–planting target. The strategies are also intended to produce a balance between forestry and other land use interests, although achieving balance will require careful consideration of strategies as they are produced and monitoring as they are implemented.

Despite these changes in emphasis and increasing awareness of the need to state objectives more explicitly, there is still a tendency to take a sectoral view of rural land use. Additionally, a social dimension is notably absent (Phillips and Williamson, 1984) and the Government is being urged to '... recognize its dominant role and try to integrate its rural policies into a coherent framework or rural land use strategy' (HMSO, 1990 p. xliv).

Although there are various instruments available for implementing policies and planning decisions, integration of policies into a coherent framework requires clear definition of objectives. There is also, however, a place for a system which allows those involved in developing rural land use policy critically to evaluate alternative policy options during formulation stages. The rapid increase in pressure on land resources and need for sound planning decisions has been paralleled by improvements in information technology. This technology can provide such a system of support for discussions and decision-making procedures (Chorley, 1988). In particular, geographic information systems offer a means of managing and analysing a wide range of land resource information and interpreting the possible consequences of decisions before they are implemented (Jeffers, 1980; Worrall, 1989; Aspinall, 1990a). Potentially this provides planners, policy-makers, resource managers and decision-makers with a powerful tool for understanding the possible consequences of their actions and decisions (Chorley, 1988).

Climate	
Mean annual rainfall	1:625 000
Accumulated frost	1:625 000
Accumulated temperature	1:625 000
Potential water deficit	1:625 000
Mean annual windspeed	1:625 000
Topography	
Altitude	1:250 000
Landform	1:250 000
Soils	
Components soil	1:250 000
Geology	
Sand and gravel	1:50 000
Biology	
Semi-natural habitats	1:50 000
Red deer	1 km resolution
Vegetation type	1:250 000
Nature conservation	
National Nature Reserves	1:50 000
Sites of Special Scientific Interest	1:50 000
Sites of interest to the natural sciences	1:50 000
Protected coastal areas	1:50 000
Royal Society for the Protection of Birds/ Scottish Wildfowl Trust and other nature reserves	1:50 000
Archaeology	
Scheduled ancient monuments	1:50 000
Archaeological sites of regional significance	1:50 000
Landscape	
National Scenic Areas	1:50 000
Areas of regional landscape significance	1:250 000
Areas of local landscape significance	1:250 000
Land use/cover	
Green plate forestry	1:50 000
Woodland grant scheme approved	1:50 000
Forestry grant scheme	1:50 000
Urban areas	1:50 000
Administrative areas	
Regions	1:63 360
Districts	1:63 360
Agricultural parishes	1:63 360
Forest districts	1:50 000
N. East River Purification Board catchments	1:50 000
Agricultural development areas	1:63 360
Estates and large farms	1:50 000

Table 1. Example spatial datasets in a geographical information system.

At MLURI a large amount of research is concerned with development of geographic information systems for application across a range of land use planning issues and activities. Before describing some of the applications however, it is necessary to describe what a geographic information system is.

Definition and basic functions of GIS

Geographic information system (GIS) is a term which describes computer facilities (hardware and software) used to handle data

1: 250 000 Scale \ 1: 50 000 Scale	1	3	4	20	22	23	26	28	31	33	34	35	36	98	100	101	118	126	129	175
4		4	68		1	1	13			4	5	1	1			1				
22	1	1	4	1	23	9	22	8	1	2	1	2		2		13	6	1	4	
33			25		3	3	19	3	1	31	5	4	3			3				
98	29							3						63	2	1				2

Table 2. Distribution of soil map units at 1:50 000 scale as percentages of units at 1:250 000. (See Table 3 on next page for descriptions of map units.

referenced to particular places (spatial domain). The main functions of a GIS are data input, storage, retrieval, manipulation, analysis, and output. These functions can be used to answer a variety of questions and present the solutions in map and table form.

Questions suited to GIS analysis range from simple 'where' and 'how much' to more complex 'what if' types. Many planning applications of GIS are based on questions of these forms. In addition, a range of more sophisticated facilities can also be integrated with these basic functions, including a range of spatial modelling procedures.

The information used in GIS typically is that traditionally presented on maps and can refer to properties of the physical and human environments, to surveys (for example, agricultural statistics collected for parishes, population density in census wards), or to flows of materials, distances between places, and any other feature which can be linked to areas or places. The wealth and variety of information which can be stored in a GIS (Table 1) provides potential for a wide range of integrated analyses and evaluations with relevance to many aspects of land use planning.

Data quality

As with all computer-based analyses, a GIS can only be as good as the data which it contains (this applies equally to any resource assessment carried out by planners and decision-makers who are also constrained by the quality of data available). A GIS has access to the same resource data as might be interpreted using more traditional cartographic methods; the principal advantage of GIS is in the flexibility and speed with which data can be accessed and interpreted. GIS also has the ability for data analysis which is unavailable with more traditional methods of map manipulation.

Two basic aspects of data quality are map scale and information content. Map data are arranged around cartographic objects and fundamental to this is the way in which objects are represented at the map scale used. For example, objects may be too small to be represented at the map scale used (and are therefore not shown on the map) or they may be of special significance and are therefore exaggerated. Maps of different scales also show the same basic information with different amounts of detail. The effect of map scale on representation of objects can be seen in Table 2. The table shows the overlap between soil map units shown on soils maps of 1:250 000 and 1:50 000 scale, the extent of overlap between the two maps indicating the effects of generalization.

Apart from map scale and information content, data quality is also affected by the way in which data are held in the computer memory. The digital representation of lines can be more accurate than the original lines drawn on the source maps. This can instill a false understanding of the accuracy and precision of the data and it should be remembered that data quality is derived from the map rather than from the representation in the computer. Computer-based analysis of data is also subject to arithmetic error due to the ways in which computers represent numbers. In all GIS-based analyses the sources of data must be acknowledged and the limitations of the data being used recognized. This demands an understanding and analysis of error as it relates to the limitations of data.

Analysis of error can become highly complex. Transformation of a dataset using GIS results in a new dataset; this has an associated error arising from the original data and from the transformations to which these data are subject in the GIS operation. For example, some analyses require transformations which alter both the position and definition of boundary data or an analysis may modify both the location of lines describing the position of features derived from topographic maps and change the meaning of classes represented by data interpreted from satellite imagery and which refer to larger areas. These both are subject to error which may be magnified by GIS analysis. GIS analyses can provide estimates of these errors and indicate an error 'envelope' which accompanies the result of analysis.

The GIS being developed at MLURI is designed to follow and manage the different types of error and the way they are influenced by the analyses being carried out. The product of the GIS analysis is both the result of the operation requested and an indication of the associated errors. The error provides bounds on the result of the GIS analysis and indicates the confidence which can be placed on the answer produced. The GIS is also based on extensive data, much of which has been derived from detailed and long-term survey of land resources in Scotland. Although this large amount of resource information is already available, there remains a need to improve the quality of that information. This can involve both field survey and use of different types of remotely-sensed data.

Sources of land use/cover data

Two important projects using remotely-sensed data to provide detailed data are the Land Cover of Scotland and mapping the distribution of bracken (*Pteridium aquilinum*) in Scotland. These projects provide baseline information for monitoring present and future changes in the countryside of Scotland and will also allow rates of land transfer between major land uses such as agriculture

SOIL ASSOCIATIONS	PARENT MATERIALS	MAP UNIT	COMPONENT SOILS	LANDFORMS
ALLUVIAL SOILS	Recent riverine and lacustrine alluvial deposits	1	Alluvial soils	Flood plains, river terraces and former lake beds
ORGANIC SOILS	Organic deposits	3	Basin and valley peats	Basins and valleys
		4	Blanket peat	Uplands and northern lowlands with gentle and strong slopes
ARKAIG	Drifts derived from schists, gneisses, granulites and quartzites principally of the Moine Series	20	Humus-iron podzols; some brown forest soils, noncalcareous gleys and peaty gleys	Undulating lowlands and valley sides with gentle and strong slopes; non–rocky
		22	Peaty podzols, peat; some peaty gleys and humus-iron podzols	Hills and valley sides with strong slopes; non–rocky
		23	Peat, peaty gleys, peaty podzols	Undulating lowlands and uplands with gentle and strong slopes; non–rocky
		26	Peaty podzols, peat, peaty gleys	Hummocky valley and slope moraines; often bouldery
		28	Peaty podzols, humus-iron podzols; some peaty gleys and rankers	Hills and undulating lowlands with gentle and strong slopes; moderately rocky
		31	Peaty gleys, peaty podzols peaty rankers	Hill sides with steep and very steep slopes; moderately and very rocky
		33	Subalpine soils; some peat, rankers and alpine soils	Mountains with gentle to very steep slopes; non– to very rocky
		34	Peat, subalpine soils; some alpine soils	Mountains with gentle and strong slopes; non– to moderately rocky
		35	Alpine soils	Mountain summits with gentle and strong slopes; non– and slightly rocky
		36	Rankers, lithosols; some alpine soils	Mountain summits with strong to very steep slopes; very rocky
CORBY/BOYNDIE/ DINNET	Fluvioglacial and raised beach sands and gravels derived from acid rocks	98	Humus-iron podzols, alluvial soils	Valley floors, terraces and mounds with gentle and strong slopes
		100	Humus-iron podzols; some peaty gleys and humic gleys	Mounds and ridges with gentle to steep slopes
		101	Peaty podzols; some humus-iron podzols and peat	Mounds, ridges and terraces with gentle to steep slopes
COUNTESSWELLS/ DALBEATTIE/ PRIESTLAW	Drifts derived from granites and granitic rocks	118	Peaty podzols, peat; some peaty gleys	Undulating uplands with gentle and strong slopes; non–rocky
		126	Peaty podzols, humus-iron podzols; some peaty gleys and rankers	Hills and valley sides with strong to very steep slopes; moderately rocky
		129	Rankers, peaty podzols; some humus-iron podzols and peaty gleys	Rugged hills with strong and steep slopes; very rocky, some scree
DULSIE	Partially sorted gravelly fine sands derived from acid schists and granites	175	Peaty podzols, peat, peaty gleys; some humus–iron podzols	Hummocky valley moraines

Table 3. The soil map units shown in Table 2 on previous page. (Extract of 1:250 000 scale soil map legend).

and forestry to be established accurately. Much of the data collection phase of the project makes use of GIS, although GIS will be of greatest use during analysis and application of the data to a wide range of questions.

Land cover of Scotland

The Scottish Development Department has contracted the Macaulay Institute to map the land cover of Scotland. Mapping is carried out through interpretation of aerial photographs, a choice guided by the requirements to map presence and extent of land cover types throughout rural Scotland. The project adopts a census approach and is planned around identification of land cover classes which will be most important in future analyses.

Six principal features are identified and mapped at a scale of 1:25 000, these six being subdivided into a large number of detailed land cover categories (as described on pages 32 and 33 of this report).

The categories reflect the information required for present and future application as well as maximizing the information which can be obtained from black and white (panchromatic) aerial photography. Photography is at a scale of 1:24 000 while mapping is at 1:25 000. About 800 base maps are required for complete coverage of Scotland.

The analysis and mapping procedure consists of four steps including interpretation of aerial photographs, map digitizing, digital databank formulation, and accuracy assessment. The first two steps in this procedure are labour intensive while the third involves extensive use of computer time. Accuracy assessment requires the interpretations to be checked by field survey. Once data are available in the GIS they can be subject to a full range of analyses and interpretations.

Mapping bracken distribution in Upland Scotland

An alternative approach to rapid collection of land cover information over large areas involves the use of satellite remotely sensed data. For example, seven satellite image scenes are required for complete cover of mainland Scotland compared to approximately 12,000 aerial photographs. Assessing the relative utility of aerial photographs and satellite imagery must balance accuracy and information content against cost, satellite imagery having a lower level of accuracy in delimiting boundaries of land cover categories and making greater use of computer time than aerial photography but having much reduced labour inputs.

The distribution of bracken *(Pteridium aquilinum)* in Scotland has been mapped through analysis of LANDSAT Multi-Spectral Scanner imagery in association with large area masking and probability mapping using GIS (Miller *et al.*, 1989). The GIS-based masking and probability analyses are developed on an extensive sample of sites, about 19 500 km^2 or almost a quarter of the land area of Scotland, and information gained from these areas is then used to guide mapping of bracken throughout Scotland. The sample sites are generally within the hill and upland areas of Scotland but include some arable and built-up land. The sample sites are used both as training data, acting as controls for the highest level of classification, and for checking the final classification, separate subsets being used for each analysis.

Mapping bracken from satellite imagery is carried out in several stages. These are field mapping, sample site image classifications, a national classification of bracken, and error checking. Information gained from field mapping is used to develop a series of maps which show areas in which bracken does not grow and which are of no interest; these maps are used as masks in image analysis. A series of weightings are also developed based on map information held in a GIS.

These show the suitability of habitat conditions for bracken growth, the datasets of most value for these analyses being topography, soils, climate and current land use. The effect of the masks and weights is to focus image classification and analysis on certain areas by excluding other areas of little or no interest and allows mapped environmental data to be integrated with satellite image analysis (Aspinall *et al.*, 1990).

	Forestry type		
	Coniferous	Broadleaf	Mixed
Brown forest soil	0.4	0.6	7.4
Humus-iron podzol	44.3	48.6	44.2
Peaty podzol	30.3	26.7	12.8
Noncalcareous gley	0.7	0.8	0.0
Peaty gley	5.8	1.1	9.6
Peat	6.3	2.0	2.2
Alpine soils	10.2	17.0	9.6
Alluvial soils	1.6	3.0	6.9

Table 4. Associations between forestry and major soil subgroups in Badenoch and Strathspey District. Values are percentages of each forestry type.

The accuracy of the bracken map produced was checked for consistency in classification across Scotland and for confusion between bracken and other plant communities. Classification consistency was high, and the greatest confusion with other plant communities was with bent-fescue grasslands and where heather and grassland communities border each other and bracken is invading.

These projects illustrate potential sources of data and the ways in which GIS can be used in data collection. The Land Cover of Scotland project is expensive, however, largely because of the labour costs, and is unlikely to be repeated. In contrast, satellite imagery is relatively cheap and future mapping of land cover across Scotland will increasingly depend on this data source. Uses of land cover maps include monitoring land cover changes as well as resource inventory, both uses being able to draw on functions available within GIS. However, the greatest strength of GIS applied to land use planning is in its ability to analyse spatial information objectively.

Illustration of GIS applied to land use planning

GIS can be used in a variety of ways for land use planning. They include monitoring and inventory, resource evaluation and assessment and more complex modelling and analysis which can be used for predicting impacts of policies or effects of change in land use. An important application of GIS considers the environmental, biological and socio-economic impacts of past and present trends in land use while GIS can also serve to carry out resource assessments for managing and directing future land use changes. Two examples from the Badenoch and Strathspey District of Highland Region illustrate these applications of GIS.

Environmental, biological, and cultural information for Badenoch and Strathspey have been compiled into a databank from maps, aerial photographs and satellite imagery. Maps with a scale of 1:250 000 provide data for soils (Walker *et al.*, 1982), land capability classifications for agriculture (Walker *et al.*, 1982) and forestry (Gauld *et al.*, 1988); digital terrain data are obtained from the 1:250 000 data produced by the Directorate of Military Survey (Smith *et al.*, 1989). Land use (buildings, forestry, roads, view points, tourist attractions) are derived from Ordnance Survey 1:50 000 sheets.

Additional land cover data are derived from aerial photography and satellite imagery. Raster and vector digital formats are used for storage and manipulation of the datasets. The raster data and satellite imagery are held with 25m pixel resolution while the digital terrain data have 100m pixel resolution. These data provide the basis for GIS-based evaluation of land cover and land use with respect to the environmental resources of the district.

No. of conservation designations :	0	1	2	3	4	Total 1-4
	% of each forest type					
Forestry type						
Broadleaf	70	23	7	0	0	30
Coniferous	69	17	14	0	0	31
Mixed woodland	51	34	14	1	0	49

Table 5. The percentages of different forest types in land subject to conservation designations.

Monitoring land use change

The location, extent and rate of recent and current land use changes are of considerable interest. For the Badenoch and Strathspey District, a variety of maps, aerial photographs and satellite imagery (LANDSAT Thematic Mapper) have been used to map change in land use between 1970 and 1988. For example, the distributions of broadleaf, conifer and mixed woodland are mapped and changes compared with datasets in the databank. This helps to answer a variety of questions about the distributions of the existing resource and the location and extent of past changes. For example, the distribution of the different forest types in 1988 can be compared with a map of soil types (Table 4). This provides an indication of the soil types with which forestry is particularly associated and allows other areas with similar soils, but which are not afforested, to be identified.

Land cover and use is not concerned only with resource information. For example, the extent of conservation designations influencing forested areas also have to be considered. Table 4 shows the percentage of forest associated with land falling under different numbers of conservation designations out of six applying in Badenoch and Strathspey. The conservation designations considered are National Scenic Areas, National Nature Reserves, Sites of Special Scientific Interest, Glenmore Forest Park, land managed by the Scottish Wildlife Trust and reserves of the Royal Society for the Protection of Birds. No land is under more than four of these six designations. The majority of woodland of all types is on land where there is no conservation designation although some 30% of broadleaf, 31% of conifer and 49% of mixed woodland is on land subject to one or more conservation designations (Table 5).

These types of comparison enable associations between land resources and land uses and land use changes to be established. This has value in easing the monitoring of past changes and providing information which can help to explain how decisions producing land use change are made in relation to the resources and environmental issues considered.

Figure 1. The number of viewpoints from which different parts of Badenoch and Strathspey District can be seen.

Assessing landscape impacts of land use change

In addition to monitoring and describing the distribution of a land use against a range of designations or resources the GIS can be used to compare land use changes with landscape. This has potential not only for evaluating past changes but also for predicting how future land use change may influence landscape and the scenic attractions of an area. Such changes and impacts, although not easily measured, may be of major importance to the economic and social structure and future of an area with respect to the tourism and recreation industries.

Two ways of evaluating landscape and the visual impacts of land use changes involve considering the location of an observer and the location of the change.

Observer location can be classified by the amount of land visible from it. Such a classification can then be used to rank impacts of any changes in land use on an observer at the location. The processes of calculating the area visible from a location is readily carried out within GIS, allowing the location to be evaluated according to the extent and context of land uses in its envelope of 'total visible land'. Land use changes throughout an area are assessed against their impact at a point or range of points. This approach derives from the question 'what can be seen from here?' Conversely, the impact of a land use change can be assessed against the total area from which it will be visible, an approach deriving from the question 'where can this be seen from?'

Analysis of visual impact does not depend on an uninterrupted view alone. The procedure for evaluating visual impact of land use changes also incorporates a weighting for distance which relates the clarity of view with the location of the observed feature. For example, forestry located on a distant horizon or break of slope has greater impact than if it is located closer to the observer but below a horizon.

A survey of casual visitors to Badenoch and Strathspey District showed 67% to rate scenery as the most 'attractive/ enjoyable' visitor attraction on Speyside (Watson, 1988) while a second study identified 'drives, picnics and outings' to be the recreational activity participated in by the largest proportion of visitors (59%). These results suggest that useful approaches to determining the potential visual impact of land use change would be to measure

- impact on 'scenery' from selected focal points for visitors
- impact with respect to a popular road access route used by visitors.

Both of these approaches can be answered using the two methods of rating impact on landscape outlined. The focal points selected for this study are viewpoints designated on an Ordnance Survey 1:50 000 map and the road route is the A9.

The digital terrain model and GIS are used to identify the areas within Badenoch and Strathspey which can be seen from each of the viewpoints. These are combined within the GIS to produce a single map describing the District according to the number of viewpoints from which it can be seen (Figure 1). This map identifies areas within the District where impact of land use changes on landscape can be expected to be

- low : areas which are not visible
- medium : areas which are visible from very few locations or are at great distance from viewpoints

Forestry strategy class	Criteria
Already planted or approved for forestry	Existing forestry Forestry development approved
Unavailable/unplantable	Land capability for forestry class F7 Urban area
Sensitive	Land capability for agricultine classes 1-3.1 National Nature Reserve Biological or mixed Site of Special Scientific Interest Scheduled ancient monument
Potential	Geological Site of Special Scientific Interest National Scenic Area
Preferred	Areas with no major constraints on forestry and where forestry would be welcome subject to good forestry practice

Table 6. Rules for allocating land to indicative forestry strategy classes.

- high : areas visible from up to eight locations and close to the viewpoints.

This method for analysis of landscape impact is not only of use in interpretation of past land use change, however, but may make a contribution to forward and strategic planning. In the example presented in the next section, the method is applied to an indicative forestry strategy in order to evaluate the consequences for landscape should future afforestation follow the guidelines expressed in that strategy.

Indicative land use strategies

A recent development in planning procedures intended to address possible conflicts of interest over use of land resources is provided by Indicative Forestry Strategies. These strategies are currently being produced by several regional councils in Scotland, and are presented in the form of maps showing areas of land with different sensitivities for forestry. The concept of indicative strategies has been welcomed by a wide range of organizations and individuals concerned with use of land resources in Scotland. Apart from the strategy map, one of the more useful aspects of indicative forestry strategies is the extent to which the consultation procedure involved in their production encompasses a wide range of views and positions. Consultation allows many conflicts to be partially resolved and has encouraged wider dialogue between land users with potentially conflicting interests and objectives.

GIS offers an efficient and flexible means of producing indicative forestry strategies, replacing more traditional cartographic overlay for interpretation and synthesis of resource information. A sieve mapping procedure is used to zone land according to a series of conditions, this being readily carried out using GIS overlay functions. The process of dialogue and consultation can also benefit from use of GIS, the fast processing of data with the GIS allowing a range of strategies to be produced and discussed. The range of strategies evaluated may include different interpretations of sensitivity and a variety of interpretations of the importance of particular features or resources. This allows both the importance of particular strategy inputs and the weights ascribed to each dataset to be identified.

The data required for producing an indicative forestry strategy are diverse and available from a wide range of sources. National, regional and local designations relating to agriculture, nature conservation, landscape and archaeological interests are considered in addition to physical limitations of land with respect to tree growth. Other demands which may be incorporated include water abstraction and existing forestry operations. Many of the data are available in map form at a range of scales and their preparation for overlay can be laborious; GIS allows relatively easy preparation of data. Datasets are then overlaid according to a series of rules. This produces a map showing the distribution of strategy classes within a region and effectively answers a 'where' question. Rules can be modified and data re-mapped to identify effects of each dataset and the importance of the priorities expressed in the rule base. Geographic information system overlay can also be used to summarize map output according to a variety of administrative units; this answers 'how much' questions.

As an example of this approach, the rules described in Table 6 have been applied to the geographic datasets for Badenoch and Strathspey District. These rules are based on the guidelines for the production of regional forestry strategies issued by the Scottish

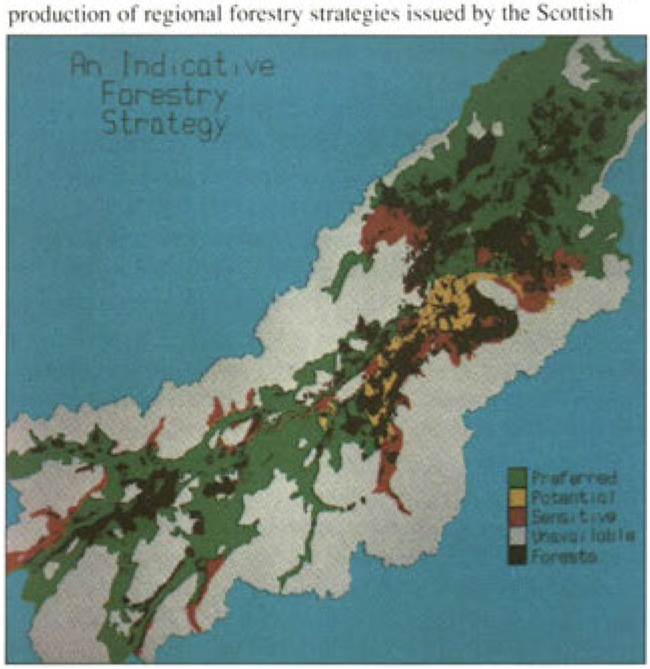

Figure 2. Indicative forestry strategy for Badenoch and Strathspey District.

Development Department (SDD, 1990). These rules produce the map shown in Figure 2.

In addition to the production of a strategy using a variety of rules, geographic information systems can also be used to consider other issues closely related to forestry. For example, infrastructure requirements (roads, bridges, sawmills) and social and economic aspects of afforestation can be investigated at both regional and more local level. Forestry can also be compared with alternative land use enterprises to assess its likely contribution to the regional and local economy. The ability to integrate such economic and social appraisals within development of an indicative strategy greatly enhances the use of the strategy for forward planning. This is particularly the case in the context of rapidly changing subsidy, fiscal and grant measures intended to attract investment into forestry, with overproduction in some agricultural products, and with policies such as set-aside.

As currently described, an indicative forestry strategy is a single–use policy although it incorporates a range of other demands on land resources. The manner in which this is achieved falls between land allocation, in which land use in an area is prescribed or excluded, and land accommodation, in which land use is agreed through consultation between different interested parties (Newson, 1990). Importantly, GIS offers the possibility for the development of multiple objective land use strategies.

Evaluating the landscape impact of implementing the indicative forestry strategy

The methods developed for landscape assessment can be used to evaluate possible visual impacts of land use changes which may

Forestry type	Area (ha)	Visibility ranking 4	3	2	1	0
Current planted	39 456	32	41	22	61	13
Unplantable	111 971	53	20	39	15	51
Sensitive	11 196	3	0	4	2	5
Potential	4 012	8	2	2	18	1
Preferred	70 220	6	36	32	4	30

Table 7. Visibility of land in indicative forestry strategy classes.

occur as a result of implementing an indicative forestry strategy. Table 7 shows the proportion of land in each of the indicative forestry strategy categories which is within the scene of view of 0, 1, 2, 3, or 4 out of five view-points shown on a 1:50 000 *Landranger* map of Badenoch and Strathspey. This provides an indication of the potential visual impact of implementing the forestry strategy and can assist in understanding the consequences of the strategy as formulated. For example, 41% of the land in areas which are 'preferred' in the strategy are visible from three or more of the viewpoints. This contrasts with 73% of existing forest which is visible from at least three of the five viewpoints (Table 7).

These examples show how the use of GIS overlay techniques for production of new information from combinations of varied data layers can be used for planning purposes. Although the evaluation of landscape impact of the forestry strategy presented is simple it also serves to illustrate the way in which a GIS can be used to investigate potential impacts of future land use changes. This offers the potential for applying GIS-based analysis and procedures to the planning and management of future changes in land use by allowing the consequences of a variety of strategies and plans to be evaluated before those strategies are implemented. As such, GIS has a role as a planning tool beyond that offered by its capabilities for data preparation, storage, retrieval and overlay, valuable though these capabilities may be. Part of this potential for use of GIS in planning integrated land use rests on linking GIS to models (Jeffers, 1980).

Land use modelling and GIS

Models can be used to predict both the direct and indirect consequences of a policy and a framework showing a sequence for using land use models and models for impact assessment is

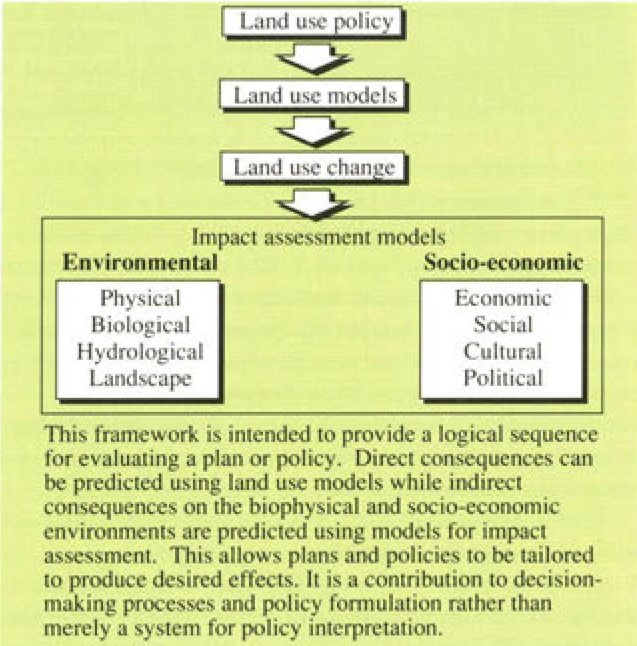

Figure 3. Framework for applying models for predicting impact of land use policies.

shown in Figure 3. Land use models are used to predict the location and extent of possible land use change. This provides a means of evaluating possible direct consequences of a policy. Models for impact assessment are then applied to the predicted pattern of land use change to predict possible effects on other aspects of land use. The examples shown above follow this form of analysis.

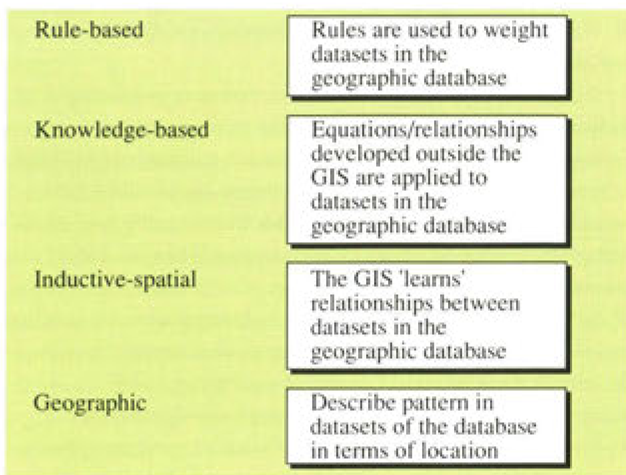

Figure 4. Models which can be used within geographic information systems.

A variety of models are currently being developed and incorporated into GIS at MLURI. Four main types of model currently are available (Figure 4) and these can be applied to different aspects of land use change prediction and impact assessment as appropriate. Rule-based modelling makes extensive use of GIS overlay and identifies areas where particular combinations of conditions exist within the basic datalayers of the geographic database. Rule-based models can also be modified within GIS to allow use of weightings, both for different data layers being overlaid and for the different features represented within a datalayer (Quarmby *et al.*, 1988). Models using rule-based weighting of data can be developed for many applications from experience in land evaluation (Davidson, 1986; Bibby *et al.*, 1982; Bibby *et al.*, 1988); and from results of scientific experiment. Alternatively existing planning and development constraints from a variety of sources can be integrated within the system; indicative forestry strategies are an example of models of this type.

Apart from models employing rules, models which transform data are required (Newson, 1988). Knowledge-based models use established equations and relationships to interpret datasets (Sivertun *et al.*, 1988), these being developed from detailed scientific study. These models can be applied to pollution prediction, hydrological forecasting and aspects of ecological land management.

Geographic information systems also allow data analysis and resource assessment through application of inductive spatial models (Walker and Moore, 1988; Aspinall, 1990b; 1990c). This form of data analysis is relatively new but has many applications including analysis of patch dynamics, conservation evaluation over wide areas, and investigating environmental health (Openshaw *et al.*, 1987; NERC, 1988). Spatial patterns in datasets are analysed against other data held in GIS to identify important explanatory relationships. These relationships can then be used to provide weights for datalayers in models (Walker and Moore, 1988) and to improve the analytical power of GIS.

Geographic models are essentially descriptive and provide a means for mapping sparse spatial datasets across wider areas to allow incorporation into GIS. For example, climatic information is frequently mapped using geographic modelling procedures, these data being important for understanding growth of crops in different areas, planning for tourism and recreational activities such as skiing, or as a basis for understanding the possible impacts of climatic changes on land use, and land management as well as for predicting social and economic consequences.

Applying these models within GIS allows some of the direct and indirect impacts of policies and plans to be predicted and considered. This permits a systematic evaluation of policies and plans and, within the limits of the models used, allows a variety of proposals to be compared. Given such a role for models in guiding decision-making, the limitations of the models used need to be emphasised in order that they are not given undue weight and considered a substitute for critical evaluation. Models do however, provide a form whereby thinking and analysis can be structured and discussion focussed. These applications of GIS in decision-making through the type of analyses described above require wider use among those concerned with decision-making and policy formulation and evaluation. The GIS methodology being developed at MLURI will provide the potential whereby plans and policies can be formulated on the basis of a wide evaluation of their likely consequences. It has the potential to lead to the evolution of a more integrated approach to land use planning, and, with appropriate developments in systems and modelling, one which is based on a holistic understanding of environment and human activity.

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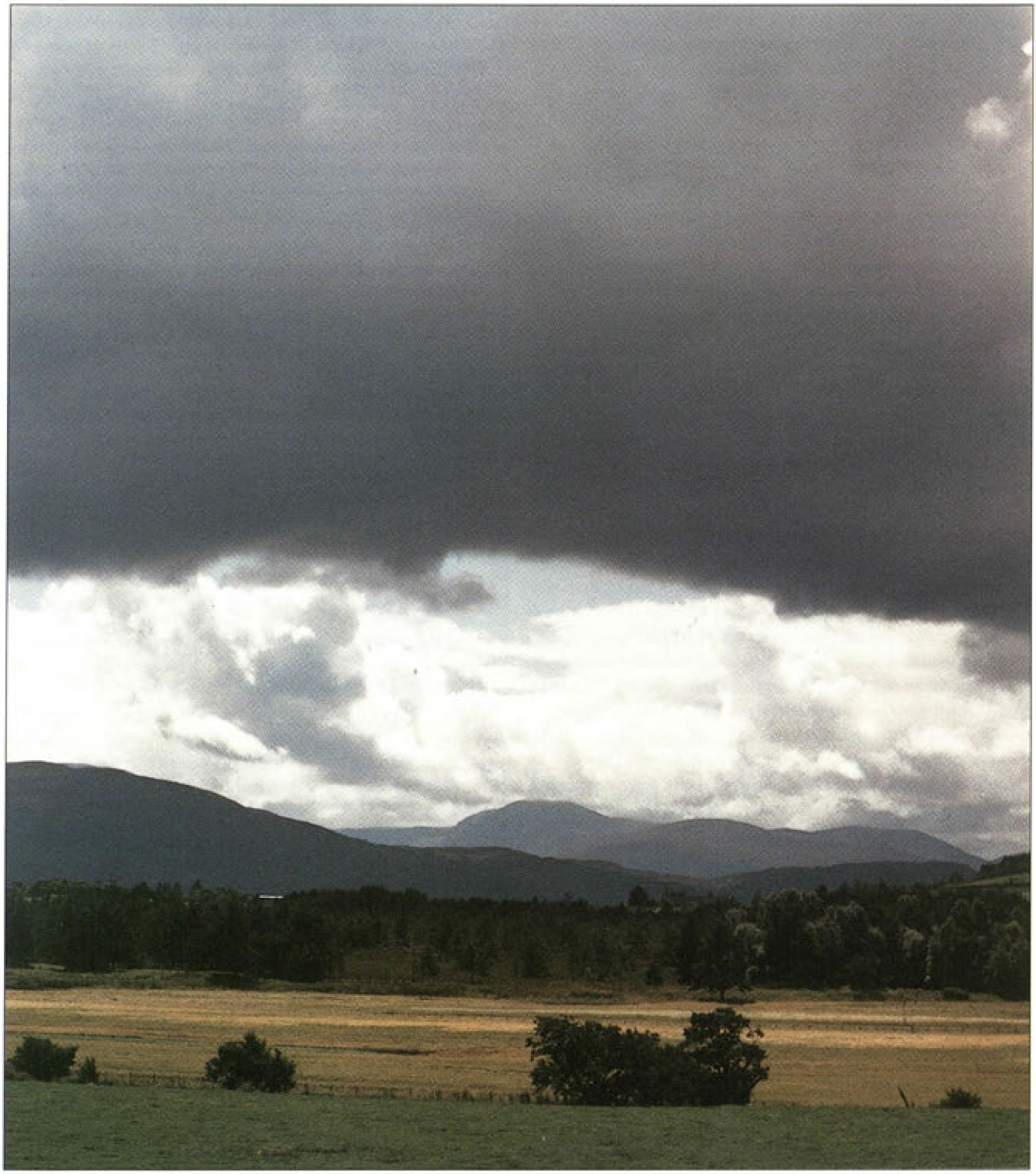

Hugh Webster - Photography Strathpeffer

CONCEPTS of PHYSIOLOGICAL ECOLOGY and their importance in hill and upland ecosystems

J.A. Milne

Physiological Ecology is concerned to answer the physiological question of how organisms function and the ecological question of why they function in the way that they do in relation to the environment that they inhabit. Ruminants, as a sub-set of organisms, can be considered as resource transformers that acquire resources through the processes of diet selection and ingestion and then partition their intake into such functions as the maintenance of tissues, growth, reproduction and storage. A knowledge of the factors which determine the effectiveness with which nutrient resources are captured from a given environment and transformed is central to the study of physiological ecology. From this study it should be possible to determine the optimal strategies for resource acquisition and allocation for any environment. These propositions are developed further by Calow and Townsend (1981), particularly in the context of the development of evolutionary theory, but it is the intention of this article to show that they have equal relevance and value in the study of how farmed ruminants use the pastoral resources of temperate regions.

Farmed ruminants, be they sheep, cattle or more novel species such as deer or goats, occupy a range of environmental conditions in terms of the pastures that they graze, the weather conditions that they encounter, the degree to which they are provided with supplementary feed and shelter and the amount of management by man that they receive. As systems of animal production have developed in the last 20 years in the northern hemisphere at least, the degree of management control exerted over the environment of animals has increased with more ruminants being housed and more supplementary feeding being given. This reflects the economic conditions whereby increased costs could be met from the prices that could be obtained by producers either from the market or as a consequence of government policy. These economic circumstances are likely to change. Moreover, with the consumers' preference for more natural products and with their desire for the maintenance of high animal welfare standards and the achievement of conservation objectives, it will become more important to match currently important ruminant livestock species to a wider range of environments, for example those associated with lower inputs, than has been the case in the last 20 years. Moreover, the introduction of novel farmed species, such as deer and goats, begs the question as to how their physiology interacts with that of land and other resources that they utilize.

Although there are a number of important areas in which the physiology of the animal interacts with the way that land and feed resources can be utilized, two examples, which relate to current and recently completed work at the Macaulay Land Use Research Institute, are dealt with in some depth to illustrate the value of the approach. These relate to (a) the seasonality of important animal functions and how these interact with the natural supply of feed resources and (b) how adaptations to the physiology of digestion and metabolism influence the acquisition of nutrients from natural feed resources.

Seasonality

Most ruminant species which have evolved in temperate regions have seasonal cycles in many physiological traits, such as intake, reproduction, coat growth, metabolic rate and anabolism and catabolism of adipose tissue, which are partially under photoperiodic control. The degree to which different species exhibit these cycles varies. Red deer have pronounced cycles of intake, oestrous activity and coat growth (see Figure 1). Intakes

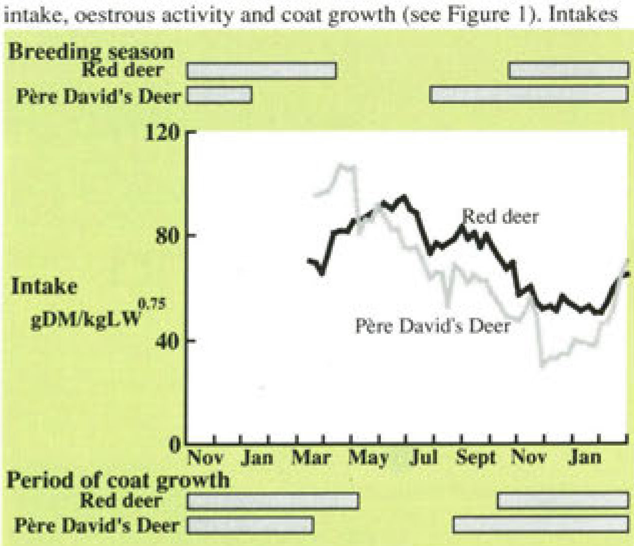

Figure 1. The seasonal patterns in voluntary food intakes, reproductive activity and coat growth in a) red deer and b) Père David's deer (from Loudon et al., *1989).*

reach a zenith in July and have a nadir in January. They exhibit oestrous cycles between October and April and have two annual cycles of coat growth and shedding. There is also evidence of a pattern in metabolic rate, which mirrors that of intake, and there is a suggestion that catabolism of adipose tissue is greatest in the spring and anabolism of adipose tissue greatest in the autumn, although quantitative evidence for this is not available yet. As can also be seen from Figure 1, different species of deer vary in the timing and to a lesser extent the amplitude of these cycles. Sheep on the other hand show a cycle in intake and metabolic rate of

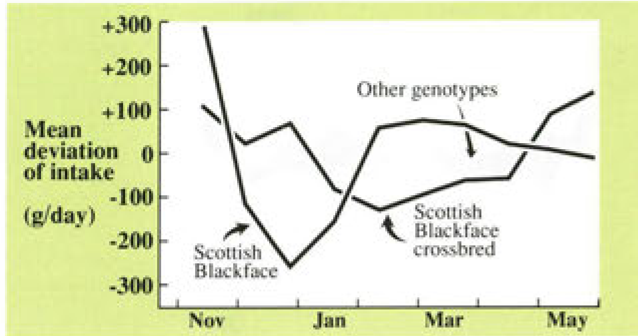

Figure 2. The seasonal winter pattern in voluntary intake by lambs of a number of different genotypes offered the same diet (from Iason and Mantecon, 1990).

lesser amplitude than that in deer (see Figure 2). The onset and termination of oestrous activity in the sheep is also slightly less seasonally pronounced than in the deer. There are differences between genotypes of sheep in the seasonality of intake (see Figure 2) with the Scottish Blackface breed and its crossbreds being particularly seasonal. It is also interesting to note that the Scottish Blackface breed is one which shows the most pronounced seasonality in oestrous activity.

Although it has been established for about 10 years that the onset of oestrous activity is controlled by changes in the release of a hormone, melatonin, from the pineal gland in response to changes in daylength, it has only been shown recently that the decline in intake and changes in coat growth that takes place in

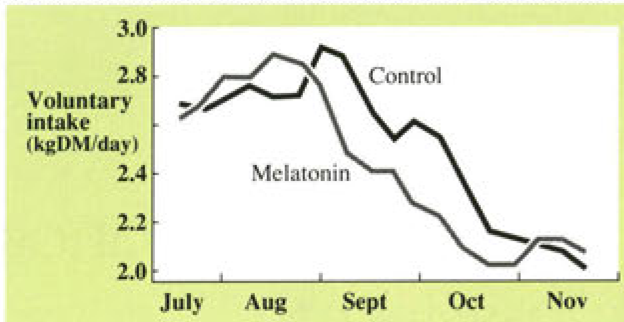

Figure 3. The effect of melatonin treatment on the voluntary intake by red deer hinds compared to untreated hinds (from Milne et al., *1990).*

the autumn are also under the control of melatonin. Evidence for this comes from a study where red deer were given daily doses of melatonin in the late afternoon to extend the period in the day over which plasma melatonin levels would be elevated. The onset of the decline in intake in the autumn was brought forward by two weeks (see Figure 3) and an incomplete winter coat was grown. These studies were all conducted under housed conditions where the animals had an unlimited supply of forage to allow them to exhibit their physiological responses to the full.

The pattern of the annual changes in the physiological variables described above corresponds closely to the supply of nutrients that is likely to be available to free-grazing ruminants in temperate regions. Nutrient supply from herbage is most abundant in the summer and autumn when intakes are at their highest and the propensity for adipose tissue deposition is at its greatest. In winter, with the cessation of herbage growth, nutrient availability

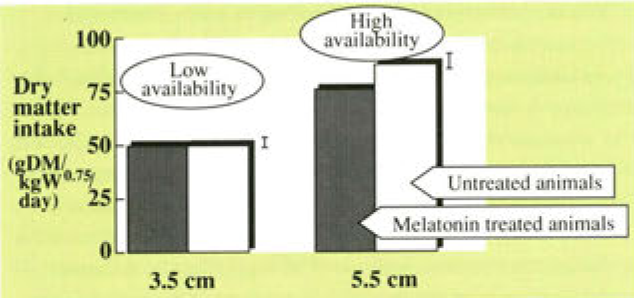

Figure 4. Herbage intake by melatonin-treated and untreated red deer hinds grazing swards of low and high availability (from Heydon et al., *1990).*

declines, which is when metabolic rate is at its lowest. It is attractive to hypothesise that these physiological cycles are in an evolutionary sense an adaptation to long-term predictable changes in resource availability from the environment (Kay and Staines, 1981). In terms of agricultural systems these putative physiological adaptations could also be used to match animal species and genotypes to environmental constraints more closely. Previous studies on genotype-environment interactions had to adopt a descriptive approach, but the increase in our understanding of more of the physiological mechanisms now allows a more prescriptive means of defining the efficiency with which resources can be used.

A fundamental assumption in the discussion above is that the physiological responses obtained in indoor studies would be expressed fully under grazing conditions. This may not hold true; there could be interactions with nutrient availability or weather conditions. Weather conditions could lead to greater increases in metabolic rate and adipose utilization in some genotypes or species than in others and override seasonally driven responses. Similarly, the low availability of herbage in the autumn or winter could reduce the ability of the animal to express, for example, the seasonally controlled intake cycle.

This latter hypothesis was tested in an experiment conducted in the autumn with red deer hinds. Hinds were either treated with melatonin, as described previously, to bring forward the period during which they would exhibit low intakes or given no treatment so that they exhibited the onset of low appetence at the usual time in the autumn and early winter. Hinds from both of these groups were grazed on sown swards maintained at two surface heights, 3.5 and 5.5cm, to provide different levels of nutrient availability, which were anticipated would lead to different levels of herbage intake in untreated animals. Figure 4 shows that this indeed was the case with a difference of 40% in herbage intake by hinds grazing the two swards. It also shows that, whilst there were lower herbage intakes by the hinds treated with melatonin compared to the untreated animals at the higher sward height, as would be predicted from the indoor studies described previously, there was no difference in the herbage intake by melatonin-treated or untreated hinds grazing at the lower sward height. This shows that the expression of an endogenous seasonal appetite cycle can be suppressed where herbage availability is limited. The mechanism whereby intake is reduced by low sward availability is by a reduction in the mass of each bite ingested, even though grazing time, and in some experiments biting rate, increases. How the changes in seasonal appetite are manifested through these mechanisms have not been explored and could yield an understanding of how the seasonal rhythms of intake are controlled.

There are several implications of these results. Doubt is thrown on the extent to which the seasonal cycles in physiological traits in animals can be related in an evolutionary sense to seasonal patterns of nutrient availability. Of course, it may be that low nutrient availability, which is created by ample herbage but of low quality, may give a different result. In these circumstances it will be the ability of the animal to select its diet that will be tested and a different set of mechanisms will be involved. Our limited knowledge would suggest that differences in the diet selected by melatonin-treated and untreated hinds might be small at both high and low nutrient availabilities, when created through differences in diet quality, but this hypothesis has yet to be tested experimentally.

The seasonal control of one physiological trait, intake, was shown to be overidden by nutrient availability from grazed herbage in the autumn. In a further experiment with lactating red deer hinds in the summer it was found that there was again no difference in herbage intake between melatonin-treated and untreated animals under circumstances of low nutrient availability but that the date of onset of the breeding season was altered (Heydon, *et al.*, 1990).

This implies that it is possible to separate under natural grazing circumstances, seasonal cycles which tend to be closely linked to one another and difficult to separate even pharmacologically. It should be clear from this example and its discussion that by developing an understanding of seasonal biology in relation to the pattern of resource availability in temperate regions that a deeper understanding can be obtained which has the potential to have important applications to land usage by ruminant species. Economically important ruminant species, other than deer, such as goats and to a lesser extent sheep and cattle, also exhibit seasonal cycles in physiological traits. Our understanding of these cycles is extending such that it should be possible in the future to manipulate their timing and extent to make more effective use of the seasonal pattern of feed resources.

Adaptation of physiology of digestion and metabolism

The seasonal pattern of increase and decline in intake described for red deer above might be thought to be associated with differences in the extent to which food is digested. Under many circumstances an increase in the intake by a ruminant of a feed is associated with a decline in digestibility of that feed, attributable to a faster passage of food residues through the gut, which reduces the time available in the gut for digestion (Milne *et al.*, 1978). Seasonal differences in intake do not produce such effects with digestibility and rate of passage of undigested residues remaining constant as intake changes (see Figure 5). The reasons for this do not need to be considered here, but with the two herbages that

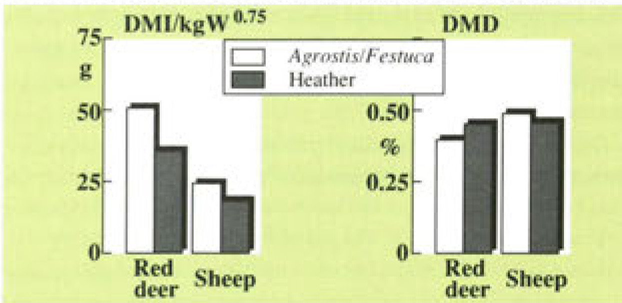

Figure 5. The voluntary intake and digestibility of heather and Agrostis/Festuca *by sheep and red deer in January. Note: in relation to* Agrostis/Festuca, *heather was digested better by deer than by sheep (from Milne* et al., *1978).*

were investigated, heather and *Agrostis/Festuca* species, digestion of the two herbages by sheep and red deer differed. The heather was digested more efficiently by the red deer than the sheep (Figure 5). At the time that the results were obtained it was not clear why this was the case. The high content of tannins found in heather, which complex with proteins in the rumen, is known to reduce the digestion of heather by sheep (Milne, 1974). Subsequent research has shown that these tannins are rendered less damaging in the deer than in the sheep because deer have a higher concentration of prolines in saliva entering the rumen (Robbins *et al.*, 1987). This provides a good demonstration of how different species can adapt their digestion to deal successfully with food items which may be important in their diet. It is this issue that is now discussed with reference to the ways that ruminants deal with the potentially toxic substances found in forage brassicas.

Forage brassica crops accumulate relatively large quantities of sulphur-containing compounds in their leaf, stem and root tissues and it is postulated that they act as protection mechanisms against a wide range of predators from aphids to sheep! The two main sulphur-containing compounds are S-methyl cysteine sulphoxide (SMCO) and the glucosinolates. However, it is their breakdown products in the rumen which lead to inappetence and poor growth rates in lambs through alterations in the animal's digestion and metabolism. Dimethyl disulphide is the breakdown product of SMCO, which causes a haemolytic anaemia (Smith, 1974). The severity of the symptoms will depend on the copper and selenium status of the animals, since these are constituents of important enzymes, superoxide dismutase and glutathione peroxidase, which help protect the red blood cells from the free-radical effects of dimethyl disulphide (McPhail and Sibbald, 1990). There are differences between species in the severity of the haemolytic anaemia with sheep being more tolerant than cattle or goats. Recent research with red deer fed oilseed rape (see Section 7 of the research summaries of this Annual Report) has shown that red deer are more akin to sheep than other species in the development of haemolytic anaemia. On the basis of reports from Europe, roe deer are more susceptible than red deer and this observation is currently being studied in a joint project between MLURI and the Scottish Crop Research Institute. The reason for the different susceptibilities between species has not been identified. Among sheep there exists a genetic deficiency in red blood cell glutathione. In most breeds only 2-3% of animals are affected but

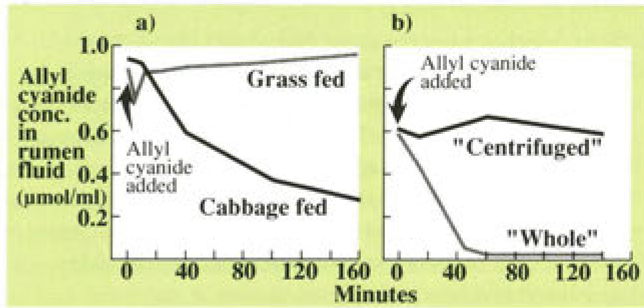

Figure 6. The effect of rumen fluid source on the degradation of allyl cyanide in rumen (from Duncan and Mine, 1989).

in the Finnish Landrace breed 20% of animals may be deficient (Tucker and Kilgour, 1973). It may be that this could offer an explanation for the between-species differences.

The other main sulphur-containing compounds, the glucosinolates, produce two main breakdown products, isothiocynates and nitriles. There are a number of glucosinolates which produce a range of breakdown products in different proportions depending on the precise conditions in the rumen. Research at MLURI has concentrated on one of the more common glucosinolates, sinigrin, which is, for example, the predominant glucosinolate found in cabbages, and which produces allyl isothiocyanate or allyl cyanide as the isothiocyanate and nitrile compounds respectively. When these compounds were given by continuous infusion into the rumen of sheep, allyl cyanide, in particular, produced variable effects on intake with the pattern of intakes suggesting that adaptation to the presence of the compound was taking place (Duncan and Milne, 1989). Further research has shown that adaptation was taking place in the rumen with the micro-organisms adapting to the presence of the allyl cyanide by developing the ability to degrade it. Evidence for this was obtained in *in vitro* studies by injecting allyl cyanide into rumen fluid obtained from sheep fed either on cabbage or a non-brassica diet, dried grass. As can be seen from Figure 6, the allyl cyanide disappeared from the rumen fluid of the cabbage-fed animal but not from that of the animal fed dried grass. Confirmation that it was the micro-organisms that were causing the disappearance of allyl cyanide was obtained when the micro-organisms were removed by centrifugation. Adaptation can also take place in the metabolism of the tissues of the animal, by, for example, the induction of enzymes, and evidence of this has also been obtained in lambs ingesting forage brassicas (Duncan and Milne, 1990).

Adaptations to such secondary compounds in some farming situations could be potentially speeded up, for example by supplying the animal with an innoculation of micro-organisms already adapted to the compound, using a concentrate supplement as a vehicle to deliver the innoculant. In more free-ranging situations such an approach is not possible. There are no doubt many adaptative mechanisms of the type described above which still await to be discovered and which may lead to the identification of animal species which are more suited to grazing some plant communities than others. Secondary compounds can also have important effects on the acceptability of plant species, as another form of defence mechanism, to ingestion by herbivores. Our understanding of the relative importance of these effects in relation to the effects described above is a central challenge to those that study chemical ecology.

These two examples give an indication of how the physiology of individual genotypes or species of grazing ruminant interacts with either the amount of food supply or its composition. From this understanding not only can animal-based systems be designed to utilize land and vegetation resources more effectively, but also the resources themselves can be more successfully sustained.

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PLANT SPECIES BALANCE IN SOWN SWARDS IN LOW INPUT AND EXTENSIVE GRAZING SYSTEMS

C.A. Marriott and S.A. Grant

Introduction

The manipulation of multi-species swards to ensure sustainability of a desired species composition depends upon an understanding of factors which determine the balance of species. The balance achieved is largely a result of interactions between the inherent capacity for growth of the component species, climatic and sward microenvironmental conditions and the impact of grazing animals. With a knowledge of such interactions it is possible to predict the consequences of a wide range of circumstances on species composition. In sown swards, for example, particular interest is currently focused on the effect of reductions in fertilizer inputs. This review discusses recent work related to sustaining white clover (*Trifolium repens*) in low input swards and considers the implications of extensive grazing systems for species balance.

Grass/clover balance in low input systems

The species composition of grass/clover swards is ultimately determined by the balance between the performance of individual grass and clover plants. Basic morphological and physiological differences between grasses and clover affect the nature of the competitive relationships that develop in mixtures. Environmental or abiotic factors have a key role in determining the outcome of such competitive interactions but the effects are modified by the presence of animals in grazed swards. An understanding of the interactions between plant species, together with information on selective grazing, is necessary for the prediction of the outcome of manipulation of timing, frequency and severity of defoliation on species balance in grass/clover mixtures.

Seasonal growth differences

Perennial ryegrass (*Lolium perenne*) has a lower optimum temperature for growth than white clover, 18-21°C compared with 24°C; it also initiates growth at lower temperatures than does clover (Williams, 1970). Ryegrass thus has an advantage over clover both early and late in the growing season when temperatures are low. Once white clover is actively growing, however, its proportion in the sward steadily increases, indicating that it has a higher rate of growth than grass. This advantage may be related to differences in specific leaf area and pattern of leaf expansion (Parsons *et al.*, 1990). The growth rate of grass in summer depends on whether floral tillers are allowed full expression in taller swards or are decapitated during close grazing. In tall swards, growth is initially very rapid; a reduction of growth in the summer then occurs because of apical dominance

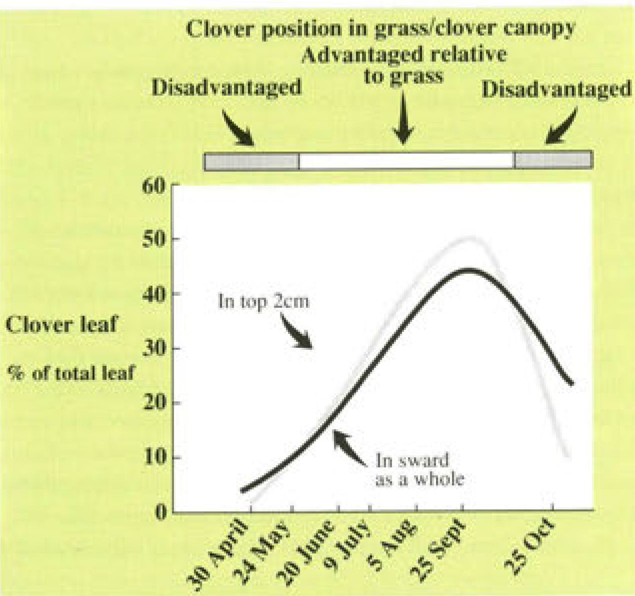

Figure 1. Clover position in grass/clover canopy.

suppressing development of daughter tillers. New leaf growth is restricted to existing vegetative tillers and the new daughter tillers which are initiated from axillary buds. Defoliation by grazing or cutting allows tillering to proceed because decapitation of floral tillers removes apical dominance and more light reaches the base of the sward; the annual growth curve of grass is, therefore, highly dependent on these factors (Maxwell *et al.*, 1988). Clover, though more susceptible to drought, does not show a mid–season decline in growth in response to height manipulation. The differences between grass and clover in their seasonality of growth and response to manipulation of sward conditions provide opportunities to minimize inter–specific competition, and a greater stability of sward composition may result.

Canopy effects

Clover leaves are arranged horizontally in the sward and thus their ability to intercept light is strongly influenced by their position within the canopy (Figure 2). Grass leaves, on the other hand, are generally erect, so that light is more evenly absorbed throughout the canopy. While the horizontal arrangement of clover leaves is advantageous when clover petioles are able to extend and maintain the laminae near the sward surface, it is disadvantageous in early spring and autumn (Figure 1). At these times low temperatures inhibit petiole extension (Marriott *et al.*, 1988), so that clover laminae occupy a low position within the canopy. The early work of Jones (1933a,b,c,d), together with more recent work (Laws and Newton, 1987; Grant and Barthram, 1990a), shows that allowing herbage to accumulate in early spring leads to reduced white clover content of grass/clover swards compared with swards which are closely grazed at this time. This is because both clover leaf appearance and stolon branching rate are less under shaded conditions (Solangaarachichi and Harper, 1987; Davies and Evans, 1990).

In late spring, clover petioles can extend and maintain laminae near the surface of the sward; periods of herbage accumulation, for example prior to a silage cut (Dennis *et al.*, 1984; Grant and Barthram, 1990a,b), are now advantageous for clover. Clover

Figure 2. Horizontal arrangement of clover laminae at the top of the sward canopy allows efficient interception of light.

laminae are intact and unshaded, and the branching rate of clover stolons is unaffected by shade at the base of the sward (Davies and Evans, 1990). The stolons accumulate energy reserves and, on cutting the sward, the high light levels at the base of the sward encourage a flush of stolon branch production; grass, on the other hand, is adversely affected as the tillers have extended and defoliation temporarily reduces tillering (Grant and Barthram, 1990b). Thus a period of rest from grazing in late spring or early summer, when clover has a growth advantage over grass, should lead to increases in clover content, and indeed this has been shown frequently in systems which incorporate a hay or silage cut (Wolton *et al.*, 1970; Curll and Wilkins, 1985; Sheldrick *et al.*, 1987).

The extent to which individual species in the sward are grazed is a function of grazing preference as modified by the way that canopy structure affects selection opportunity. Thus, even if clover was not preferentially grazed, its position in the canopy (with proportionately more of its leaves in the grazed upper horizon of the sward than grass) means that a greater severity of defoliation of clover than grass occurs (Milne *et àl.*, 1982). However, during the main part of the growing season in continuously stocked swards, this disadvantage appears to be more than offset by a greater capacity for growth and clover increases its contribution to the sward (Parsons *et al.*, 1990).

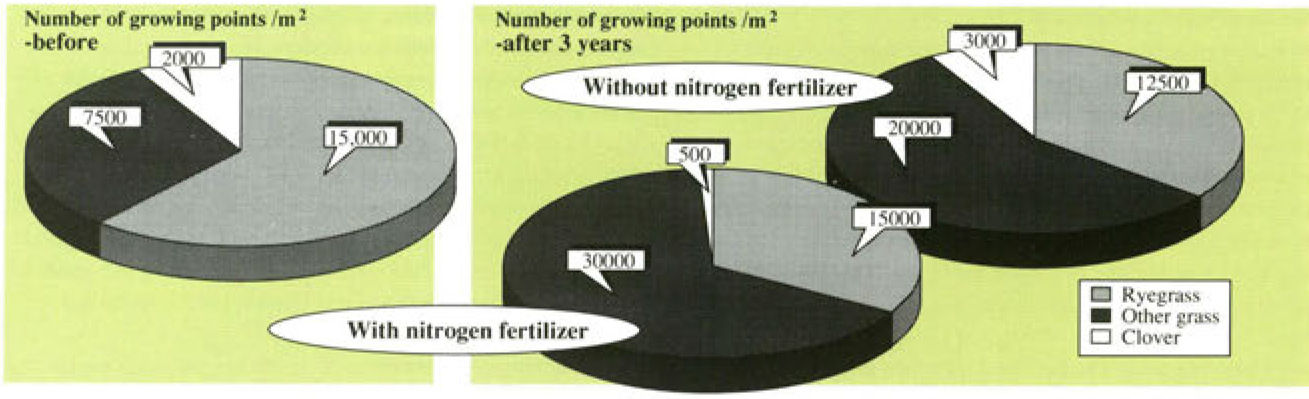

Figure 3. Small amounts of N fertilizer can have a large effect on clover content. Nitrogen fertilizer should be kept to a minimum to encourage clover.

Nitrogen nutrition

Clover has access to two sources of N; it can fix atmospheric N_2 and, like grass, take up mineral N from the soil. Competition for N between grass and clover is complex because N uptake by grass can be influenced by clover in two opposing ways. Clover may increase the supply of available N through transfer of fixed N but it may also compete for mineral N. The balance between competition and transfer is not constant, but varies during the growing season (Vallis, 1978).

Barthram *et al*., (unpublished) showed that even small applications of N fertilizer, applied repeatedly, reduced clover content; the ryegrass population, on the other hand, remained constant where N was applied but declined slightly in the absence of N fertilizer (Figure 3). Other grasses, such as *Poa* and *Alopecurus*, increased substantially in both cases. Both the absolute numbers of clover growing points and their contribution to the total population were less when N was applied. Initially 8% of the growing points were clover; after 3 years a similar percentage was found in the swards given no N fertilizer, but it had declined in the N-fertilized swards to only 1%. Fertilizer N also reduced N_2 fixing activity of clover on both a ground area and a plant unit basis (Grant *et al*., 1986). Nitrogen fertilizer, therefore, has the potential to alter species balance and reduce the content of clover, in addition to increasing total herbage production.

Treading and stolon burial

Apart from defoliation, there are inevitable consequences of the presence of grazing animals on swards. Treading can cause different degrees of damage to different plants (Edmond, 1964; Curll, 1980). Especially in wet weather, treading disturbs the soil and can lead to burial of stolons of clover. Burial has little effect on stolon growth and death of stolon branches if leaves remain on the plants (Grant and Marriott, 1989). Removal of leaves, however, caused a reduction in stolon growth in both buried and unburied treatments, with a greater reduction in the buried treatment. A substantial increase in death of stolon branches occurred when stolon burial and leaf removal were combined. These responses are attributed to acropetal translocation of energy reserves to new growth on main stolons, and a reduction in the partitioning of assimilates to support smaller buried branches.

On wet, heavy soils, burial of stolons can be quantitatively significant. For example, on a poorly drained noncalcareous gley soil, within 5 weeks of marking stolons, over 50% were buried and after 29 weeks all marked stolon sections were buried. Changes in species balance, resulting from a reduction in clover content associated with stolon burial, are likely to occur on wet heavy soils, under high grazing pressures.

Excretal return

A further inevitable consequence of the presence of animals is excretal return. Urine return is particularly important because the bulk of the N excreted is in urine, and adverse effects of even small amounts of fertilizer N on clover have been clearly shown. One important feature of addition of N in urine is the patchy pattern of its deposition (Hilder, 1966). Only small areas of the sward are affected at any one time, but they can receive the equivalent of 300–600 kg N/ha. In a series of experiments, urine was applied in either spring, summer or autumn, to areas protected from subsequent excretal return by graze through cages (Marriott *et al*., 1987; Grant and Marriott, 1989). Such cages allow animals

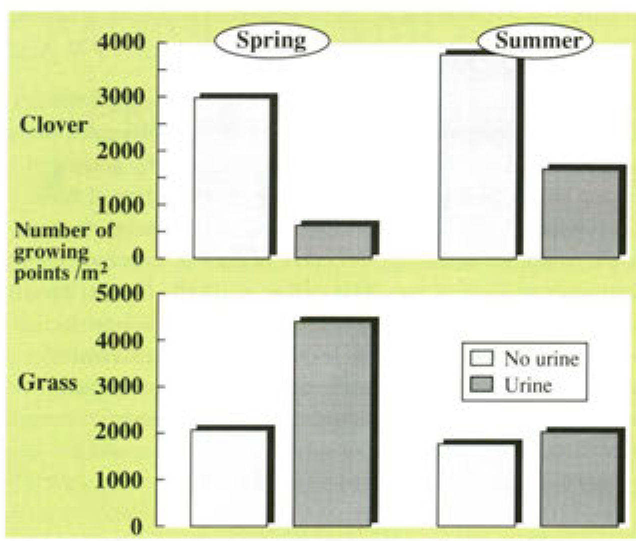

Figure 4. Urine adversely affects clover populations. Clover populations are adversely affected by spring and summer applications of urine but the effect on grass is variable.

to graze a strip along the edge of the cage, but neither tread nor excrete on this area. After urine application in the spring and summer, there were dramatic reductions in the number of clover growing points, which were not necessarily accompanied by

Figure 5. Patchiness of clover can occur as a result of excretal return.

increases in the population of grass tillers (Figure 4). The effects on clover were most pronounced when urine was applied in the spring, when clover was growing more slowly than grass, and reductions in populations to 20% of those in untreated areas were found. Changes in clover populations are due to increased death of clover stolons, as well as reductions in the production of new growing points through branching of stolons (Grant and Marriott, 1989). In the autumn, when growth of both grass and clover is slow, there was very little effect of urine on either plant species. This work shows the extent to which urine can affect clover and, without doubt, it plays a major role in creating patchiness of clover in mixed swards (Figure 5). The results suggest that, in grazed swards, the adverse effects of urine return on clover will partially offset the advantages of short swards in spring.

To summarize this section, our understanding of the effects of sward conditions and N fertilizer application on clover content in grass/clover swards suggests three ways which favour the sustainability of clover content. These are: to use hay and silage harvests at appropriate times of the year, to minimize fertilizer N inputs and to avoid high stocking rates on wet, heavy soils.

Species balance in extensive systems

Most recent research on grass/clover swards has been conducted under conditions which maintained optimal pH and levels of mineral nutrients, especially N, P and K. However, likely changes to lower levels of input, and removal of pasture from grazing, require that studies are extended to include less than optimal conditions (Figure 6). A greater understanding of interactions between a much wider range of species than simply ryegrass and clover is needed to enable prediction of the effects on species balance and clover content. There would be implications for animal diet selection, which could in turn affect species composition of the sward. In addition the rates of soil processes such as mineralization and immobilization of nutrients could be affected. Such changes and possible differences in soil physical parameters, for example bulk density and porosity, will also influence plant dynamics. In the following sections some general effects of nutrient stress and grazing on plant growth and species composition are considered.

Nutrient stress effects

In the absence of fertilizer additions, plant growth will be increasingly limited by the supply of plant available nutrient resources. The relative growth rate of individual plants will decline and the life span of leaves will increase; a seasonal peak of shoot expansion may be difficult to detect (Grime *et al.*, 1988).

When nutrient supplies are restricted, the balance between uptake and internal recycling of nutrients in plants will change to favour an increased component of internal recycling (e.g. Simpson *et al.*, 1982). In such circumstances, those species which have efficient and well–developed mechanisms to conserve nutrients within the plant, defined by Grime (1974) as stress tolerators, should be most successful. Nevertheless the nutrient content of both herbage and plant litter may be less when nutrient levels are lower. For example, the N content of ryegrass in unfertilized swards was 30–40% lower than that in N-fertilized swards (Marriott, unpublished).

In addition to effects of nutrient stress on individual plants, there will be effects on species composition. It is predicted from resource competition theory (Tilman, 1980) that numerous species can persist only if they are differentiated in their abilities to compete for different limiting resources. Interspecific differences in factors such as root morphology, root cation exchange capacity and rhizobial and mycorrhizal infection are likely to be involved. Evidence that species composition can be controlled, or at least influenced, by nutrients comes from three sources: surveys of plant distribution in the field, experiments involving the addition of nutrients in the field and autecological studies of species which occur in habitats of differing fertility.

The positive relationship between soil pH (a simple guide to nutrient status) and species density for grasslands in the Sheffield area shows that optimum density occurs at around pH 6.5 (Lloyd *et al.*, 1971). Surveys show the different environments occupied by individual species. For example, *Nardus stricta* is found predominantly at low pH, *Agrostis tenuis* over a wide pH range, but with a peak around 4.5–5, and *Festuca ovina* is evenly distributed across the range (Grime and Lloyd, 1973).

Classic experiments which show the effect of application of fertilizer are the Park Grass experiment at Rothamsted (Thurston, 1969) and Milton's (1940) experiment in Wales. In the Park Grass experiment, in the absence of grazing and with two hay cuts per year, fertilizer application led to dominance by a few fast-growing grasses, whereas unmanured plots retained a diverse population of over 40 species. In Milton's experiment, by contrast, an infertile Welsh grassland dominated by a few unproductive species was changed to a species-rich mixed grassland in response to N, P, K and lime applications. Controlled grazing accelerated the process and helped to maintain the changes initiated by the nutrients.

Experiments with individual species in isolation show they have very distinctive growth responses to nutrients (Bradshaw *et al.*, 1960, 1964), but caution is needed in extrapolating such information to field conditions. Dry matter responses of *L. perenne*, *A. tenuis*, *F. ovina* and *N. stricta* to a range of N and P levels suggest that *L. perenne* will always be the most successful species regardless of nutrient level. But in a mixture, low yielding species have an advantage under conditions of nutrient stress and *L. perenne* is outcompeted by *A. tenuis* (Bradshaw, 1969; van den Bergh, 1969). White clover has a higher requirement for P and K

Figure 6. Swards containing a wide range of species will become increasingly important when fertilizer inputs and grazing are reduced.

than associated grasses, and, in general, it becomes more competitive with companion species as nutrient status increases (Harris, 1987). However, as shown earlier, the response to N is rather different and clover is favoured when N availability is low.

Grazing effects

In an ungrazed sward the major effects on species composition will arise through competition between plants for light, water, space and nutrients. Grazing, or mowing, will modify this competition. For example, uniform defoliation alters the competitive balance between *L. perenne* and *Holcus lanatus*. The taller *Holcus* dominates under light or infrequent defoliation, but *Lolium* is the most successful competitor under frequent severe defoliation (Watt and Haggar, 1980).

It is unlikely that each plant suffers equally when swards are grazed. Many factors intervene, including patchy plant distribution, heterogeneity in plant size, plant form and life history, differences in nutritive value and resultant effects on patterns of grazing. These factors will ultimately determine the effect of defoliation by herbivores on species dynamics and sward composition. It can be postulated that, if grazing preferences for particular plant parts or species exist, the full impact will be felt when availability of food is high, since animals may be less selective when food supply is low.

Selective grazing could reverse the relative competitive abilities of plant species. For example, *Nardus* in *Agrostis-Festuca* grassland is normally uncompetitive in the absence of grazing, but it becomes aggressively competitive when its competitors are eaten and it is avoided (e.g. Nicholson *et al.*, 1970).

If the herbivore prefers the least competitive species, the plant will suffer a dual disadvantage and may be greatly reduced in abundance or may even disappear from the sward. Some minor annual herbs, particularly in Mediterranean environments, might respond in this way. Reductions in *Deschampsia flexuosa*, a minor component in the sward, occur under grazing, whereas the dominant *F. ovina* increases (Grant *et al.*, unpublished).

The herbivore may switch between species depending on their relative abundance and accessibility; as the herbivore reduces one species it may transfer to the newest dominant. An example of switching is the change in preference shown by grey and fox squirrels; they switch between acorns of black and white oak depending on their availability (Smith and Follmer, 1972).

Plant species may be removed by the herbivore in proportion to their abundance in the grazed horizon (e.g. Milne *et al.*, 1982); the effect on sward composition will depend on the relative grazing tolerances of the individual species, on their ability to regrow and their morphological responses to grazing. However, this situation is only likely to obtain in simple swards under nutrient sufficiency, where the range in feeding value between species is very small. As nutrient stress increases and a wider range of species coexist, the drive to select species with higher digestibility will increase. For example, in contrast to the situation in sown swards, clover is strongly selected by sheep in *Agrostis-Festuca* grassland (Grant *et al.*, 1985).

The timing and intensity of grazing are also vitally important. Seasonal grazing will alter diet selection, because selection will be strongly influenced by plant life history. Grazing in winter only will interfere little with seed setting stages, and so might be expected to increase numbers of species. Treading may incorporate dead material and increase nutrient turnover and, in addition, light conditions in the sward may be improved and spring growth encouraged. The effect of summer grazing on flowering will be strongly influenced by the intensity of grazing and, in short swards, seed heads will occur only on prostrate species. At low levels of utilization, ingress of taller species can occur, whereas closely grazed swards will be dominated by prostrate, rhizomatous, stoloniferous or basal rosette habits.The importance of the grazing animal is again evident when considering microheterogeneity in the sward environment. Hoofprints, faeces patches and patchy grazing can all provide areas for colonization, and nutritional heterogeneity is created as a result of excretal return and camp areas.

Figure 7. Floristic change in unfertilized grass/clover swards is examined under different seasonal grazing regimes.

Conclusions

Many studies have examined floristic change in communities in response to grazing, but comparisons have not been made before in sown grass/clover swards subjected to nutrient stress (Figure 7). This subject area is being addressed at MLURI in a multidisciplinary long–term experiment conducted at three sites on soils of differing inherent fertility. Detailed studies of plant interactions, aspects of diet selection and animal behaviour, and the soil component of the system are included. The experimental treatments include a fertilized positive control, and a range of unfertilized treatments, which represent the most severe experimental nutrient stress which can be imposed and, therefore, will accelerate any changes which are likely to occur. Different combinations of intensity of winter and summer grazing are superimposed, which will allow a range of hypotheses relating the grazing animal to floristic change to be tested. Support cutting experiments will determine plant physiological responses to nutrient stress and defoliation; research will include biomass partitioning, and nutrient acquisition and remobilization studies.

From this work the sustainability of grass/clover systems without fertilizer inputs will be determined, and the responses of grass/clover swards to inputs of fertilizer lower than those currently applied may be predicted. On a more general level, it will allow the testing of many of the theories of plant–herbivore dynamics which, as Crawley (1983) has pointed out, greatly outstrip empirical understanding.

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Soil and environmental properties examined by geostatistical methods

The continuous spatial and temporal variation that characterises the environment has been examined through the application of geostatistical concepts, with particular focus on soils, topography and climate.

On the Scottish Crop Research Institute farms soil profile available water for potatoes has been calculated at 25 m intervals along transects and at the nodes of a 100 m square grid from soil observations and results of analyses.

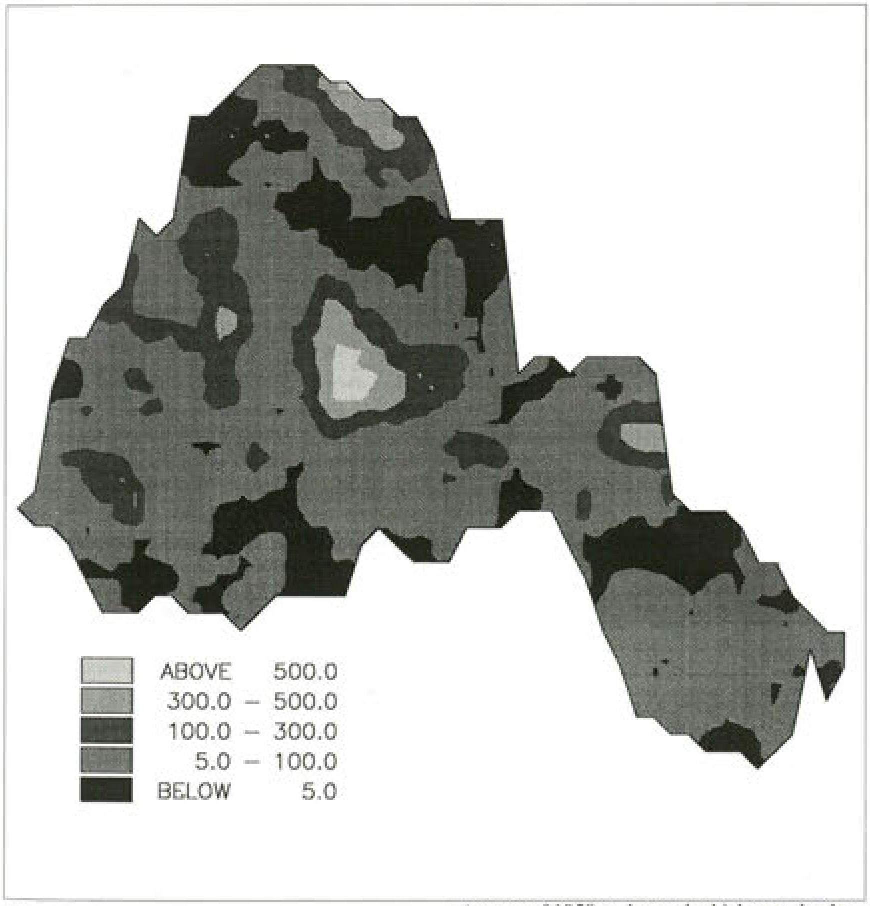


Figure 1. Contour map of peat thickness at Coalburn opencast coal site, ordinary kriged estimates, peat depths in cm.

The relationship, expressed as the average semivariance, between pairs of observations separated by 25, 50, 75, 100 m distances was computed and plotted as a semivariogram. Combining this relationship between semivariance and separation distance with field values probabilistic estimates (kriged values) have been derived for interpolated closely spaced points. Contoured maps of soil available water for potatoes prepared using these estimates will aid experimental plot selection and farm management. For agroforestry experimental sites at the Glensaugh Research Station similar contour maps of soil available water have been prepared from data collected at 10 m spacing along transects and at the nodes of a 50 m grid. The results will assist the analysis of future measurements of tree growth in relation to soil properties and moisture stress.

A contour map of peat thickness on an opencast coal site at Coalburn, Lanarkshire, has been derived from measurements on a 100 m square grid (Figure 1). The semivariograms for four directions and the fitted isotropic model (Figure 2) show:

a) nugget variance of 0.35 m^2, accounting for small scale variation and observational or experimental error

b) sill semivariance of 2 m^2 consisting of the nugget variance plus the range of variance due to spatial dependence

c) range of 1050 m, beyond which peat depths are independent.

Peat depth spatial relationships on this lowland site fit a pentaspherical isotropic model. This contrasts with an anisotropic linear model found at Lephinmore hill farm and indicates that the lowland peat can be characterised by fewer measurements. Using weighting coefficients derived from the semivariogram model and an ordinary kriging procedure, the contour map of peat thickness has been computer generated. The procedure will find application in mapping proposed opencast coal sites carrying peat.

The risk of windthrow poses a major danger to timber production and the economics of forestry. From observations of topex, soil characteristics and elevation during a preplanting survey of Rannoch Farm, Perthshire, the windthrow hazard score semivariogram has been modelled (Figure 3) and estimated values mapped (Figure 4) by disjunctive kriging. Of particular relevance to silvicultural management are the conditional probabilities mapped in Figure 5 that values will exceed a critical value, so allowing choice to the forester in the level of risk accepted.

The long-term average of accumulated temperature is an important parameter in modelling the land capability for forestry and values are available at 200 recording stations throughout the U.K. Modelling the variation between the stations gives different semivariograms in the north-south and east-west directions reflecting the differing effects of longitude and latitude on incoming solar

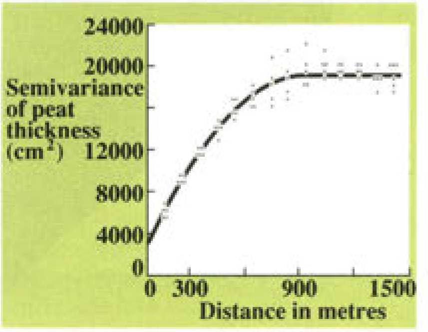


Figure 2. Isotropic semivariogram of peat depths at Coalburn opencast coal site, Lanarkshire, including fitted pentaspherical model.

radiation. Applying a standard lapse rate for temperature change with elevation to give data at a standard elevation, sea level, for each site reduces variability in the data (standard

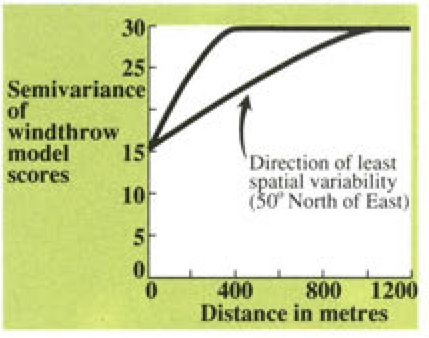
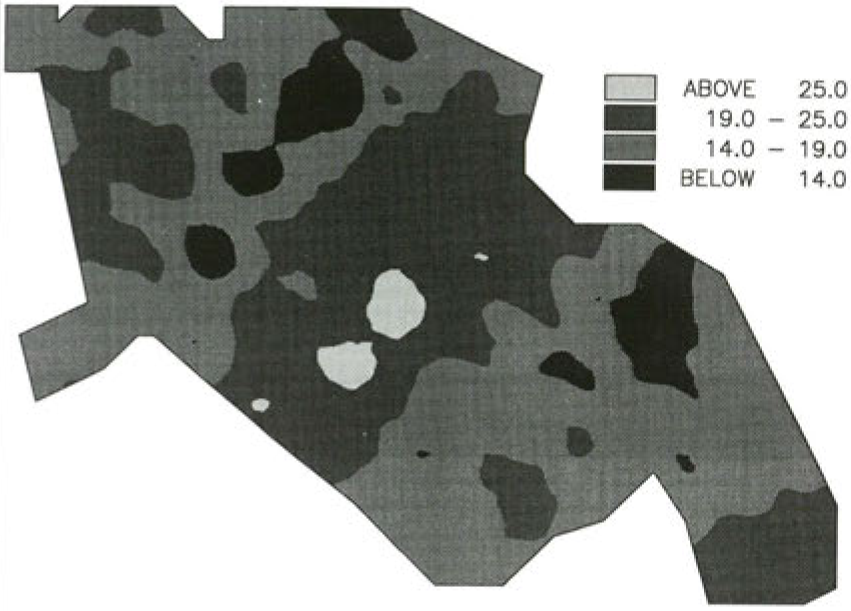


Figure 3. Anisotropic semivariogram of windscore assessments at Rannoch Farm, Loch Rannoch, showing envelope of fitted model.

deviations, site = 298, sea level = 277) and the nugget semivariance reduces considerably. A structural analysis of the semivariogram is required before deciding the most appropriate form of kriged estimates to produce. When interpolated estimates of sea level temperature have been prepared for Scotland digital elevation data will be used to prepare an accumulated temperature map.

Contact name: **Gordon Hudson**

(Figures 4 and 5 are on the next page)



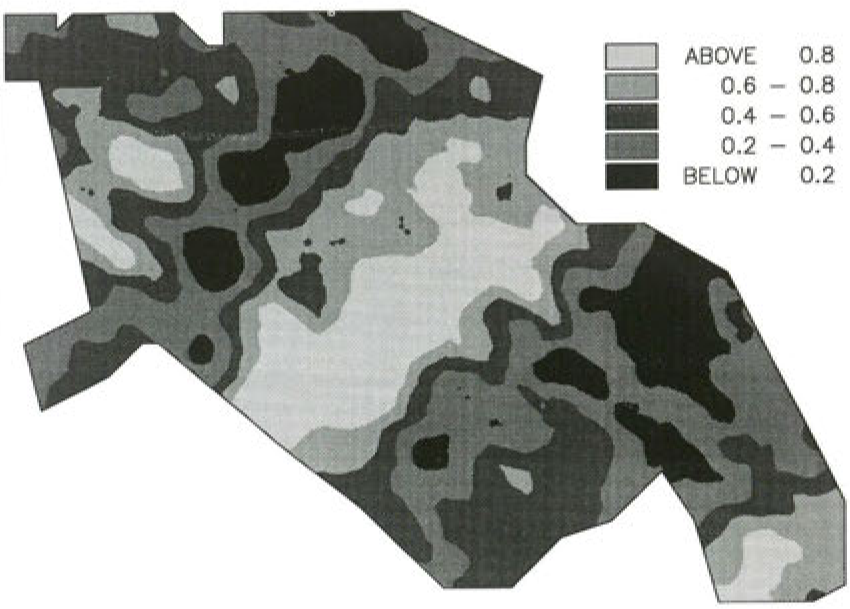


Figure 4 (above). Rannoch Farm, Loch Rannoch. Windthrow hazard scores (disjunctive kriged estimates).
Figure 5 (below). Rannoch Farm, Loch Rannoch. Conditional probability that windscore is greater than 19.0 (disjunctive kriged estimates).

Rural land cover in Scotland by air photo interpretation

The Scottish landscape and environment are the focus of major public interest and concern in government policy formulation. A crucial element amongst many interacting factors is land cover to which the appearance of the countryside, the use of the land and the wildlife it supports, closely relate.

The aim of the research objective is to compile, through the interpretation of aerial photographs, a comprehensive database of the land cover throughout Scotland to form a baseline against which future or past changes can be measured. The project is funded by the Scottish Development Department (SDD) which commissioned the programme of aerial photography flown during 1988-89. Principally panchromatic, but of colour in the Midland Valley, the photos are 1:24 000 scale.

Applying experience gained over long periods in the use of air photographs to aid soil and land mapping, MLURI staff, in discussion with SDD, formulated categories for 124 types of land cover (Table 1). Intricate patterns of two or more types of cover are recognized as mosaics.

The clarity of appearance in air photographs and ease of interpretation depend on the type of feature being identified, the tonal characteristics of the photograph and the time of year it was taken. Principal and major features in the table are generally interpreted readily with high degrees of accuracy. However, semi-natural ground vegetation as observed in the field and in its appearance on air photographs can merge gradually over wide zones. Other features such as bracken appear only in photos taken when the plants are well-grown.

Most agricultural land is enclosed by fences, hedges or walls and is readily recognised in photos. Distinction between ley pastures and winter-sown grain crops can be difficult and although interpretations for agricultural land can be made readily, discrimination within this principal category is imprecise and is attempted only for generalised categories of improved grass land and arable land.

Interpretations are made for a wide range of sub-categories based on natural features such as rockiness, presence of scattered trees or erosion of peat, and on management features such as muirburn, ploughing for forest plantation establishment or tree felling. A miscellany of minor categories such as quarries, open water, golf courses and cemeteries are recognized and have clear air photo appearance. Minimum sizes have been assigned for individual occurrences of each feature to be interpreted, for example 2 ha for woodland, 10 ha for semi-natural ground vegetation. Lesser areas of many types of feature are recorded as line or point data.

Interpretations are carried out under standard good-quality mirror stereoscopes and land cover features are delineated on transparent overlays on photographs. Interpreted information is transferred by Sketchmaster on to

Principal features	Major features	Main features	Sub-categories based on
Semi-natural ground vegetation	Heather and dwarf shrub heathland	Dry heather moor Wet heather moor Undifferentiated heather moor	Muirburn Rock outcrop Scattered trees
	Undifferentiated coarse grasslands	Undifferentiated coarse grasslands	Rock outcrop Scattered trees
	Smooth grasslands	Smooth grasslands with rushes Smooth grasslands with low scrub Undifferentiated smooth grasslands Undifferentiated bracken	Rock outcrop Scattered trees
	Blanket bog and other peatland vegetation	Blanket bog with dubh lochans Undifferentiated blanket bog	Erosion Scattered trees Mechanised exploitation Domestic exploitation
	Undifferentiated salt marsh	Undifferentiated salt marsh	
	Wetlands	Wetlands	Scattered trees
	Dune lands	Bare dunes Partially stabilised dunes Links with grassland Links with heathland	
	Montane vegetation	Undifferentiated montane vegetation	Rock outcrops
Woodland	Coniferous woods	Plantations Semi-natural	Mapped areas Lines of trees Clumps of trees
	Broadleaved woods	Broadleaved woods	
	Mixed woods	Mixed woods	
	Undifferentiated low scrub	Undifferentiated low scrub	
	Management features	Management features	Recently ploughed land Former woodland recently felled Open canopy young plantation
Agricultural land	Agricultural land	Improved pasture Arable land	Rock outcrop Scattered trees Scattered farmsteads
Farms and developed rural land	Isolated farmsteads and other buildings	Isolated farmsteads etc.	With trees With no trees
	Miscellaneous developed features	Factories Airfields Golf courses Cemeteries	
Bare ground	Miscellaneous bare ground	Cliffs, crags & screes Quarries Bings Paths Hill roads Water	Mapped areas, lines or points
Miscellaneous features	Built-up land		
	Transport features in a rural context	Road Rail	
	Cloud-obscured areas		
	Snow-obscured areas		

Table 1. Land cover features for interpretation.

1:25 000 Ordnance Survey Pathfinder Series maps for checking and compilation.

Vector digitizing of the compiled information is the first step to conversion to quadtree format using SPANS software and creation of a raster data set stored on the VAX 3600 computer.

Interpretation has been completed for 26 000 km^2 in regions throughout Scotland: the Northern Isles, Caithness and Sutherland, the Outer Hebrides, the area around Inverness, the Western Highlands, Grampian, Perthshire and Fife, the Midland Valley and Galloway.

The project has attracted major interest from a number of public bodies, including local authorities, the Forestry Commission, Nature Conservancy Council and Countryside Commission for Scotland.

Contact name: **Cyril Bown**

The bracken problem in Scotland

Bracken infests significant areas in the hills and uplands of Scotland. It frequently occurs on the better soils of these regions and over post-war decades has been generally perceived as increasing in extent.

The aim of this research objective has been to establish:

1. rate of spread of bracken
2. the environmental niche with which it is most commonly associated
3. the national distribution of bracken-dominated plant communities
4. how bracken is perceived by farm holders.

This report deals with each topic in terms of its mapping and geography. Biological, botanical or economic studies are related and on-going in other research groups.

Rate of spread of bracken

Changes in the area of bracken cover were measured at four sites: Poltalloch (Argyll and Bute); Glensaugh (Kincardine and Deeside); Sourhope (Roxburghshire) and Gatehouse-of-Fleet (Stewartry). Land survey observations and photogrammetric measurements were made to determine long-term rates of change in bracken cover (over a period of 40 years) and annual bracken front measurement.

Bracken fronts were observed to be different locations up to 10 m apart from one year to the next. On average retreats of 0.1 to 3 m were observed between 1985 and 1986, compared to advances of 0.1 to 1 m between 1986 and 1987. These differences correspond to a later occurrence of frosts in the early spring of 1986, and illustrate the perturbations to be expected in bracken front location over a year.

The area of bracken-dominated plant communities changed in a range of +3% to -0.5% per annum over a 35 to 40 year period. The restrictions on areal change depended upon stocking rates, drainage and climatic factors. The greatest decrease was, however, more likely to be due to the growth cycles of vegetation types. Average change in the area of bracken cover was an increase of 1.0% per annum.

Environmental niche most commonly associated with bracken presence.

Bracken-dominated plant communities were mapped from field survey and air photographs in seven sample areas. Satellite image classification of bracken was then extended over each area and checked. This provided the basis for observing characteristics of the environment that were most commonly associated with bracken presence.

The results indicated bracken is most commonly found where:

1. land is of an easterly or southerly aspect
2. land is below 450 m above mean sea level
3. the dominant soil types are humus-iron podzols or brown forest soils
4. the accumulated temperature is greater than 990 day°C per annum
5. there is a low occurrence of late frosts.

Multivariate analysis of bracken presence with respect to the environmental characteristics measured provided a basis for assigning prior probabilities to each element of data for probability mapping of bracken. This improved image classification results and highlighted geographical differences in the niche of land available for bracken.

National distribution of bracken-dominated plant communities

The sample areas provided controls on a classification of bracken-dominated plant communities across Scotland. The sample areas were augmented with three satellite image classification test areas and extensive field mapping. The classification excluded land interpreted as improved grassland, arable land or built-up areas and land above 450 m above mean sea level. This left 63,250 ha of bracken-dominated plant communities, which is 1.3% of the land available for bracken in the marginal hill and uplands, equivalent to 1.8% of the total rough grazings in Scotland.

The figure of 63,250 ha includes a correction in area due to the angle of slope on which bracken is found and an estimate for bracken presence in Shetland, Orkney, the Western Isles and north-west Skye which were not included in the image classification. The Borders, Galloway and Argyll have the highest proportions of bracken to rough grazings, compared to Highland Region which has the lowest. In general, in eastern Scotland, bracken is confined to higher altitudes compared to western Scotland because of the greater agricultural land use of the lowlands.

The perception of bracken by farm-holders

A questionnaire survey of a representative sample of 1600 farm holders in upland Scotland revealed 29% with bracken present on their land. Of these, 68% considered bracken to be a problem and some 62% had actually undertaken some form of bracken control.

When the replies for farm holders with bracken present are studied, four groups are identifiable:

1. half the holdings consider bracken a problem and have attempted bracken control
2. one quarter do not believe bracken a problem and have not attempted bracken control
3. one eighth believe bracken a problem but have not taken control measures
4. one eighth do not believe bracken a problem and have not taken control measures.

Bracken was considered a problem, in particular, by those holdings with total grazing land of less than 5 ha or more than 765 ha and a high proportion of land as rough grazings.

Bracken control measures were, generally, at least partially effective. Successful control was more likely with chemical methods (54% total clearance) compared with cutting methods (15% total clearance).

A report on the bracken problem in Scotland has been produced on behalf of DAFS.

Contact name: **David Miller**

Development of a land use modelling and information system

The remit of the MLURI requires that spatially-defined attributes of the land be amenable to mathematical manipulation, according to statistical, physical, biological, political or socio-economic models. There is therefore a need to bring together the necessary elements of computer hardware, software and data, to enable data input, storage, processing and presentation, for any selected region, scale and attributes.

An information and modelling system is being created to satisfy these requirements. It will not consist of a single program running on a single computer; rather, it will comprise a collection of software and data, operating on a network of hardware resources, and accessible via any user's terminal.

The hardware will consist of a set of SUN work-stations with high-resolution colour monitors, linked by a local area network (LAN) with the Institute's general-purpose VAX computer. Storage for large quasi-static spatial data sets will be on optical disc, to supplement storage on magnetic disc for more frequently changed data, as well as working data sets. A high-resolution electrostatic colour plotter will provide the means for producing plots up to AO size. Figure 6 shows an overview of the supporting hardware for the system; Figure 7 shows the software and data elements.

Networking software, together with windowing protocols (x-windows) will enable a user at a work-station to manage multiple processes on work-stations and the VAX computer at the same time. Other users with ordinary terminals or networked PCs will have access to only one process at a time, but on any appropriate computer.

A number of software packages are being installed to handle the major tasks of cataloguing information of various kinds, and manipulating spatial data. The aim is to avoid writing software which simply duplicates already-available packages. Extensions to these packages will be written or commissioned as required.

The thesaurus developed by the Commonwealth Agricultural Bureau (CAB) will be used as the basic set of keywords for cataloguing data. Other keywords will be added as needed, particularly to suit the needs for cataloguing programs.

The CARTONET/PHOTONET package, developed in the Geography Department at Edinburgh University, has been installed to provide cataloguing facilities for all spatial data sets, including those in non-computer-readable form (maps and aerial photographs). This program stores bibliographic data in a standard form (UKMARC) so that records may be exchanged with other institutions. A user will be able to search the catalogue for data sets within a selected geographical area, which satisfy specified content criteria.

The ORACLE relational data base management system (RDBMS) holds the Institute's extensive soils inventory data set,

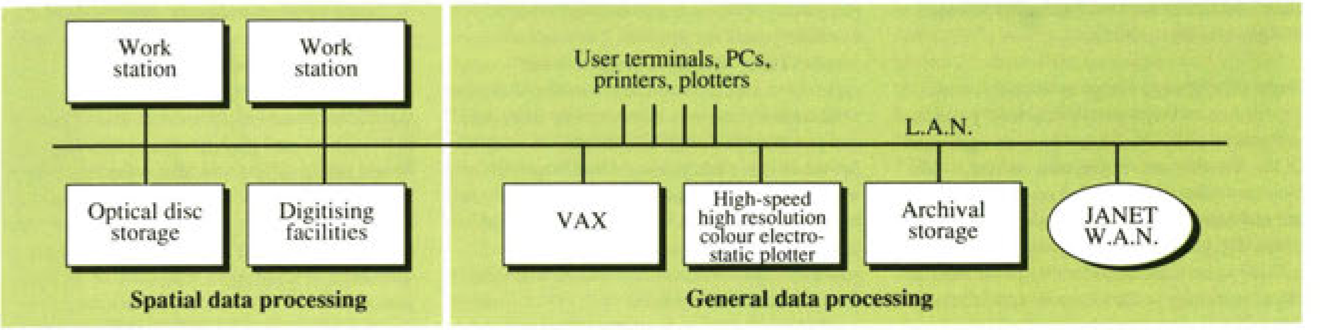


Figure 6. Hardware to support a land-use modelling and information system.

comprising attributes of soils sampled at intervals of 5 km across the national grid. All tabular data are held under ORACLE, and spatially located data will also be catalogued under CARTONET.

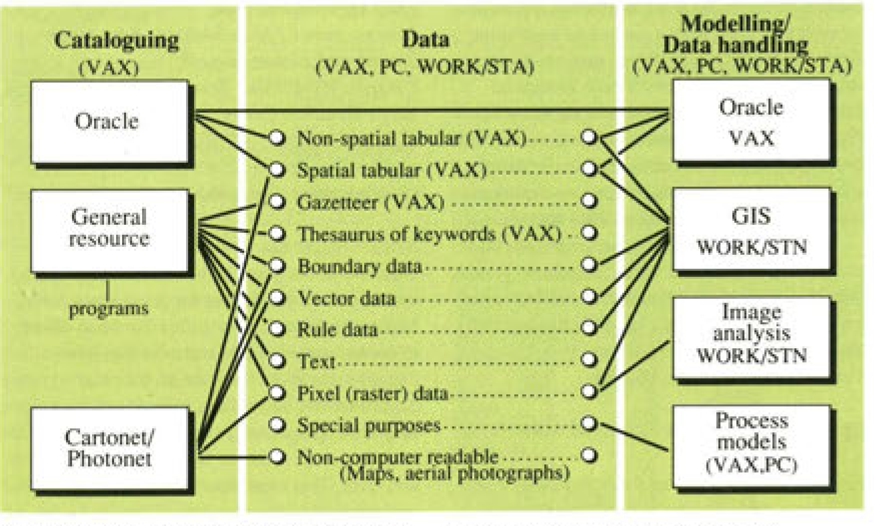


Figure 7. Software and data for the information and modelling system.

The principal software for manipulating spatial data will comprise Geographic Information System (GIS) and Image Analysis packages, executing in the work-stations. The aim is to have a single GIS package (possibly PAMAP) and a single image-analysis package (possibly ERDAS). An essential requirement for the GIS package is the facility to perform any desired computations on the corresponding pixels associated with two or more spatial data sets, at each point within the geographical area being considered, thereby generating a new spatial data set. Such computations define models of physical, biological or socio-economic aspects of the land and its use. The GIS package then serves to manage the details of storing, accessing and presenting the data, leaving model specification and implementation proper to the user. The ability to generate and use digital elevation models is also essential.

The PAMAP package as it stands appears to offer most of the required facilities. Negotiations are being conducted with the developers of the package (PAMAP Graphics Ltd., a Canadian company) to enable the full range of required modelling capabilities to be implemented. These facilities will then enable staff to develop models pertaining to any geographical extent from a small unit such as a farm, to the whole of Scotland, limited only by the availability of data of the required scale and precision. Models which have no spatial component (such as those describing chemical and biological processes) will stand alone, as independent programs.

Data sets for Scotland, relevant to the modelling work of the Institute, are being assembled. These include:

- soils (both national inventory point samples and boundary data)
- land cover (boundary data)
- topography
- political and statutory boundaries
- climate
- roads and rivers
- farms census data
- place names

In order to bring the various elements together, and provide comprehensive assistance to the user, a program has been designed to serve as a high-level catalogue of data programs and information about data-manipulation procedures. This will include a gazetteer.

Contact name: **Chris Osman**

Land suitability for the disposal of sewage sludges and farm slurries

Disposal of sewage sludge to the sea is now regarded as environmentally unfriendly and is likely to be phased out over the next eight years. Of the few alternatives disposal on land is the most cost-effective. Disposal on landfill sites and in forestry plantations are also viable alternatives. The amount of sewage disposed on land is likely to increase considerably in the next few years, especially in the Glasgow and Edinburgh areas. Farms with intensive livestock- rearing units, or where the wintering of cattle is practised, often have to store large volumes of slurry until spreading conditions are suitable. In 1989, Council Directive 86/278/EEC, concerned with protection of the environment and in particular of the soil when sewage sludge is used in agriculture, took effect. It considers the agronomic value of sewage sludge but recognizes the possible deleterious effect of heavy metals on plant growth and for human nutrition. The Directive sets maximum permissible values for the concentrations of heavy metals in soil (including Cd, Cu, Ni, Pb, Zn, Hg and Cr). It is proposed either to set maximum quantities for the amounts of sludge used per year (expressed in tonnes of dry matter per unit area per year) while observing limit values for heavy metal concentration in sludge, or to ensure that limit values for the quantities of heavy metals that can be added to the soil on the basis of a 10-year average are not exceeded. Also, up-to-date records must be kept on quantities of sludge produced, quantities supplied for agricultural use, composition and properties of sludge, type of treatment carried out, recipients of the sludge and locations where the sludge is applied.

Also in 1989 the Code of Practice for Agricultural Use of Sewage Sludge was published, and complements the Sludge (Use in Agriculture) Regulations 1989, which enforces the provisions of the above EC Directive.

A number of factors pertaining to site conditions, soil physical and soil chemical characteristics, together with recent literature, have been considered. It has been decided to base the suitability classification on three categories of suitability or degrees of risk, plus a category for land unsuitable or of unacceptable risk. The factor assessed in the category of least suitability or greatest risk will determine the overall rating. Some of the factors are easily assessed in the field or are easily quantifiable, whilst others are based on interpretative systems. A number of the factors and assessments are already well proven in the Land Capability Classification for Agriculture. The guidelines will be underlain by a number of assumptions pertaining to management, economic and logistical considerations.

Site factors such as slope, rockiness, frequency of flooding and potential for run-off into waterways must be considered. Soil physical factors such as bulk density, texture, porosity and drainage status affect the ability of a soil to accept the water contained in wastes (frequently 93%), and also to tolerate farm machinery used for disposal. Estimates of wetness class, relation of retained water capacity to particle-size class, number of days of field capacity, number of machinery work days and poaching risk/trafficability may be adapted for use in this classification. Direct injection of wastes into the soil may be made mandatory in order to reduce odour nuisance and potential spread of pathogens, in which case slope, rockiness, soil stoniness and texture will affect the special machinery used.

Potentially toxic elements (PTEs) and soil pH are the main soil chemical factors to be considered. Soil pH affects the availability of elements to plants; crop damage is more likely to occur on acid soils. The Code of Practice sets limits for the potentially toxic elements at different pH levels Land with a soil pH less than 5 must not be used for sludge application and is classed as unsuitable. Land where the soil content of one or more of these elements already exceeds this limit is also classed as unsuitable. Work in PU3 RO 021810 will provide information on the movement of PTEs in a range of Scottish soil series of agronomic significance. The sampling programme continued in 1989-90. It is hoped that metal concentrations in sludges will decrease as industrial waste pre-treatments and new production techniques are introduced.

The possibility of using the microcomputer programme Automated Land Evaluation System (ALES) which is based on FAO land evaluation methodology, and further develop and test the classification, is to be investigated.

Contact name: **Andrew Hipkin**

Upland sheep systems - Bronydd Mawr

Nineteen eighty nine was the first year of a new three-year project to investigate the effects of level of nitrogen (N) fertilizer applied to grass/clover swards. Another innovation is that lambs are now finished within the experiment as opposed to previous phases which have produced store lambs. Two levels of nitrogen (200 kg N/ha/year in four dressings (N200) and 50 kg N/ha/year as a single spring dressing (N50)) are being run in combination with four stocking rates (18, 15, 12 and 9 ewes with lambs/ha) in five treatments (N200/18, N200/15, N50/15, N50/12 and N50/9). After weaning, lambs are retained within treatment plots but on separately fenced areas. Sward height on the grazing areas for ewes are given the highest priority; any area surplus to the separate requirements of ewes and lambs is conserved for silage. Lambs are removed at a finishing live weight of 34 kg; all unfinished lambs are removed 10 weeks after weaning.

An estimate of clover content in April showed no significant differences between treatments or replicates. Large differences in clover content of the N200 and N50 swards were measured in August (1510 vs. 4133 growing points/m^2); however, because of large differences between replicates these are significantly different only at the 10% level of probability.

Some between-treatment differences in sward height did occur during the season, partly due to difficulty of management during a droughty year. However, there were no significant treatment differences in estimates of individual animal performance to weaning. Sward height differences after weaning resulted in the ewes on the N50/15 treatment being in a significantly lower condition than those on other treatments at mating. However, there was no difference in subsequent reproductive performance. There were no significant treatment differences in the percentage of lambs finished.

Early season differences in rates of herbage production resulted in treatment differences in silage yield (kg DM/ha) and in the proportion of the total area pasture closed for silage. These two factors led to very highly significant differences in yield of silage per ewe; N50/9 (266.5 kg DM/ewe) produced most and N50/15 (65.9 kg DM/ewe) least.

Contact names: **Alan Sibbald, John Roger Jones* and Elaine James***

* IGAP, Welsh Plant Breeding Station, Bronydd Mawr Research Centre

Grazing control experiment

Surface height has proven to be a reliable indicator of the capacity of continuously grazed swards to provide fodder for the grazing animal. Many experiments now adjust the stock density to control sward height and maintain this capacity relatively constant. In the past, experimenters have either controlled sward height using decision rules and labour-intensive sward measurements or have resorted to trial and error. This experiment measured the performance of simpler sets of decision rules. One set changed stock density by a percentage of the current density (Percentage method) whilst a second required changes that depended on the concentration of mass near the surface sward and an estimate of the rate of consumption of grass by the animals (Absolute method). A third set was similar to the second but with the addition of a growth anticipation factor (GAF) which allowed foreseen changes in the growth rate to be pre-empted by the experimenter. The decision rules were tested on an upland sward and a reseeded heather hill using sheep. The target sward height was 4 cm and sward measurements and stock changes were made weekly.

The Percentage method failed to control sward height of the upland sward, whereas both variants of the Absolute method performed acceptably, except during periods of rapid acceleration of growth (Figure 1). The Absolute method also achieved better control of the sward height of the hill reseed during the spring. During much of the summer, this sward was seriously droughted, limiting the control that could be achieved. The use of the growth anticipation factor led to a marginal improvement in the control achieved at both sites.

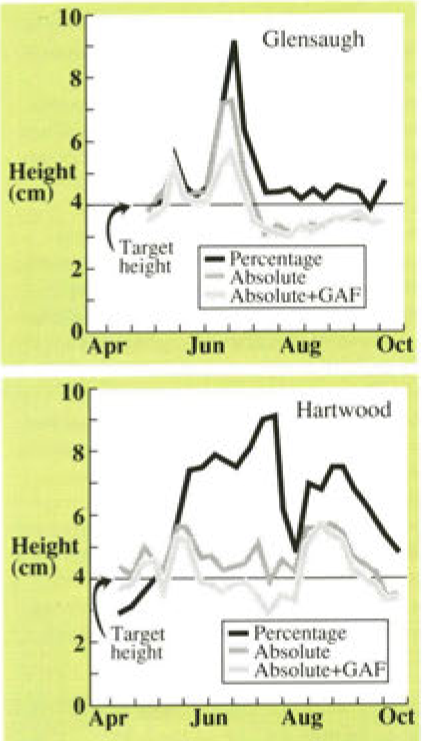


Figure 1. The effect of using three different sets of decision rules to control sward height at Glensaugh and Hartwood.

It is expected that the Absolute method will provide an adequate degree of control for many experiments. Where sward height must be very tightly controlled, more frequent sward height measurements/stock changes may prove more effective than the use of a growth anticipation factor.

Contact name: **Nick Hutchings**

The establishment phase of silvopastoral production systems

In common with other sites in the UK a large-scale silvopastoral experiment was set up in 1988 as a basis for evaluating the establishment phase and as a long-term resource for silvopastoral research. Three tree species (sycamore (SY), hybrid larch (HL), and Scots pine (SP)) are used over a range of planting densities (100, 200, 400 and 2500 stems/ha). The latter is a fenced forest control with no grazing; lower densities are on grazed plots, and trees are individually protected by shelters. An agricultural control (AG) with grazing and no trees is also included. Ten treatment combinations, replicated three times, are used as follows: AG, SY100, SY400, SY2500, HL100, HL200, HL400, HL2500, SP400 and SP2500. The sycamore treatments and the agricultural control are in common with the other sites in the UK.

There are no significant treatment differences in sward height during the growing season, though, in late season, swards were lower than the required seasonal sward height profile as a consequence of a drought in June and July. Stocking rates were reduced to core animal numbers (12.5 ewes plus lambs/ha) for much of the season and supplementary feed was supplied to these animals throughout July. There were no significant treatment differences in ewe or lamb live weights throughout the season. Lamb live weights at weaning and ewe pre-mating live weights from 1989 compare well with those from 1988.

Following the replacement of trees lost in 1988, survival in 1989, based on data collected by the Forestry Commission (Figure 2), was good with an overall mean of 86%, though the wide-spaced treatments had significantly lower survival levels than the forestry controls (81.7% vs. 94.6%, $P<0.01$). This is probably due to the activities of the grazing animals. However, there appears to be a differential effect of tree density and tree species on survival rates (Table 1).

		Tree species			
		HL	SY	SP	Mean
Planting density (stems/ha)	100	62.0	92.7	-	77.3
	200	74.3	-	-	74.3
	400	83.3	98.3	79.3	87.0
	2500	94.7	98.7	90.3	94.6
Mean		78.6	96.6	84.8	86.0

Table 1. Survival (% age) of trees in 1989 (Data provided by the Forestry Commission).

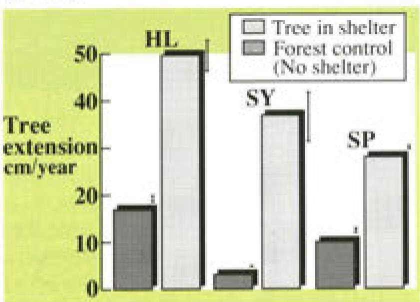


Figure 2. Height extension rate of trees in 1989 (Data provided by the Forestry Commission).

Hybrid larch shows a reducing rate of survival with reducing tree density while sycamore shows much less of a trend. This could indicate a positive preference of animals for hybrid larch, resulting in browsing damage to exposed roots by sheep or rabbits, or a greater resistance of sycamore to similar levels of browsing damage. It might also indicate a greater resistance of sycamore to non-selective trampling damage of exposed roots or soil compaction around trees. The reduced survival of hybrid larch with reducing tree density confirms previous observations that the sheep:tree ratio in establishing agroforestry systems may be an important factor in tree survival. Further measurements will be made in an attempt to identify the apparent differences in the responses of sycamore and hybrid larch.

Tree extension rates were good, trees of all species in shelters extending significantly faster in 1989 than the unprotected trees in the forest controls (41.8 cm/annum vs. 10.3 cm/year, $p<0.001$). Extension rates in shelters of hybrid larch (49.7 cm/year±3.27) were significantly greater ($P<0.05$) than sycamore (36.9 cm/year ±5.22) and sycamore significantly greater than Scots pine (28.0 cm/annum ±0.37).

Contact names: **Alan Sibbald, Chris Nixon***

* Forestry Commission

Development of methods of data handling for a national Geographic Information System (GIS)

Geographic Information Systems have shown themselves to be important tools for manipulating geographical and other spatially related datasets. Current work has developed at a regional level and the extension to the national scale is requiring further research and development in handling of the large datasets involved.

In principle, working with datasets at the national level has a number of advantages. For instance, there are no artificial boundaries dividing datasets into manageable portions. These can cause problems when making an assessment that crosses such a boundary. Also, data management should be simpler as all data relating to a given parameter are held as a single unit.

For such an approach to be feasible a data structure that can allow GIS manipulations without excessive overheads is needed. The chosen data structure, the quadtree, has been extensively used for GIS in both research and commercial systems. This structure is created by dividing the data into quadrants and then continuing to divide the regions created into quadrants until each region can be represented by only one data value. The regions created by this method are in a range of sizes that depends on the complexity of the original data. Only the information on the position of the regions and their data value is kept. This creates a structure that has the advantage of requiring considerably less storage than the original raster data format, while maintaining the required flexibility for calculation.

A number of different approaches to storing and handling quadtree data have been investigated and a system has been designed to meet the special requirements of large datasets. Developments so far have been in the creation of an appropriate file structure and the development of the algorithms to extract data from this structure efficiently. This prototype demonstrates the feasibility of the approach used and will provide the central core of the final system. The prototype system is currently being used to investigate the limits of the available computer systems and the design of file-handling algorithms for more advanced processing.

The system under development is based on a quadtree structure with a minimum region size of 25 m square. Initial investigations with the datasets from the national peatland database have shown a reduction to approximately 3% of the original storage requirements. Tests of simple GIS procedures to overlay datasets held in this format have shown that considerable time savings are possible when compared with the currently available facilities.

Alongside the development of the system for handling the national datasets there is a programme of data collection underway building on the foundations of the GIS datasets already produced for the north east of Scotland. Contact name: **Alistair Law**

Impact of changes in land use in scenic upland areas on vegetation, wildlife and landscape

The changes in vegetation composition and structure on hillsides following the short-, medium- and long-term removal/reduction of sheep are being studied at 11 sites in eastern, western and northern Scotland. These data are being compared with changes in indices of abundance of key wildlife species. Each site has an 'experimental' area where sheep were reduced/removed between one and 20 years ago and a 'control' area which is still grazed by livestock. Four or five main vegetation types have been defined at each site (for example grassland, flush, wet/dry heath). The sampling procedure involves measuring the height, cover and layering of individual species and the main vertical strata within each of these vegetation units. The number of sheep, deer, lagomorph and grouse droppings in the standing crop of dung were counted and signs of vole (*Microtus agrostis*) activity (runs, food caches, nests and droppings) recorded on a presence/absence basis. This year measurements were taken once at each site between late May and early July. Vole assessments were repeated on six of the sites in late autumn.

Comparison of sheep dung counts showed that there was significantly less sheep dung on the reduced versus control areas at all but two of the sites. Amounts of red deer (*Cervus elaphus*) dung were approximately equal to those of sheep on five sites and at three of these locations there was significantly more deer dung on the reduced sheep treatments. Elsewhere deer dung amounts were much lower than sheep dung and no difference between control and reduced was found. This indicates that where deer are already numerous, reduction of sheep numbers is followed by an increase in the utilization of the ground by deer.

At the same five sites where significant amounts of red deer dung were found, virtually no change in vegetation composition or structure was found, even after up to 20 years without sheep grazing. This highlights the ability of wild herbivores, and particularly red deer, to maintain upland sheep grazings in a virtually unchanged state. Repeated burning on parts of four of the sites appears to have produced a similar effect (Figure 3). At two of these with total exclusion of grazing for nearly 30 years, scrub birch, willow and rowan have become established (Figure 3).

On the six sites where amounts of deer dung were low, many types of vegetation have

Figure 3 a (top) At site A where sheep have been kept off the right-hand side of the face for nearly 20 years, vegetation is virtually the same as on the sheep-grazed side to the left due to either continued burning or grazing by red deer. Figure 3b(bottom) In contrast at site B where both sheep and deer have been excluded from the right-hand side of the face for over 20 years, heather cover and height have increased significantly and birch scrub has developed.

responded rapidly to the reduction in sheep numbers (particularly the grasslands and drier dwarf shrub communities). Consistent increases in vegetation height were found, both for individual species and for the main vegetation layers or strata , particularly at the lower levels, for example moss, litter, herb and grass layers (Figure 4).

Furthermore, at these same six sites significantly more signs of vole activity (particularly runs) have been found - even where grazing has only been reduced for one year. The increase in vole sign abundance is positively correlated with increases in overall volume of vegetation; a similar association has been found with voles on a range of grasslands in North America (Birney *et al.*, 1976, Grant *et al.*, 1982). Our results suggest that the volume of vegetation in the lower strata (moss, litter and grass) may be particularly important. Plots with a tussocky structure, and particularly tussocks of tall *Juncus* species, also contained significantly more vole signs than plots without tussocks.

Measurement of the horizontal structure of the vegetation was made by estimating the percentage cover of the main strata combinations. Comparison of the differences between control and reduced areas on different sites suggests that there is a broad trend from homogeneous grass swards at high grazing levels, to increasing heterogeneity and fragmentation as dwarf shrub communities increase their cover, until with very low levels of grazing a homogeneous sward is again attained, this time dominated by dwarf shrubs.

However, it appears that some changes in this horizontal heterogeneity and the cover of individual species are being underestimated because of the way the sampling was stratified within broad vegetation types. Sampling during the second field season will therefore concentrate on quantifying changes in vegetation patch size at a larger scale. Vole and dung measurements will also be repeated, and it is intended to quantify the repeatability and accuracy of the visual estimation methods used in measuring vegetation cover and structure. Contact name: **Diane Hope**

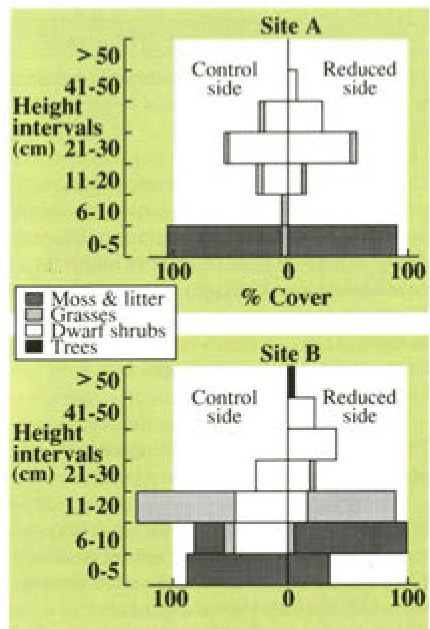


Figure 4. Vegetation profiles for the heaths shown in Figure 3. The profile for site A shows the similarity in the height and cover of vegetation. At site B, dwarf shrubs, moss and litter are taller on the reduced side and there is some tree cover.

References

BIRNEY, E.C., GRANT, W.E. and BAIRD, D.D. 1976. Importance of vegetative cover to cycles of *Microtus* populations. *Ecology*, **57**, 1043-1151.

GRANT, W.E., BIRNEY, E.C., FRENCH, N.R., and SWIFT, D.M. 1982. Structure and productivity of grassland small mammal communities related to grazing-induced changes in vegetative cover. *Journal of Mammalogy*, **63**, 248-260.

Changes in drainage water quality during afforestation of deep peat

Cutbacks in agricultural production in the EC have resulted in afforestation currently being the greatest single land use change taking place in the UK. The impact on the environment is a matter of considerable controversy, and in certain areas of the country, hydrological and hydrochemical effects ascribed to forestry practices can extend for considerable distances downstream. About 90% of all forestry activity in the UK is taking place in Scotland; in 1977-87, 1950 km^2 were planted in Scotland, the majority of which comprised Sitka spruce and lodgepole pine. These species and their admixture are at the focus of arguments concerning the presently-arrested afforestation of the deep peats of Caithness and Sutherland, in the so-called 'Flow Country'.

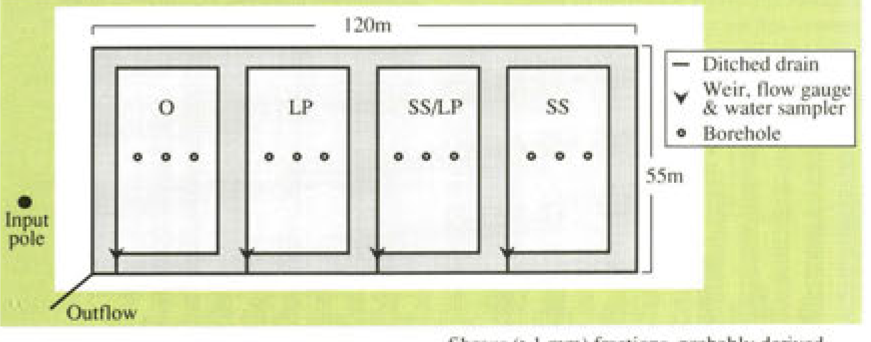


Figure 1. Plot layout at Bad a' Cheo. Four randomized replicates. Planted plots: 20 x 9 trees at 2 m x 2 m spacing.

In the 1988-89 Annual Report, a preliminary description was given of a collaborative experiment with the Forestry Commission, Northern Research Station, aimed at quantifying various effects of the afforestation of deep peat at Bad a' Cheo, Rumster Forest, Caithness (see plot layout in Figure 1), part of the famous Causey Mire. Since that report was written, initial effects of site preparation have been observed, such as sediment losses and increased

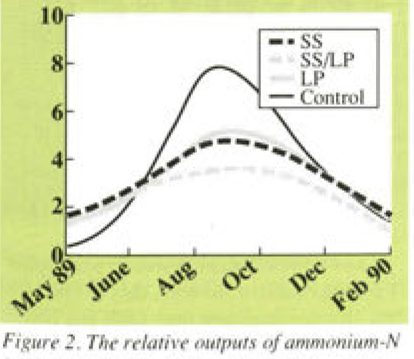


Figure 2. The relative outputs of ammonium-N in plot drainage waters.

mineralization of C, N, and S. The hydrology of the plots has changed dramatically during the interval, the ploughing of the afforested plots allowing an accelerated water drawdown compared with the control plots, drainage flowrates from the ploughed plots being nearly twice those from the controls. After the dry summer of 1989, the flowrate pattern switched, with the drainage from the controls becoming twice that of the planted plots. Planting was carried out in spring 1989, accompanied by standard hand-applied fertilizer, equivalent to 60 kg P/ha on the Sitka/lodgepole mixture plots, 60 kg P/ha and 100 kg K/ha on the pure Sitka (SS) plots, and zero on the pure lodgepole (LP) and control plots.

The most visually obvious effect of the cultivation of the peat, even in the control areas with a simple perimeter drain, has been seen in the increased colour and turbidity of the drainage waters. This applies to the control as well as to the planted plots. FC data for suspended sediment yields from the outlet weirs in the planted plots were almost twice those from the control plots. Samples from the first sediment collection have a high proportion of fibrous (>1 mm) fractions, probably derived from large particulate peat caused by disturbance during site cultivation. The sediments present in water samples comprise mixtures of humified materials, with polysaccharide, lignin, peptide and long-chain hydrocarbon components. The yields of humic substances from the drainage waters are different from those in the water extraction of the peat, with a greater proportion of the organic acids in a truly soluble form.

The Bad a' Cheo peats are relatively high in both N (1.9-2.2%) and S (1.1-1.6%) compared to other blanket bogs; the S content reflects the

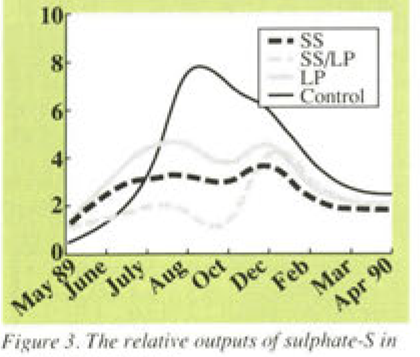


Figure 3. The relative outputs of sulphate-S in plot drainage waters.

large marine influence on the inputs to the bog, rather than any anthropogenic effect. Flow-weighted output of ammonium ion in the drainage water (Figure 2) shows that the control output lagged behind the planted plots up to the flow switch discussed above, and this was accompanied by a peak of N mineralization and ammonium production in August-September 1989, in which the production from the control plot outstripped its planted counterparts. In the early part of 1990, outputs of ammonium-N were remarkably similar from all of the plots. To maintain a relative picture of N-release, the content of organic N in the drainage waters varied between 2-3 times greater than the ammonium ion concentrations, and nitrate ion was rarely encountered in concentrations greater than one-tenth of the ammonium.

The behaviour observed for S (Figure 3) is that two maximal outputs can be observed. In the planted plots, the first rewetting after the drying effect of summer 1989 generated an S mineralization at the end of July, followed by a definite decline in output during September-October. The control plot lagged behind in its production of S, until late August-September,

The appearance of ochre in the drains is typical of mobilization processes accompanying the drainage of deep peat.

probably a reflection of the lower hydraulic conductivity of the mass of the block of unploughed peat, but the total production appears to be greater than the planted plots. At December-January, a very definite peak production of sulphate in the mixed plot is accompanied by similar, less evident S-mineralization in the other planted plots and the control.

Future work at the Bad a' Cheo site will concentrate on quantifying the rates of mineralization of C, N and S, in order to construct budgets for these elements, in addition to the overall hydrochemical budgets. Detailed reactions of the system to storm inputs will also be studied.

Contact names: **Hamish Anderson, John Miller**

Enhanced atmospheric interception by Sitka spruce

The size and structure of tree canopies ensure that they are efficient sinks for atmospheric pollutants, generally leading to increased rates of deposition due to the turbulence induced by canopies. Hydrological and hydrochemical data have been collected from several sites with mature coniferous trees in central Scotland, including Sitka spruce (SS), Norway spruce (NS), European larch (EL) and Scots pine (SP), all more than 35 years old, at sites at

	Sitka spruce	Norway spruce
Bark		
young	0.080	0.079
old	0.046	0.044
Balquhidder		
1st year needles	0.137	0.090
>2nd year needles	0.124	0.096
Loch Ard (Kelty)		
1st year needles	0.180	0.089
2nd year needles	0.166	0.108
>2nd year needles	0.180	0.106
Loch Ard (Chon)		
1st year needles	0.149	0.098
2nd year needles	0.148	0.107
>2nd year needles	0.136	0.120

Table 1. Concentration of S in bark and foliage.

Balquhidder and Loch Ard (Kelty and Chon). Examination of sulphur chemistry in inputs and tree throughfall showed higher concentrations of sulphate-S under Sitka spruce compared to all other species. In fact throughfall + streamflow amounts under Sitka spruce are greater than recommended critical loads to these soils of 8-16 kg/ha/year.

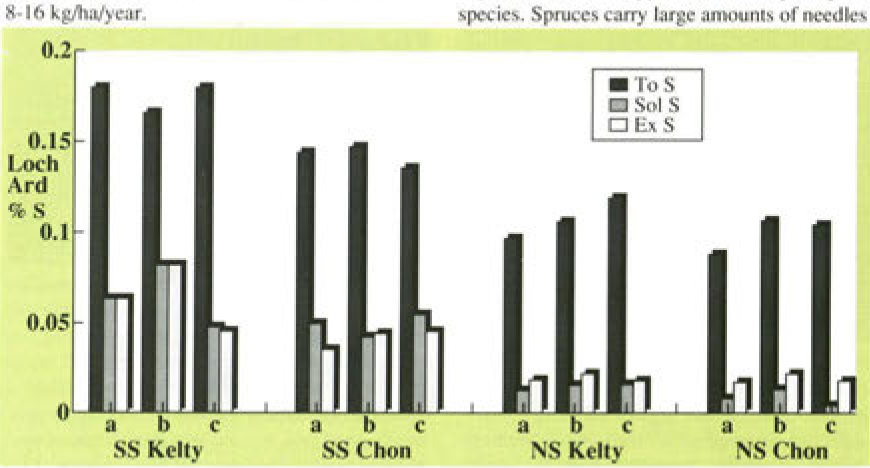


Figure 4. Water-soluble, extractable and total S in spruce needles

At Loch Ard additional sulphur is required to balance inputs and throughputs, either through increased interception of wet and/or dry deposition, enhanced leaching of foliage-sulphur or some combination of all factors. Calculations using chloride ratios for data collected in interception gauges with an inert capture surface could only account for an additional 2-3 kgS/ha/year as intercepted wet deposition. Analysis of tree components for total sulphur showed that although there were no species differences for some components, for example bark, there were considerably higher concentrations in Sitka spruce foliage of all ages (Table 1). Needle litter, however, showed little species differences in total sulphur, and generally spruce needle litter samples were all in the range 0.09-0.10%.

To satisfy amino–acid/protein requirements, the S/N ratio (Gram atoms) should be 0.028-0.030 and this was confirmed by amino-acid analysis of spruce needles and needle litter which were all in range 0.026-0.029. However, calculations of S/N ratios in foliage from both spruce species showed excess sulphate in Sitka spruce, a finding confirmed by the determination of both water-soluble and extractable (0.01 M NaCl) sulphate (Figure 4).

		Sitka spruce	Norway spruce
		µeq S/l	
Throughfall	summer	129.5	85.9
	winter	179.7	94.1
		kg/ha/0.5 years	
Throughfall + stemflow	summer	13.0	8.0
	winter	23.2	14.1

Table 2. Concentrations and amounts of S in Sitka and Norway spruce throughfall (crown–drip).

Further examination of the hydrochemical data also suggests a seasonal pattern in sulphur behaviour, particularly higher winter concentrations and amounts for Sitka compared with Norway spruce (Table 2). A possible mechanism is interception of sulphur as ammonium sulphate aerosol formed by reactions between NH_3 and SO_2. These aerosols would be effectively scavenged by forest canopies and the efficiency of collection would depend on size, canopy structure and perhaps species. Spruces carry large amounts of needles compared to other studied species, with Sitka bearing more current, 1st year needles which would form the outer structure of the conical canopy (Table 3).

Examination of data from an extended range of sites across Scotland under different SO_2 loadings, all forested with mature Sitka, indicated that the highest S/N ratio in needles was found in the area with the highest SO_2 levels, and that the greatest enhancement of throughfall sulphate compared to inputs occurred in sites with the highest foliage S/N ratio.

	kg/ha			
	SS	NS	EL	SP
1st year needles	4.8	2.8	0.2	2.8
2nd year needles	4.7	5.1	0.5	3.1
>2nd year needles	12.2	13.6	1.0	2.7
Total needles	21.7	21.5	1.7	9.6

Table 3. Interspecies comparisons of outer and inner canopy components.

These observations strongly suggest that sulphate accumulates on Sitka spruce foliage mainly by enhanced interception of dry deposition.

Contact names: **JohnMiller, Hamish Anderson**

The effects of source area limestone application on stream chemistry

The Kelty stream system, tributaries of the River Forth near Aberfoyle in central Scotland, was identified during the Surface Water Acidification Programme (SWAP) as an area which historically was capable of sustaining a viable fish population, but with current stream conditions now unsuitable for fish survival. Stream pH values are now in the range 4.1-4.3 (50-70 µeq H/l) with calcium concentrations of 0.5-0.7 ppm (25-35 µeq Ca/l). The stream catchment soils are predominantly peats and peaty gleys developed on mica-schists and most of the catchments areas (>70%) are mature forest, mainly Sitka spruce planted between 1950 and 1955, with some new planting (P86) in the upper catchments.

Heavy rates of limestone (10 t/ha), as an amelioration treatment were applied to the source areas of two acidified streams A & B (SA in Figure 5) in September 1988. Stage height, pH, temperature and conductivity were continuously monitored at G1 and G2 (Figure 5), along with daily composite sampling for complete chemical analysis. The combined outflow is being monitored at G3 by the Forth River Purification Board (FRPB), and the Freshwater Fisheries Laboratory (FFL) has carried out surveys of stream biota at G3-5, along with periodic stream hydrochemical monitoring.

Stream conditions from September 1988 to spring 1990 improved with calcium concentrations now 1.0-1.2 ppm (50-60 µeq Ca/l) and raised pH values of 4.5-4.6 (25-30 µeq H/l), but during periods of high streamflow during rainfall events (average annual rainfall is around 2500 mm), the conditions generally declined with reduced calcium concentrations and lowered stream pH values. Periodic vegetation and soil surveys and sampling of the treated source areas have indicated no major changes in the vegetation to date and that there has been an appreciable incorporation of the limestone into the upper organic 10 cm of the soil profile. Exchangeable calcium is now 30-50 meq/100 g in the upper 5 cm of the treated soils compared to 5-10 meq/100 g in the soils of adjacent control areas. There are also evidence that although if the limestone is placed directly into the streams it will be completely dissolved in 150-180 days, there are still appreciable amounts of limestone on the vegetation/soil surface available for dissolution even after 18 months.

A further treatment of limestone was applied to the source areas of stream A only in May 1990. This fine limestone flour (90% less than 75 microns) was applied to selected stream source areas by air (MD Air Services helicopter) at 10 t/ha to 15 ha in a total catchment area of about 150 ha. The aim is to raise and maintain calcium concentrations to above 2 ppm and pH values to >5.5; even during storm events, these conditions should ensure fish survival. Current predictions from a survey of published data by the North of Scotland Hydro-Electric Board

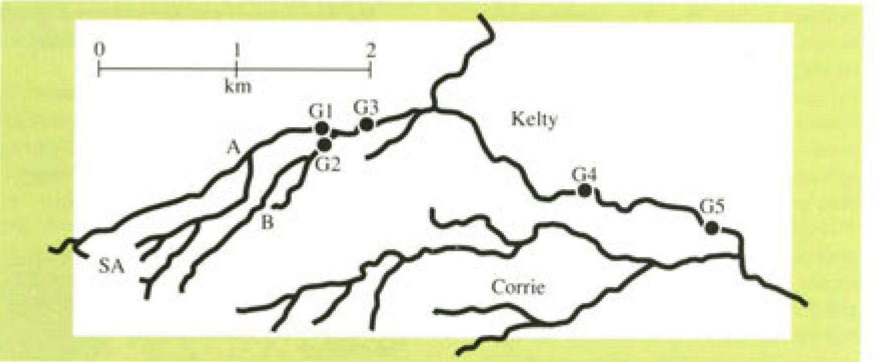


Figure 5. Kelty catchment.

(NSHEB) suggested that applications at this rate to the percentages of the catchment area would improve stream conditions for 3-5 years.

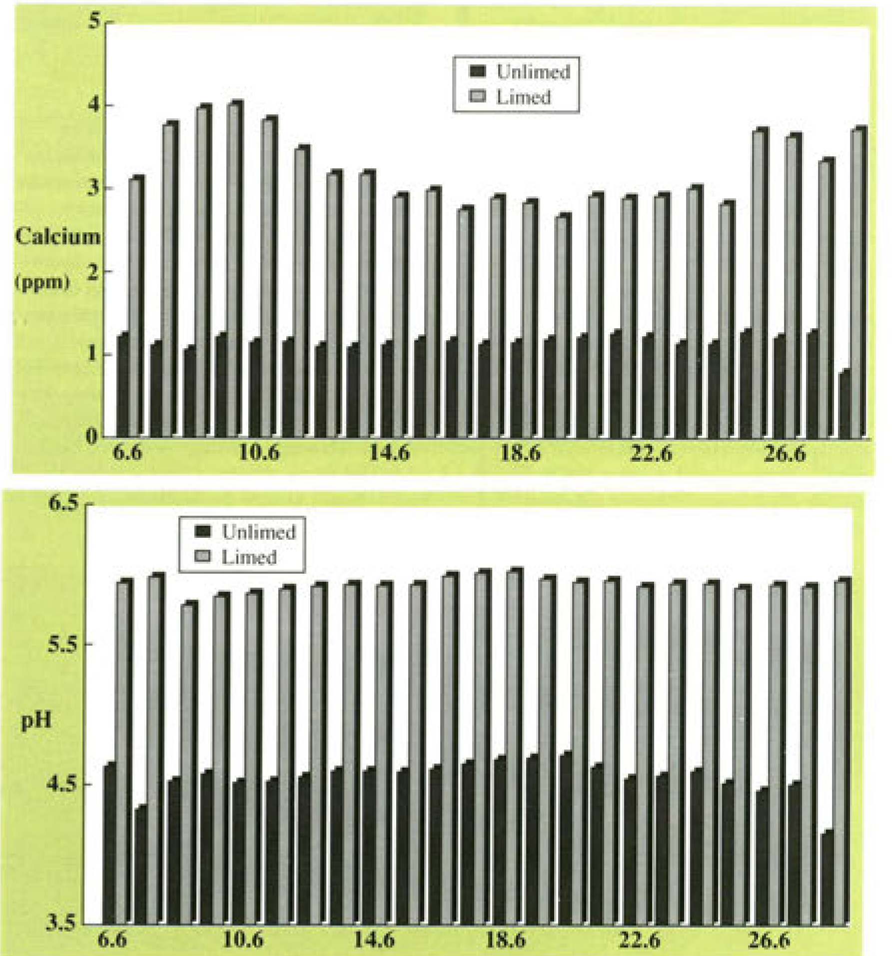


Figure 6 (a) top (b) below. Comparative hydrochemistry in June 1990 between limed and unlimed streams

Stream hydrochemistry to date is satisfactory. Figure 6 shows a typical run of data for June 1990, there being one major rainfall event on the 6th followed by a dry spell and subsequently some further rainfall events on the 24th and 26th. Comparison of some stream chemistries between stream A and stream B shows that calcium concentrations have now been increased from around 1 ppm to 3-4 ppm Ca (150-200 µeq Ca/l) (Figure 6(a)) and that pH values are now greater than 5.5 (<5 µeq H/l) (Figure 6(b)). To date there has been no evidence of dramatic reductions in concentrations during rain-fall events; whereas conditions in stream B do decline at high flow, those in stream A improve, with increased calcium conditions at higher flows.

The hydrochemistry of the combined streams A and B at their confluence at G3 are also satisfactory (Table 4) with calcium concentrations being maintained above 2 ppm with pH values of 5.4-5.6 under different flow conditions.

If these conditions are maintained at G3-G5, then experiments in fish survival, including egg hatching and fish placement, will be carried out by FFL in late 1990/early 1991. Monitoring at G5 will also allow the identification of any migration of fish stocks from the Corrie stream system into the Kelty stream (Figure 5). Outflow measurements at the gauging station G3, along with measured input and output hydrochemistry, will allow the calculation of annual calcium budgets to assess the long-term effectiveness of this amelioration.

	mg/l(ppm)
Ca	2.9-3.1
Na	3.7-4.2
K	0.2-0.4
Mg	0.4-0.5
Fe	0.5-0.7
Mn	0.05-0.06
Al	0.07-0.08
Si	0.5-0.6
SO_4-S	1.6-1.8
Cl	5.0-6.0
pH	5.4-5.6

Table 4. Stream chemistry of combined streams A+B and G3.

Periodic vegetation and soil sampling will continue in order to assess any imposed changes in vegetation structure, including tree foliar analysis of the limited treated source areas which have recently-planted trees.

Contact names: **John Miller, Hamish Anderson**

Cycling of caesium in organic soils

Very little movement of ^{134}caesium occurred down the profile of peaty podzols over the period of 18 months after soil application on both an improved reseeded grass/clover site and on a rough grazing site supporting indigenous grasses and heather (Table 5). Only a small proportion of the caesium behaved as though it were exchangeable as judged by chemical extractability. About 2% of the caesium was found in the above-ground plant material harvested from the reseeded site during the 18 month period and there was no discernable progressive change in availability with time.

	Peaty podzol	
	Improved pasture	Rough grazing
Root matt (0-6cm)	6.0	7.1
0-3cm	54.3	40.8
3-6cm	36.8	50.0
6-9cm	2.1	1.9
9-12cm	0.4	0.2
>12 cm	0.4	0.0

Table 5. Distribution (%) of ^{134}Cs activity in 10x10cm soil blocks 15 months after application to the field at 3cm depth.

Considerable differences in the extractability of ^{134}caesium were observed for the peaty podzol soil compared with low-ash peat: less than 15% of the caesium in the peaty podzol was released by extraction with 1M ammonium acetate, whereas all the caesium was released from the peat by this reagent. One major difference between the soils is the relatively higher mineral matter content of the peaty podzol.

The results support the concept that initially most of the added caesium occupies exchange sites on the organic matter from which it would be readily available to plants. With time the caesium would gradually move to less available sites which may include fixed forms on soil minerals and organic matter.
Contact names: **Martin Cheshire, Charles Shand**

Atmospheric deposition of lead on Scottish hill and upland soils

There is a growing public concern about the introduction of heavy metals into the environment, in particular toxic elements such as lead and mercury. It is well known that roadside soils and vegetation have high concentrations of lead derived from petrol additives but it is not so widely appreciated that remote upland soils have enhanced surface concentrations of lead, up to 500 ppm in some instances. As soils sampled in the 1940s show this effect, it is not attributable solely to the use of lead petrol additives but probably results from the heavy atmospheric pollution widely experienced during the industrial era.

The lead isotopic composition varies in nature according to the origin of the lead and this is being used to try to differentiate between the various components of atmospheric inputs, in particular between anthropogenic and geochemical sources. Three small plots (c. 1.5m x 1.5m) have been set up at the Glensaugh Research Station. Two plots are at a distance from the road, one on the reseeded area and one on indigenous vegetation high on the hill, but the third is immediately beside the road on the climb to the Cairn o' Mount. This is a road with relatively low traffic levels but with hard-working vehicles climbing the hill. Lead, taken from grass in the roadside plot, had a very low $^{206}Pb/^{207}Pb$ ratio of 1.09 which is about the same as the lead collected in rain-water in remote areas of Scotland. This would suggest that these two leads have the same origin, that is that lead in rain-water in remote areas has its origin in petrol additives and is carried over a long range in the atmosphere. This input of anthropogenic lead of petrol origin is continuous. It is noteworthy, however, that rain-water collected at Hartwood in the Central Valley has a higher isotope ratio which indicates other sources of lead inputs. As the rain-water also contained particulate matter with a high concentration of iron it is reasonable to deduce that this other source of lead is industrial, possibly the Ravenscraig Steel Works.

Waters	Rainwater	Stream
Cairngorms	1.08-1.10	
Chon	1.09-1.11	1.140
Sourhope	1.11	1.164
Hartwood	1.13	
Soils	Surface	Deep
Listonshiels No. 3	1.147	1.175
Cairnsmore of Fleet No. 4	1.160	1.202
Easter Cringate No. 2	1.154	1.166

Table 6. Lead isotope ratios ($^{206}Pb/^{207}Pb$) for water and soil samples.

The lead isotope ratios in the surface horizon of three selected profiles, known to have high surface concentrations, are considerably lower than the isotope ratios in deeper horizons. This leads to the conclusion that the surface, organically-bound, lead is of a different, probably anthropogenic, origin than the deeper mineralized lead. This would probably be from industrial sources accumulated over many decades as the soils were sampled before the major increase in the use of lead petrol additives. These profiles will be resampled to check for further reduction in isotope ratios through subsequent deposition of lead from petrol. The three profiles showed different characteristics and it is particularly noticeable that the B horizons in the Easter Cringate No. 2 profile had considerably lower isotope ratios (1.135 to 1.145) than the surface horizon (1.154). This might have resulted from pedological or hydrological processes within the profile and suggests that lead isotope compositions may be used to investigate soil formation processes.

A few stream-water samples have been analysed but the lead concentration is often too low (<5 ppb) for reasonable isotopic analysis to be achieved. In some cases, however, the concentrations are considerably higher (50 ppb) and the isotope ratios (1.14-1.16) are comparable to the ratios in the surface horizons of the three profiles. The data available so far are too limited to draw definite conclusions but certainly the lead in stream water is not the same as in rain-water and must be derived mainly from soils, most probably the highly enriched surface horizon. This suggests that a slow leaching out of soil lead may take place and the lead is not so tightly bound as to be irremovable.
Contact name: **Jeff Bacon**

Nitrogen and phosphorus dynamics in reseeded blanket bog peat

On an area of poorly drained, reseeded blanket bog at Forsinard, Sutherland, total annual dry matter production of grass/clover swards on experimental plots continued to improve following treatment with 5 Mg/ha of ground limestone in November 1988 (Figure 1). In

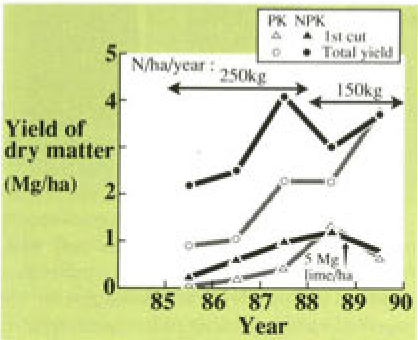


Figure 1. Dry matter yields, Mg/ha, at the first cut and the total yield for grass and grass/clover plots at Forsinard, Sutherland.

contrast, the dry matter production for the first cut taken in June showed a decline compared with the yield in 1988 suggesting that nutrient immobilization stimulated by the application of lime was competing with plant uptake during spring. Yield of grass receiving 75 kg N/ha as urea, 30 kg P as granular superphosphate and 60 kg K as potassium chloride was not significantly

Treatment	1988 NH_4	1988 NO_3	1988 PO_4	1989 NH_4	1989 NO_3	1989 PO_4
PK	0.06	0.02	3.81	0.05	0.04	0.19
NPK	5.35	0.04	9.95*	0.24	0.05	0.30
SE	1.19	0.032	0.80	0.155	0.006	0.013

* Significantly different from PK at $P<0.05$

Table 1. Concentrations, mg/l of NH_4^+ and NO_3^--N and PO_4^{3-}-P in run-off water collected from PK and NPK treated plots at Forsinard in 1988 and 1989 for 4 weeks following fertilizer applications in April.

different from that of grass/clover treated with P and K alone at the same rates. This was largely due to the healthy growth of clover in plots not given N. Current studies of the fate of the fertilizer N applied to these plots have used ^{15}N labelled mineral nitrogen.

For the first 3 years of this experiment a total of 180 kg P/ha were applied as granular superphosphate, but cut herbage accounted for only 14 and 34 kg P/ha on PK and NPK treated plots, respectively. Microbial-P, measured by the chloroform fumigation method, corresponded to 40 kg P/ha in the surface 5cm of the peat and was not influenced by applications of N. This value is greater than the 21 kg P/ha measured in the microbial biomass beneath unfertilized indigenous vegetation. This leaves a considerable proportion of unaccounted fertilizer P.

Concentrations of NH_4^+ in run-off water were low even during the period immediately following applications of 75 kg N/ha as urea (Table 1). Nitrate concentrations were also small indicating yet again that nitrification is not active in this peat. In contrast, phosphate concentrations increased sharply following dressings of 60 kg P/ha in April and were significantly increased by the addition of urea. In spring 1989, only 30 kg P/ha was applied and there was no marked increase in concentrations of phosphate in samples of run-off and no effect of fertilizer-N. In addition to the lower application of P, increased retention of P in the peat may have resulted from the application of lime the previous autumn either directly by chemical combination with calcium or indirectly by immobilization in the microbial biomass.
Contact name: **Berwyn Williams**

Importance of soil protozoa, nematodes and earthworms in the mineralization of nitrogen from soil organic matter

Protozoa and nematodes are the major secondary grazers in the soil and implicated in the release of mineralized nitrogen. The study of the environmental factors in the soil influencing the release of nitrogen by protozoa has been extended to include the effect of nitrogen-deficient bacterial prey. The bacterial cultures were grown initially in a continuous flow culture apparatus where the nutrient content of the whole bacterial population can be carefully controlled. Subsequently, the bacteria were harvested and fed to ciliated protozoa in a mineral salts medium where no bacterial growth was possible. When fed nitrogen-deficient soil bacteria (*Arthrobacter globiformis*) with a nitrogen content of 3.7%, the common soil ciliate (*Colpoda steinii*) did not release any nitrogen for the first 140 hours despite feeding on bacteria from the start of the experiment. After 300 hours, these ciliates had released 0.06mM of (NH_4^+)N when fed nitrogen-deficient, *A. globiformis*.

When *C. steinii* ciliates were fed the same species of bacteria with a larger nitrogen content (9.7%), the protozoan release of (NH_4^+)N occurred immediately and 0.35mM (NH_4^+) was released by 80 hours. Similar attempts to produce nitrogen-deficient populations of another common soil bacterium (*Pseudomonas fluorescens*) failed as these bacteria ceased to grow in nitrogen-limited media. Clearly, in nitrogen-stressed soil environments specific shifts in the bacterial community can occur and the nutrient content of the bacterial prey is an important factor in protozoan recycling of nitrogen. Such, considerations have yet to be incorporated in any simulations of nitrogen transformations in soil.
Contact name: **John Darbyshire**

Interactions between soil enzymes and clay minerals in relation to nitrogen availability in pastures

Excretal returns comprise a valuable source of organic nitrogen which, after enzymatic transformation, can provide plant available N. The enzyme urease, which hydrolyses urea to NH_4^+ and CO_2, plays a major role in this process. The clay mineral components of the soil can adsorb urease with a resulting decrease in enzyme activity. Within the soil system, clay minerals can also adsorb soil organic matter, particularly humic and fulvic acids which usually comprise over 60% of the total organic matter in pastures. Thus within the soil, there are interactions between clay minerals, urease and soil organic matter, but these interactions are poorly understood in relation to an effect on urease activity.

Humic and fulvic acids inhibit the activity of urease, the effect increasing with increasing concentrations of humic substances in solution. This inhibition results from interactions between the humic substances with both the enzyme and the urea substrate. The inhibition of urease activity produced by humic substances decreases with an increase in soil pH and ceases completely above pH 7.0. The inhibition is, therefore, greater in the acidic soils found in upland and marginal areas than in those soils found in the better class of agricultural land. Another consequence of adsorption of urease by

Copper concentration (µg/ml)	Humid acid concentration (µg/ml) 0	10	100
0	0	+7	+11
0.05	71	28	-5
0.10	-88	-86	-11
0.50	-90	89	69

Table 2. Influence of interactions between humic acid with cupric copper ions on urease activities at pH 7.1 expressed as positive (+) or negative (-) effects.

humic substances is that the enzyme is protected from being destroyed by proteolytic enzymes and can thus remain active for long periods in the soil.

Urease activity is also inhibited by cupric ions. At pH 7.1, humic acid slightly enhances urease activity (Table 2) and can abolish the inhibitory effect of the copper. The precise amount of inhibition depends on the concentration of the copper ion and the ratio of this ion relative to humic acid. The adsorption of copper by humic substances, and the interactions with urease, have considerable implications for the disposal on to agricultural land of sewage sludges, pig slurries and distillery wastes, all rich in copper.
Contact name: **Derek Vaughan**

Sulphur status of hill and upland soils

Sulphur deficiencies are likely to occur in regions of relatively low atmospheric inputs, on leached, light-textured soils of low absorption capacity and where farming practices utilize high analysis (low S) fertilizers. Such is the situation in north-east Scotland and though sulphur deficiency has been recognized for some time in the lowland/arable context, it has not been fully appreciated in the hill and upland context. The survey of the sulphur status of soils on hill and upland farms has been extended beyond those taken in 1988 to include over 160 soil and herbage samples from the areas of Glen Esk, Glen Clova, Glen Moy, Tomintoul, Correen Hills and Glen Foudland. The major soil associations sampled were Corby, Strichen, Tomintoul and Foudland. A microbiological test showed fewer soils giving a response to sulphur: 12% for 1989 compared with 20% for 1988. Analysis of the herbage for total sulphur for both 1988 and 1989 surveys gave a narrow range of values between 0.1 and 0.3 %S.

A summary for the two years of the range of plant-available sulphate sulphur in those associations where sufficient data are available is shown in Figure 2. Over 40% of soils for the Tarves and Countesswells Associations showed either low or very low sulphur content. Just under one third of the Corby soils were in this category and less for the Insch and Strichen Associations. Conversely these latter two associations contained a small number of soils in the excessively high category. Grassland might be expected to respond to sulphur additions when the soil content is as high as 10 mg S/kg soil.

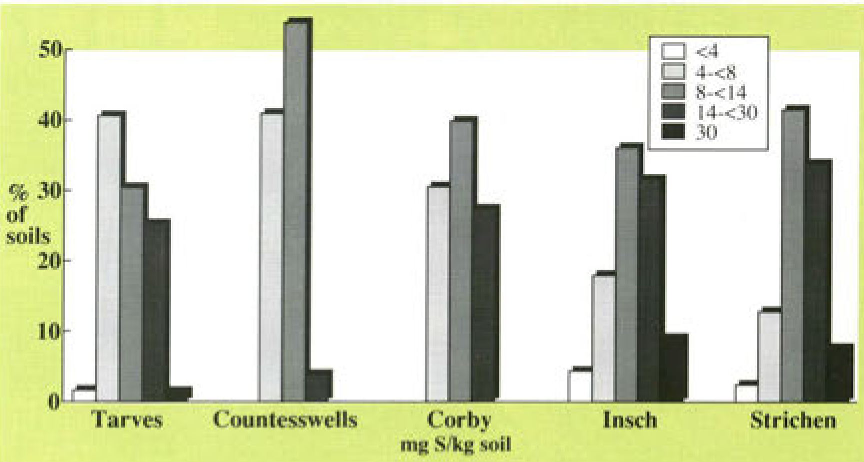


Figure 2. Plant-available sulphur in five hill and upland soil associations.

Sulphur deficiencies can be remedied by the application of elemental sulphur to soil or herbage. This is converted to a plant-available form (sulphate) through oxidation, primarily by microbial action. In the UK, and particularly in Scotland, finely-divided (micronized) forms of sulphur, which were originally formulated as fungicides and are applied as a foliar spray, have been used. However, these formulations tend to be expensive. Cheaper forms of elemental sulphur, produced by grinding and sieving processes, are available.

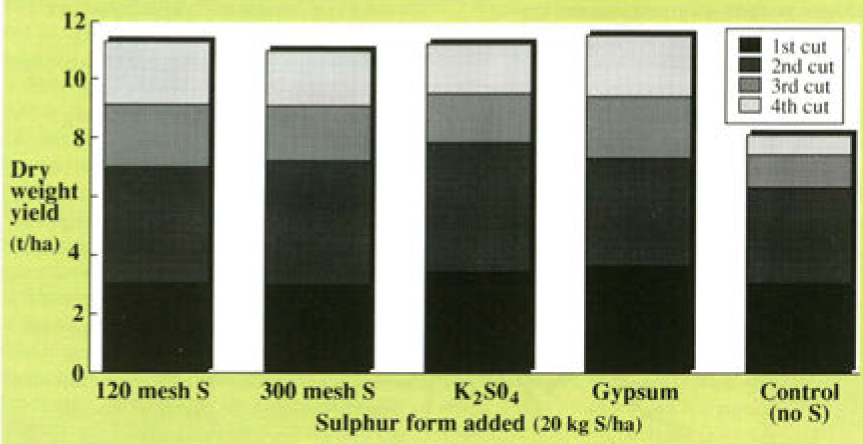


Figure 3. Response of a mixed sward to sulphur additions at an upland site (Wartle).

A field trial using two different mesh sizes of elemental S and two forms of sulphate-S (gypsum and potassium sulphate) on grass/clover were set up in 1989 on an upland site at Wartle (28 miles west of Aberdeen). In addition, a pot experiment was carried out to assess the response of both ryegrass and clover to elemental sulphur. The results of the field experiment are summarized in Figure 3. The site was very responsive to sulphur additions: total dry matter offtake was increased from 8.4 t/ha to 11.5 t/ha (a mean increase of about 37% over the control). Elemental sulphur was found, over the whole season, to be as effective as either potassium sulphate or gypsum. Early advantages of the sulphate forms were counter-balanced by a greater residual effect of the elemental S later in the year. There were no differences between the two mesh sizes of elemental sulphur used (120 and 300). Both caused a yield increase at the second and third cuts though this was less than that caused by the sulphate forms. At the fourth cut the response to elemental sulphur was greater than that to sulphate, both potassium sulphate and gypsum showing signs of running out. The pot experiments confirmed the response of both ryegrass and clover to added S.

Improved upland pastures on a significant fraction of soils in north-east Scotland may well benefit from the addition of sulphur, applied as elemental S or otherwise, which will give improved yield and utilization of the nitrogen applied as well as possible improvements in herbage quality.

Contact names: **Denise Donald, Steve Chapman**

Determine factors controlling the availability of selenium from soils to plants

Selenium is an essential element in the diet of sheep and cattle and has been shown to be involved in a number of important physiological processes most notably together with vitamin E in the protection of the animal tissue from oxidative stress. It has been estimated that 10% of Scotland is Se deficient and that fodder grown in these areas may contain insufficient Se for animal health. Deficiency can be prevented by adding Se to the soil but to be effective practically and economically, soil treatments require to be long lasting. Since the margin between sufficiency and excess is narrow, such methods must avoid producing herbage with initially high levels of Se. A comparison has been made between the efficacy of soil treatments with sodium selenite (100g Se/ha), sodium selenate (10g Se/ha) and a prill formulation containing 1% Se (20g Se/ha) on sites of the Countesswells, Foudland and Stonehaven Soil Associations known to produce Se-deficient herbage.

The uptake of Se by herbage on the three sites following soil application in the spring was monitored by taking four herbage cuts through the year in May, June, September and October. The pattern of uptake on the three soils was similar with a rapid initial uptake producing herbage with relatively high concentrations followed by a rapid exponential decline producing herbage with near background concentrations in autumn, the levels depending on the form of Se treatment. Thus the prill formulation which contained Se as sodium selenate was added to the soil at a rate calculated to provide twice that of the pure sodium selenate treatment, but by the end of the season the levels of Se in herbage were closely

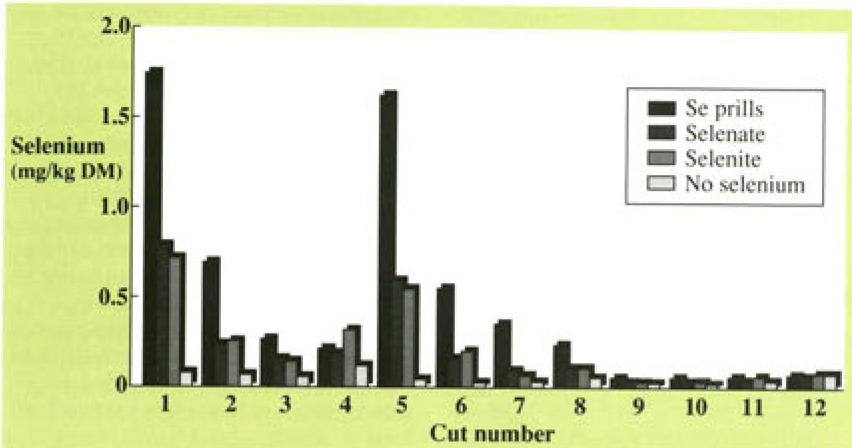


Figure 4. High nitrogen treatment cut 1-4, 1985; 5-8, 1986; 9-12, 1987.

similar although the initial levels of Se in the herbage were roughly doubled. The sodium selenite treatment was at a rate 10 times that of the equivalent selenate as it was anticipated that it would be rapidly fixed in soils. The effect of the application of nitrogenous fertilizers was to change sward composition, to substantially increase dry matter yields and to change Se concentration levels in herbage. Figure 4 shows the Se levels found in the herbage over three successive years on the Foudland Association soil treated with different Se compounds during 1985 and again in 1986. Figure 5 shows the

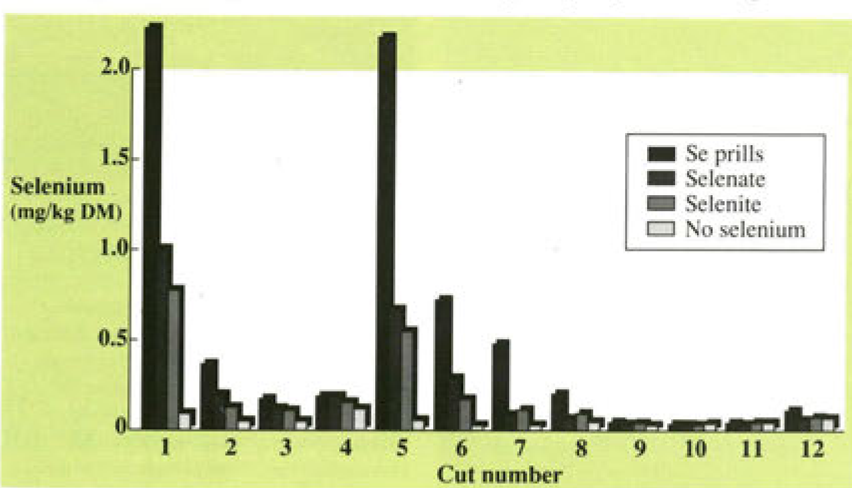


Figure 5. Low nitrogen treatment cut 1-4, 1985; 5-8, 1986; 9-12, 1987.

effect of high nitrogen fertilizer treatment (80kgN/ha) at the outset and repeated after each harvest cut. Statistical analysis shows that Se concentrations are significantly higher in the first harvest of herbage on plots receiving high N and that there was evidence of a negative effect of N on Se concentrations at the second, third and fourth harvest where Se concentrations were lower than in corresponding herbage from plots receiving low N. However, there was strong evidence that total Se uptake was significantly higher over the four harvests of 1985 on those plots receiving high N. Similar trends were also observed following the second treatment in 1986 although the positive effect of nitrogen on herbage Se levels in the first harvest was not statistically significant. Figures 4 and 5 also show that even after treatment in two successive years there is no residual effect in the herbage produced in the third year.

The results of this study show that soil treatment with sodium selenite or sodium selenate alone or incorporated in prills can be used to increase Se levels in Se–deficient herbage in a controlled way and that the treatments employing the rates used in this experiment last over one season without producing toxic levels but with no apparent residual effects in the subsequent year. Although the prills gave no advantage in maintaining Se levels in herbage compared with sodium selenate, they do offer safer handling, less risk of poisoning, and the option of distribution in conventional fertilizer spreaders.

The nature of the matrix of the commercial prill formulation used in these studies was investigated by electron microscopy-microprobe analysis. This technique, in addition to determination of Se and Ca content by ICP spectroscopy, showed the prills to be calcium carbonate with a coating of a sodium Se salt. The amount of Se (1%) and its oxidation state (VI) was confirmed by hydride generation atomic absorption spectroscopy.

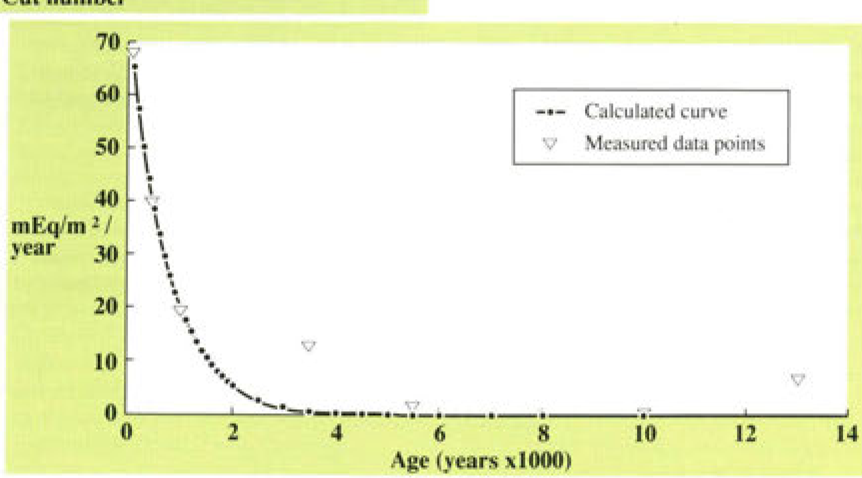
Contact name: **Charles Shand**

Chemical weathering of minerals in upland catchments

Chemical weathering of soil minerals provides inorganic nutrient cations to soil solutions, and is the main long-term mechanism by which the acid neutralizing capacity of a soil is replenished. The rates at which base cations are released from soils have been determined in five upland catchments from the chemical analyses of a number of soil profiles in each catchment by calculating the amount of the element lost from each profile and dividing by the age of the profiles, assumed to be 10,000 years as they are post-glacial.

These long-term weathering rates indicate that base cations are lost at rates of 26-72 mEq/m^2/year (Table 3). Potassium is the element which has been lost in greatest quantity in most catchments, followed by Na, Mg and Ca in every catchment except Sourhope where the order is Mg, Na and Ca. In each catchment the weathering rate reflects the abundances of the bases in the parent material of the soils. However, when base weathering rates are adjusted for abundance in the parent material, then Ca and Na are the most mobile cations in

Figure 6. Plot of weathering rate of Ca against the age of soil profile for chronosequence of seven profiles from Glen Feshie. The mathematical expression of the calculated curve is y=74.35 exp (-0.0013lt), where y is the weathering rate and t is the age.



Catchment	Bedrock	Ca	Mg	K	Na	Sum
Mharcaidh	Granite	2	3	14	13	32
Kelty	Quartz-mica-schist	2	3	11	10	26
Chon	Quartz-mica-schist	5	12	23	32	72
Glensaugh	Quartz-mica-schist	5	9	25	17	56
Sourhope	Andesite	4	15	18	10	47

Table 3. Chemical weathering rates (mEq/m²/year)

the catchments located in quartz-mica-schist, with Mg being the most mobile cation in the catchments on andesite and granite.

The loss of base cations is due mainly to the weathering of three minerals: (i) plagioclase feldspar which releases Na and Ca; (ii) chlorite which releases Mg; (iii) mica which releases K.

The long-term weathering rates in Table 3 are rates of loss averaged over 10,000 years. In a chronosequence of soil profiles on alluvial terraces from Glen Feshie dated at 13,000, 10,000, 5,500, 3,500, 1000, 450 and 80 years before present, the rate of loss of each base cation was shown to decrease exponentially with time (Figure 6). The rate for Ca decreases from an initial value of 70 $mEq/m^2/year$ to less than 5 $mEq/m^2/year$ after 2000 years. This is probably due to rapid initial weathering because of exposure of fresh mineral surfaces, and the presence of fine mineral particles in the newly laid down alluvial material, followed by a slowing down in the rate of weathering after the highly reactive particles have been depleted and weathering reaches a steady state. As a result, current weathering rates will be less than those listed in Table 3.

Contact name: **Derek Bain**

	ppm Fe released (mean of 6 replicate flasks)		Dry wt mycelium (mg) (mean of 6 replicate flasks)	pH (mean of 6 replicate flasks)
	Tolypocladium geodes	Unidentified sp.	Unidentified sp.	Unidentified sp.
Flasks with iron phosphate	37 (SD=8.4)	17 (SD=6.8)	109 (SD=19.4)	2.7
Flasks without iron phosphate	<1	<1	52 (SD=22.3)	

Note 1. Less than 1 ppm Fe detected in uninoculated controls
Note 2. Dry wt. mycelium of *T. geodes* not given, because of difficulties in separating mycelia and spores form residual iron phosphate
Note 3. pH of filtrates (mean of six replicates) from uninoculated flasks-4.6

Table 4. Iron release in culture fluids of fungi, from upland situations, grown in presence or absence of strengite (iron phosphate). Dry weights of fungal material in flasks also given.

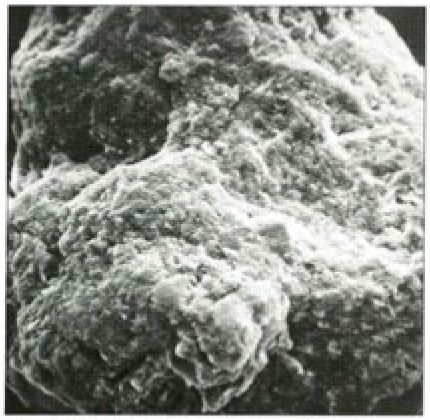


Figure 8. Scanning electron micrograph of partially solubilized Eppawala rock phosphate grain (x1000).

Potential of soil micro-organisms as bio-inoculants to improve phosphate and iron release in hill and upland situations

In acid soils, the availability of phosphate to plants is limited because of its fixation by free oxides and hydroxides of aluminium and iron, and the formation of insoluble metal phosphates. We are studying the solubilization and utilization of iron phosphates by soil micro-organisms and Table 4 shows the extent to which Fe is released into the culture media where strengite, an iron phosphate, was supplied as sole source of iron and phosphate to the organisms. In the case of the unidentified fungus (no conidia formed, only chlamydospores produced, even on exposure to UV light). Although little phosphate was detected in the culture filtrates, the microbial biomass was high in phosphate. An indication of the extent to which the sterile fungus solubilizes iron phosphate is shown in Figure 7. A proportion of the iron was also associated with the fungal biomass and was characterized by electron paramagnetic resonance (EPR) spectroscopy which pointed to complex organic chelates being formed. Under soil conditions lysis of this biomass by other micro-organisms (mainly Actinomycetes) could make the phosphate and iron more readily available to higher plants.

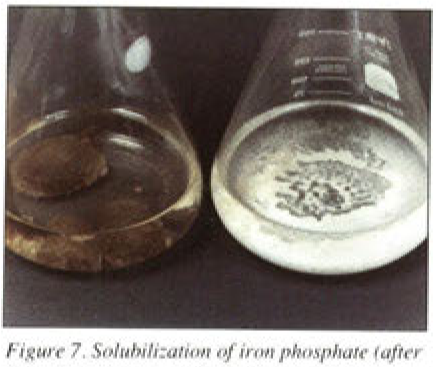


Figure 7. Solubilization of iron phosphate (after 6 weeks incubation at 25°C) by an unidentified fungal species (in flask to left of photograph). Flask to right of photograph, with iron phosphate but not inoculated.

Examination of the culture fluid of the above fungi by high performance liquid chromatography (HPLC) has tentatively identified oxalic, Keto glutaric, citric, malic, succinic and fumaric acids and such acids would be actively involved in the solubilization of the iron phosphate. Preliminary studies show that the unidentified fungal species is able to solubilize rock phosphate from Sri Lanka (Figure 8) which contains some apatite ($CaPO_4$) but is mainly composed of calcium, aluminium, iron and phosphate. It is feasible that the fungi under study could be used as bio-inoculants to improve plant growth in hill and upland situations where plant nutrients are limited.

Contact name: **David Jones**

The effect of nitrogen supply on the internal nitrogen cycling and leaf demography of deciduous trees

The internal cycling of nitrogen (N) in deciduous trees can be considered as the withdrawal of N from senescing leaves and storage overwinter in perennial woody tissues, until remobilization in the spring for leaf (and root) growth. Such internal cycling is important to the tree as a means of increasing the efficiency of N use and also in allowing spring growth to occur with little reliance on uptake of native soil N. The dynamics of the seasonal internal cycling of N in sycamore (*Acer pseudoplatanus* L.) have been studied in relation to N supply and leaf demography.

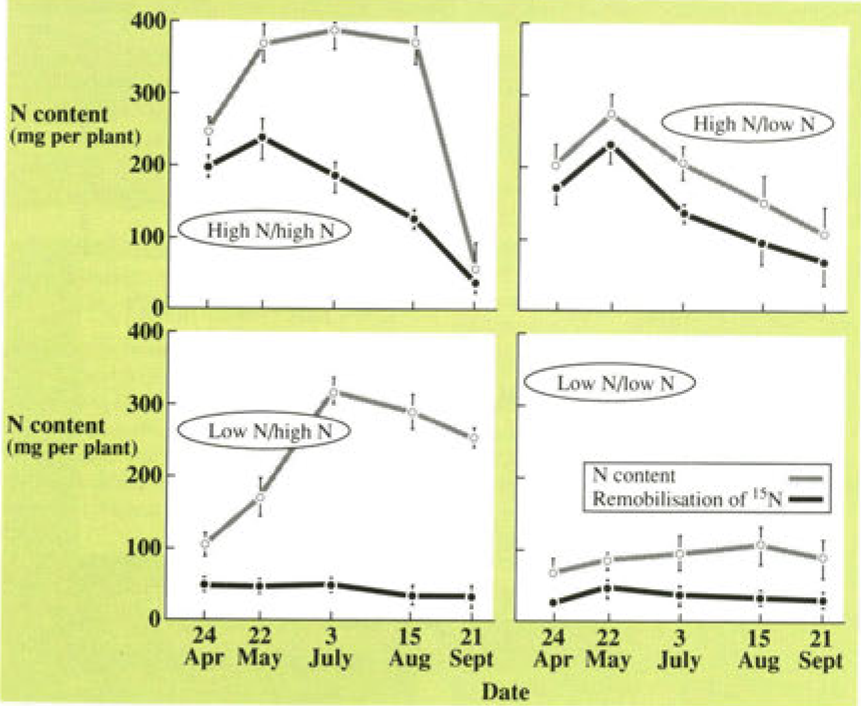


Figure 1. The effect of N supply in 1988 and 1989 on the N content and remobilization of ^{15}N for leaf growth in 1989 (Low N=1.0 mol N/m^3, High N=6.0 mol N/m^3.

Four–year old seedling trees were grown in sand culture through 1988 with either a poor (1.0 mol /m^3) or generous (6.0 mol /m^3) N supply provided with the irrigation, to precondition their growth and capacity for N storage over winter. Throughout 1988 all the N provided was labelled with ^{15}N (to 5.0 atom %). In 1989 recovery of ^{15}N in the leaves showed that their initial spring growth was independent of the current N supply of either 1.0 or 6.0 mol N/m^3 and depended only upon the N supplied in 1988 (Figure 1). A net loss of ^{15}N from perennial tissues and recovery of ^{15}N in the growing leaves confirmed that the current N supply had no effect on the remobilization of N from overwinter stores in the roots and stem.

After the first eight weeks of growth, remobilization of stored N had finished and leaf demography was influenced by the current N supply only. Plants preconditioned to 6.0 mol N/m^3 in 1988 but receiving only 1.0 mol N/m^3 in 1989 were unable to sustain their leaf growth; after remobilization of N finished there was premature canopy senescence. In contrast, trees preconditioned with 1.0 mol N/m^3 in 1988 but receiving 6.0 mol N/m^3 throughout 1989 greatly increased their leaf growth once the internal cycling of N had finished. This was brought about by N uptake stimulating the growth of many small leaves on axillary shoots at the base of the canopy. Leaf numbers, therefore, increased but mean area per leaf decreased.

The trees were inefficient at withdrawing N from senescing leaves in both years, allowing most of the N to fall from the tree with the moribund leaves. The overwinter storage of N and subsequent spring remobilization for leaf growth was dependent largely upon the direct uptake of N into the stem and roots during late summer and autumn. The trees had a high nitrogen use efficiency (NUE), ranging from 49-128 gDm/gN for the plants receiving 1.0 or 6.0 mol N/m^3 throughout both years, respectively. Methods for assessing NUE in the field rely upon measuring the withdrawal of N from senescing leaves (as indicated by leaf litter N concentration). Such measurements would have significantly underestimated NUE, as no account of the direct N uptake late in the season for storage would have been made.
Contact name: **Peter Millard**

Influence of soil phosphorus concentration, pH and aluminium on uptake of phosphorus by ryegrass

Uptake of P by ryegrass seedlings has been measured as functions of time, concentration and pH, as a basis for determining effects on P uptake and transport. It has been established that uptake of ^{32}P, from 0.1 mM P in nutrient solution, is much steeper in the first two hours when 1 ppm Al is present in the solution (Figure 2). This is considered to be due to adsorption of Al/P complexes in the root cell walls. Subsequent linear uptake of ^{32}P represents transport to the shoots and accumulation of P in root cell vacuoles. The rates of both these processes are doubled in the presence of 1 ppm Al. Intermediate Al concentrations produce intermediate effects. At higher Al concentrations, toxic effects on root growth and phosphate uptake occur. Measurements on more mature ryegrass plants gave similar results to those from seedlings.

It is known that pH has a major effect on Al^{3+} activity, though pH itself had no significant effect on P uptake, at least in the short term. However, although a number of experimental

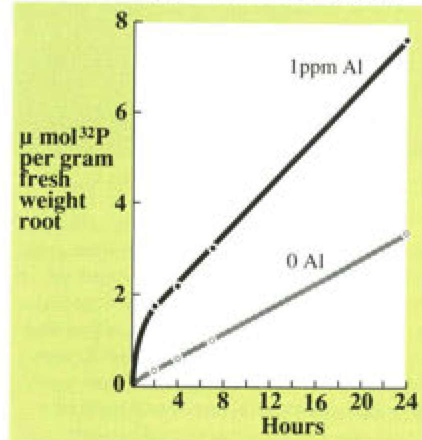


Figure 2. Total ^{32}P uptake by ryegrass seedlings as a function of time from nutrient solution containing 0.1 mM P and 0 or 1 ppm Al.

treatments were run at pH values above that considered favourable for the maintenance of free Al^{3+} activity, the results showed effects proportional to the Al supplied. It seems possible that the P accumulated in root cell vacuoles, and even that transported, may occur in the form of alumino phosphate complexes.

Exchange rates for P in various compartments of the root cells can be measured by allowing the root to absorb ^{32}P for a few hours, and then following the appearance of radioisotope in unlabelled solution used to wash the roots. Recent experiments of this kind show that P absorbed in the cell walls is readily exchangeable and therefore available for subsequent uptake, supporting the view that uptake may occur in complexes with Al. Further examination of elution data indicates that a major proportion of absorbed P is soon assimilated into organic compounds which exhibit extremely slow rates of P exchange.
Contact name: **Alan Macklon**

Growth and nutrient dynamics within contrasting short rotation farm-forestry management systems

A collaborative experiment between MLURI and the Central Scotland Countryside Trust has been established to evaluate the nutritional

Figure 3. Short rotation poplar at Hartwood Research Station.

implications of intensively managed short rotation forests. Such plantations provide an opportunity for the establishment of woodlands on isolated or difficult areas of agricultural land. Owners may expect an income in 5 to 20 years rather than the 40 or more years required to generate substantial income in conventional forest systems. The intensive management required to implement short–rotation forestry includes heavy weed control and removal of whole-tree produce. Rates of nutrient removal may increase several-fold under such management regimes and the aim of this project is to quantify rates of biomass production and relate these to rates of nutrient loss. Species of willow, poplar and alder have been planted at 1.0m spacing for the production of coppice material on three–year cutting cycles, (Figure 3) following an initial cut-back in year one. Poplar and alder are also being grown as single stems at both 1.0m and 1.5m spacings on a rotation of 10 years. Rates of production and partition of biomass within the different management systems are being quantified annually through destructive sampling. Light interception measurements are being taken weekly to compare the seasonal canopy development across species for both coppice and single stems. These will be supplemented by gas exchange studies made during each year to quantify rates of net photosynthesis and respiratory losses of carbon associated with each production system.
Contact name: **Mike Proe**

The effects of widely spaced conifers on understorey pasture production

An experiment was set up with Sitka spruce trees at three heights (originally 3m, 5m and 8m) thinned to three spacings (4m, 6m and 8m) equivalent to 625, 278 and 156 stems per

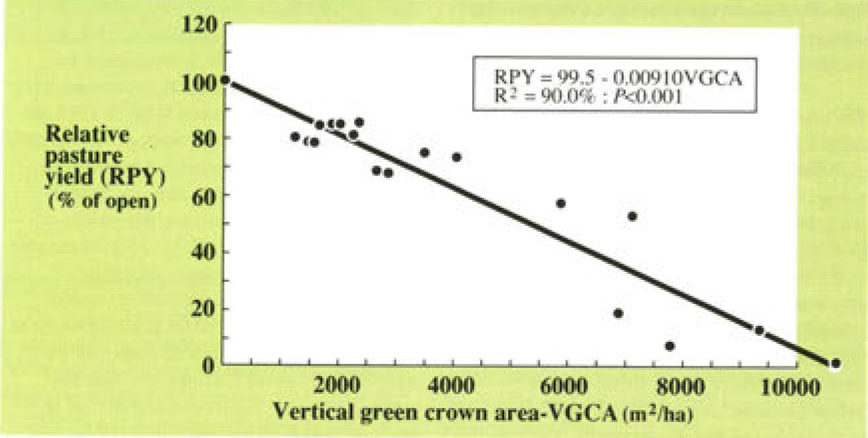


Figure 4. Relationship between RPY and VGCA.

hectare. The tallest trees had the lowest four whorls of branches removed. Sward boxes sown out with ryegrass were distributed in a stratified pattern beneath the nine tree-canopy structures created. Sward boxes in an open (control) situation were also set up. Herbage growth was measured directly from the sward boxes for two

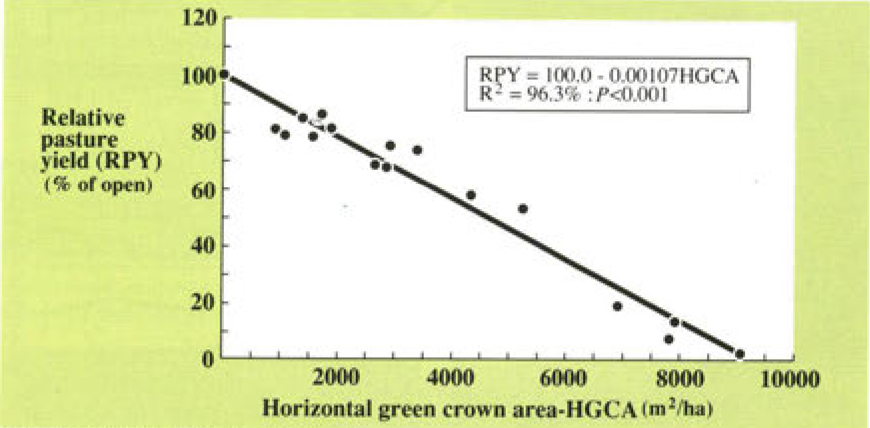


Figure 5. Relationship between RPY and HGCA.

full growing seasons, 1987 and 1988. In addition a limited number of boxes were monitored for a range of microclimate parameters.

Simple quantification of the canopy structure of the trees has been calculated in two ways assuming them to be regular cones. Firstly as a Horizontal Green Crown Area (HGCA the sum of the horizontal projections of the individual tree canopies (triangles) per unit area in m^2/ha) and secondly as a Vertical Green Crown Area (VGCA, the sum of the vertical projections of the individual tree canopies (circles) per unit area in m^2/ha). Both of these estimates take account of the density of the trees, the size of the trees and the extent to which the crown has been modified through removal of branches by pruning.

A regression of data for annual herbage production (expressed as a Relative Pasture Yield (RPY), the percentage of open yield) from the treatment combinations, including open sites, for each of two years (n=20) with VGCA is shown in Figure 4, and with HGCA in Figure 5.

Both regressions are very highly significant. However, the equation with HGCA gives the better fit suggesting that under regular conical crowns of conifers in the uplands of the UK there may be a greater component of lateral shading than vertical shading affecting understorey pasture production.
Contact name: **Alan Sibbald**

Measurement of ryegrass leaf extension rate within a controlled environment

A system has been developed which allows the simultaneous measurement of the leaf extension rate of four ryegrass plants whilst situated within a controlled environmental cabinet. It is based on the use of linear variable differential transformer (LVDT) devices which transduce a change in linear displacement of the LVDT core to a change in voltage output.

A single ryegrass leaf is attached by a small piece of sticky tape to a nylon monofilament line. The line is looped over a rod of polytetrafluoroethylene (acting as a low friction pulley) and attached to the LVDT core. In turn the LVDT core is attached with similar line to a small weight which ensures the line is kept taut and the plant leaf is held erect. As the attached ryegrass leaf extends, the LVDT core falls an equivalent distance causing a change in the LVDT voltage output. In the LVDT model used, a 1 mm displacement of the core gives a 0.5v change in voltage. The voltage output of all four LVDT channels is recorded every 90 seconds for up to 24 hours on a data logger. Several runs

Figure 6. Two LVDT devices within a controlled environmental cabinet also showing attached data logger and visual display unit.

or one run for several days, of all four channels, can be stored on the data logger before it is necessary to down-load the data into a computer allowing easy subsequent data manipulation. A visual display unit connected to the data logger allows the output of the current run over the previous 1.5 hours to be displayed for each channel.

Figure 7. Detail showing attachment of LVDT core to plant.

The novel aspects of this system are the simultaneous use of four independent LVDTs which make the system amenable to processing large plant numbers and locating the LVDTs within a controlled environmental cabinet (Figures 6 and 7) allowing independent control of temperature, humidity and light of the plants' environment. The cabinet's temperature control system causes slight vibrations within it making it necessary to add small beads of plasticine to the nylon line above the plant leaf to avoid resonance vibration.

This system is currently being used to investigate the extension of ryegrass leaves after being exposed to periods of cold temperature and also the regrowth of ryegrass leaves after defoliation.

Contact names: **Barry Thornton, Graham Gaskin**

A model of the canopy development of grass under grazing

Current models of grassland neglect the uneven spatial distribution of nitrogen and herbage that results from selective grazing and the uneven distribution of dung and urine. This becomes particularly important when considering low input grazing systems where selective grazing could have a profound effect on the rate of cycling of nitrogen, its loss or retention within the system and on the growth of grass.

The first step towards including spatial variation in a grass model has been to describe the distribution of herbage in the vertical plane. This is important because this largely determines how much of that herbage can be bitten by the grazing animals. Grass growth is predicted using an existing model (Johnson and Thornley, 1983) and then this growth is translated into the length, height and orientation of new leaves, the factors which determine the vertical distribution. The model of Ungar and Noy-Meir (1988) is then used to graze this sward.

The fate of grass leaves is either to be

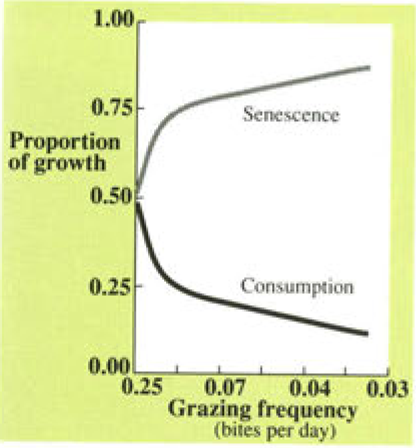


Figure 8. Model prediction of the relationship between grazing frequency and consumption or senescence over a range of growth rates for a sheep–grazed sward maintained at a height of 5 cm.

consumed by the grazing animal or to die of old age (senesce). The balance between the proportion of growth which is consumed or senesces depends on the growth rate, the environment and the way in which the sward is managed. The model can be used to look at the result of changing the stock density to maintain a constant sward height in the face of varying growth rate. To maintain a constant sward height as the growth rate increases demands an increase in the frequency with which any particular area is grazed. Figure 8 shows that as the frequency of grazing decreases, more of the grass senesces and less is consumed by the animals.

Contact name: **Nick Hutchings**

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UNGAR, E.D. and NOY-MEIR, I. 1988. Herbage intake in relation to availability and sward structure: grazing processes and optimal foraging. *Journal of Applied Ecology*, **25**, 1045-1062.

Potential productivity and use of N_2 fixing shrubs

The biological potential of three nitrogen–fixing shrubs (gorse, broom and tree lupin) in different upland systems has been considered in three experiments. The first continued an investigation of growth and utilization of gorse by goats; the feeding value of gorse, and also broom, was measured in a complementary indoor trial. In the final experiment, part of a study to determine the potential of nitrogen-fixing shrubs as nurse species in tree systems, the seasonal pattern of growth and winter survival of tree lupin in an upland environment was investigated.

Figure 9. Tree lupins growing in an upland environment.

Measurements of biomass production and utilization of gorse by goats were continued for a second season at Nether Kidston, Peebles. Net DM production over a 24–week growing season was 14.4 t/ha, of which 6.8 t/ha was green foliage. This greatly exceeded net production of herbage on an adjacent pasture, which was 2.7 t/ha over the same period. The major part of the diet of goats in both summer and winter was green foliage of gorse.

In the indoor feeding trial, the organic matter (OM) intake of gorse by goats was greater than that for broom, 670 g/day compared with 374 g/day. The quality of the broom herbage offered to the animals was higher than that of gorse; OM digestibility of broom was 60% while gorse was 53%.

The seasonal growth and winter survival of two ages of tree lupin plants (1 year old and seedlings), which were planted into a perennial ryegrass sward at Glensaugh in June 1989, was investigated. Morphological measurements of plants were made at monthly intervals until September and destructive harvests were made at planting and in September. During the growing season, main stem length increased from 50 to 799 mm and above-ground DM increased from 0.7 g to greater than 130 g in seedling plants. All plants survived the winter and continued to grow well during the following year. Future work will involve planting of tree lupins alongside trees.

Contact name: **Carol Marriott**

Quantification of root system development using a microrhizotron

The root growth of several tree species has been studied using a non-destructive microrhizotron system. A miniature borescope (diameter 10 mm) is placed in glass tubes which allows root growth to be viewed *in situ*. Counts of points of contact with grid squares can be made at any chosen time interval. Treatment differences can be examined by performing an analysis of variance on the counts themselves or root density can be estimated from counts when roots are not uniformly orientated by using either tubes angled at around 55° to the vertical or if both vertical and horizontal tubes are used.

The effect of nitrogen on the development of the root system of Sitka spruce and sycamore was investigated using glass tubes at angles of

Figure 10. View of cherry and grass roots through a microrhizotron tube.

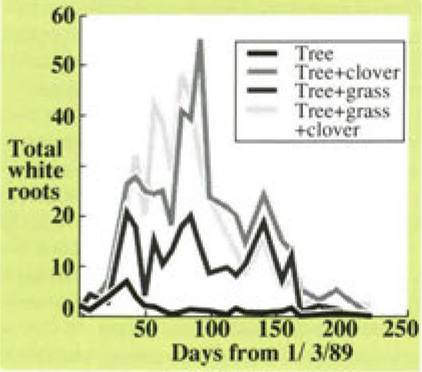


Figure11. Seasonality of white cherry root counts.

45° and 0° to the vertical. Nitrogen had the effect of increasing white root counts, fresh weight and diameter in both species. The correlation between fresh weights and counts of white roots was high for sycamore (r = 0.89; $P < 0.001$), whereas for Sitka spruce it was not significant at the 5% level (r = 0.44). The counts and fresh weights of white roots showed similar trends and mirrored periods of leaf and needle production. Counts have the advantage of measuring changes in the same tree, and are less time–consuming than whole tree harvesting.

The effect of grass and clover competition on root growth and seasonality of cherry roots has been studied both in the field and in the laboratory. Counts of first and last point of root contact were made on vertical and horizontal tubes placed in square pots. Figure 10 shows a brown cherry root with branches and another dark brown cherry root. Also shown are finer diameter white grass roots in the same zone of soil showing two points of contact. This highlights how a visual classification can be made using this method when roots of different types are grown together. Seasonal changes can be studied (Figure 11) and related to shoot growth. With cherry, the maximum period of shoot extension precedes the maximum point of white new tree root growth. The greatest number of white unsuberised cherry roots were consistently found where grass and clover were also growing in the same pot. The least were found where trees were grown alone. This could indicate a competitive effect of the grass and clover on the cherry growth with the cherry plant having to put more carbon resources into roots in order to keep up adequate nutrition when competition exists. A similar trend was found in the field where trees grown in competition with grass fertilized with higher levels of N had produced significantly more new white roots than the trees under grass with lower rates of N fertilizer.

Contact name: **Lorna Dawson**

Nutrient availability beneath pure and mixed tree species

It has now been shown in previous studies at Culloden Forest, Inverness, that net mineralization of N was significantly greater in the forest floor beneath a mixed stand of Scots pine and Sitka spruce than under spruce planted in pure stands. It was not possible to say whether this was a cause or a consequence of the improved growth of the trees in mixture because the stand was 15 years old and the differences in growth rate had started to emerge when the trees were about 9 years old. Current work is aimed at obtaining unequivocal evidence that both gross and net rates of mineralization of N are greater in soil and humus beneath the mixed species and that enhanced mineralization is the reason for the improved tree growth. Studies have been extended to an experimental site at Speymouth forestry where plots of Sitka spruce in mixture with either Scots pine or larch were planted in 1981. In these investigations the *in situ* incubation technique which causes some sample disturbance is being replaced by one that uses the dilution of ^{15}N labelled pools of mineral-N to measure rates of both gross mineralization and immobilization of N.

Contact name: **Berwyn Williams**

Determine the scope for manipulation of the floristic composition and nutritive value of *Molinia* grassland by grazing

The effect of defoliation by grazing or cutting on the productivity of *Molinia* grassland and on changes in the floristic composition has been researched to determine the sustainability of *Molinia* grassland under grazing.

The study consists of a long-term grazing experiment with dry hill cows, and support cutting experiments. The grazing experiment began in 1985, and is replicated at two sites; Riccarton Junction, Roxburghshire, and Cleish, Fife. There are two grazing treatments and plots are stocked during the period of *Molinia* growth only. The treatments are designed to utilize approximately one-third or two-thirds of the *Molinia* leaf production, and cattle numbers are adjusted twice weekly to maintain target *Molinia* lamina lengths until growth stops. A number of small grazing enclosures were set up at the start of the study.

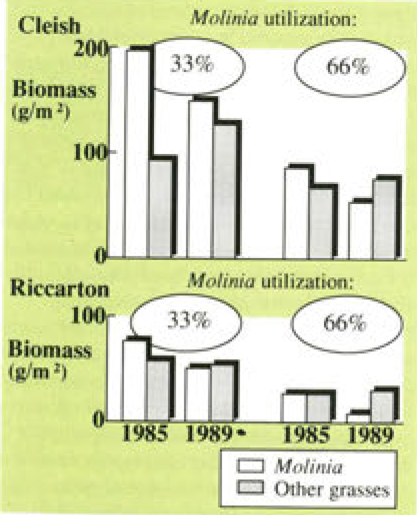


Figure 1. Biomas (DM) of green Molinia *and of other green grasses at the end of the grazing period, after 1 year (1985) and after 5 years (1989) grazing.*

Animal measurements (diet selection, intake and live-weight gain) to establish feeding value were completed after three years, and the results were reported in 1987. The grazing treatments and sward measurements were continued to establish the effects of grazing on the plant community. Annual floristic records indicate that *Molinia* cover showed an initial decline on all grazed plots compared with the ungrazed exclosures. After four seasons of grazing its cover appears to be stabilizing at around 60% under light grazing but is continuing to decline under heavy grazing. The main increased species are the other broad-leaved grasses. A comparison of the end of grazing biomass cuts for 1985 and 1989, year 1 and year 5 respectively (Figure 1), indicate an order of reduction in *Molinia* comparing 1989 with 1985 of 25-35% under light grazing and 38-65% under heavy grazing.

A cutting experiment, which was replicated at two sites (Cleish and Sourhope), investigated the effect of removing 33% or 66% of lamina length either once only in June, July or August, or repeatedly in June, July and August. An uncut control was also provided. The treatments were imposed for three successive years after which the plants were allowed an uninterrupted season's growth before harvest. Plant biomass, leaf mass, tiller number, weight per tiller and weight per basal internode were all significantly reduced by repeated cutting compared with single or uncut treatments. The effects of light defoliation (33% leaf removal) were variable between experiments, but three years of repeated heavy defoliation (66% leaf removal) reduced tiller size by 51% at Cleish and by 59% at Sourhope compared with uncut controls; tillering capacity (estimated by counting the tiller buds on the basal internodes) was reduced by 34% at Cleish and by 26% at Sourhope.

The results show that grazing to remove 66% of *Molinia* leaf in summer will lead to greatly reduced *Molinia* cover and productivity, and to the development of a grassland with an increased proportion of other broad-leaved grasses. Light grazing to remove 33% of the leaf, though leading to reduced *Molinia* cover compared with initial amounts, may be compatible with sustaining *Molinia* as a major species of the grassland community.

Contact name: **Sheila Grant**

Effects of rest periods from grazing on species balance in ryegrass/white clover swards

The hypothesis being tested in this study is that in mixed species swards provision of a rest period from grazing will lead to a change in the species balance in favour of the species which currently have the greatest capacity for growth. In the case of ryegrass/white clover swards, the responses of the grass and clover to temperatures are such that in early spring and autumn ryegrass is able to grow faster than white clover while the reverse is the case in summer. It was postulated, therefore, that the outcome of incorporating a silage cut in an otherwise continuously stocked regime would vary depending on timing. The timing of conservation was varied by growing each of two clover varieties (the small-leaved Kent or medium-leaved Milkanova) with either a very early flowering ryegrass (Aurora) or a late flowering variety (Melle). The cutting dates for silage were 17 May (Aurora) and 29 June (Melle).

The consequences of the different responses to temperature of grass and clover for their leaf distribution in the canopy, and hence ability to intercept light, in relation to timing of the rest periods is illustrated in Figure 2.

The effects of the treatments on clover content, whether expressed as biomass of clover or as clover as a proportion of total live mass (see Figure 2) were as predicted, i.e. clover content was decreased by early conservation and increased by late conservation when compared with continuously stocked controls. The treatment effects persisted and were evident in the population densities of grass and clover at the end of the year. Total grass populations were higher on plots sown to Aurora than Melle grass cultivar and on those sown to Milkanova than to Kent clover cultivar. Conservation was associated with reduced grass tiller density. Examination of the change since the start in sown and weed grass densities suggests that the increase in grass density on plots sown to Milkanova was mainly an improvement in the sown grass, while the reduction associated with conservation was mainly due to loss of weed grasses. Comparing the conserved and grazed plots, clover population density was reduced by early conservation but was increased by late conservation (Figure 2). The smaller cultivar, Kent, had a higher population density than the larger Milkanova. By October the biomass of Kent was also increased compared with Milkanova.

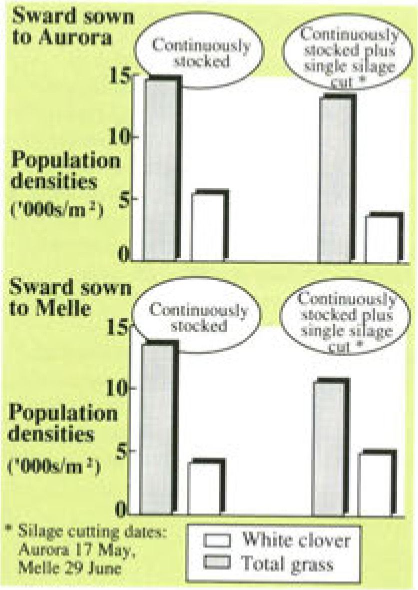


Figure 2. Effect of incorporating a silage cut on species balance of ryegrass/white clover swards as influenced by earliness of ryegrass flowering and hence, timing of the conservation period.

The experiment, which confirmed the hypothesis that the species balance in ryegrass/clover swards can be altered in a predictable way, will be continued for a second season when, in addition to repeating the measurements made in the first year, information on seasonal variation and treatment effects on the relative behaviour of grass and clover with respect to mean height within the canopy and rates of vertical height increment, the respective order of expansion of leaf area during the rest periods, and specific leaf area (leaf area per unit weight) will be collected to understand more fully the mechanisms involved.

Contact names: **Sheila Grant, Titus Barthram**

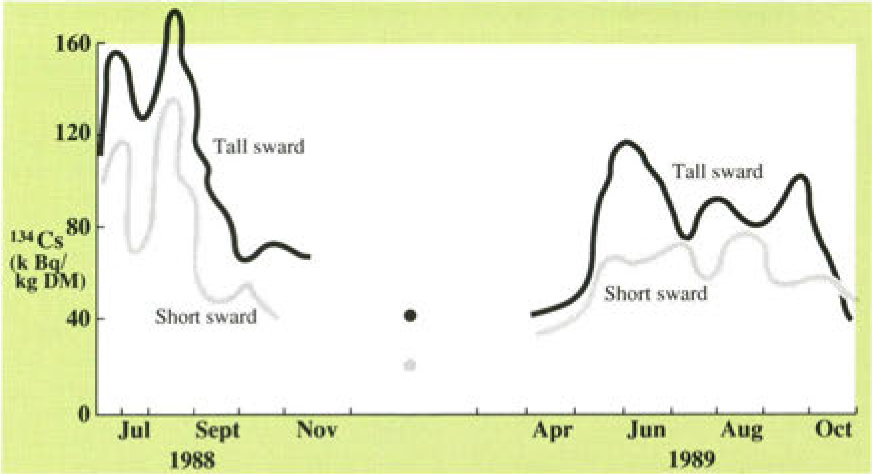


Figure 3. ^{134} Cs concentrations in unseparated herbage.

Effects of sward conditions on radiocaesium cycling in hill and upland sheep systems

Prior to the nuclear accident at Chernobyl in 1986 little attention had been given to the potential effects of radioactive fall-out on the sheep production on Britain's hill and upland pastures. After the accident, predictions of the extent of contamination in sheep considerably underestimated the radiocaesium levels found in sheep grazing grass and moorland vegetation on organic soils in parts of Cumbria, Wales and Scotland. To study the effects of soil and pasture type on the soil-plant-animal transfer of radiocaesium under field conditions, an experiment was set up on a site at Glensaugh Research Station on a grass/clover reseed on a peaty podzol. On the reseed a number of small subplots were artificially contaminated by injecting ^{134}Cs directly into the topsoil in order

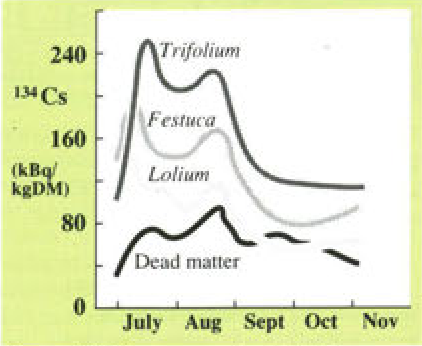


Figure 4. ^{134}Cs concentrations in Lolium perenne, Festuca rubra, Trifolium repens *and dead matter on the tall sward in 1988.*

to study the long-term effects caused by root uptake and transfer of radiocaesium to above-ground plant parts.

The effects of grazing intensity on pasture contamination were investigated on two continuously grazed swards on the reseed, maintained at sward heights of 3 and 5cm from May to September in 1988 and 1989. In both years the ^{134}Cs concentrations in the vegetation were consistently lower on the short sward than on the tall sward. This may have been caused by differences in growth and sward structure between swards of different height and herbage mass. The seasonal changes in the ^{134}Cs concentration in unseparated herbage and individual plant species followed very similar patterns on both swards (Figures 3 and 4). The concentrations increased in spring with the onset of growth and decreased in autumn. During the summer, considerable fluctuations occurred which were possibly related to changes in growth conditions. There were only small differences in ^{134}Cs concentrations between *Lolium perenne*, *Festuca rubra* and *Trifolium repens*, but 4-5 times higher concentrations were measured in *Cerastium fontanum* and regenerating *Calluna vulgaris*.

Sward species composition, and herbage intake and dietary composition of the sheep were measured to estimate the daily ^{134}Cs intake and the contribution made by different plant species. Seasonal variations in plant ^{134}Cs levels as well as differences in plant ^{134}Cs levels between swards had a strong influence on the ^{134}Cs intake. In summer the calculated daily ^{134}Cs intake of a sheep was up to 50% higher than in autumn, and on the tall sward the intake was up to 60% higher than on the short sward. Despite its low proportion in the diet of the sheep, *Cerastium fontanum*, with its high levels of ^{134}Cs, contributed up to 30% to the daily ^{134}Cs intake in summer.

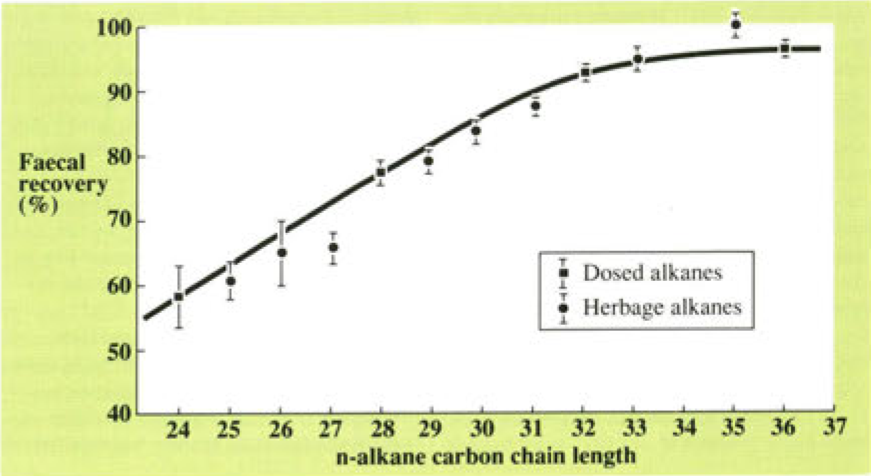
The annual plant uptake of the ^{134}Cs injected into the soil was about 3.1% on the short sward and 6.5% on the tall sward, most of which was cycled back to the pasture via senescing plant material and excreta. Only approximately 0.14% of the ^{134}Cs on both swards would be contained in the sheep at the end of the grazing season in September. The results confirm that the soil-plant transfer of radiocaesium on organic soils is particularly high compared to mineral soils and may lead to high tissue levels in sheep.

Future work will enable us to compare the radiocaesium transfer on the reseed with that on adjacent indigenous and permanent pastures.
Contact names: **Carol Salt, Bob Mayes**

Assessment of diet composition of goats grazing mixed indigenous hill vegetation

The use of dosed C_{32} n-alkane and C_{33} alkane, which is present in the cuticular wax of herbage plants has enabled reliable estimates of herbage intake to be made. There may be as many as 12 types of alkane in plant waxes, with over 90% having odd-numbered carbon atoms. Different plants exhibit differing patterns of alkanes; it may thus be possible to estimate the plant composition of the diet of the grazing ruminant by examination of the alkane patterns in the faeces. However, it has been shown that the recovery of alkanes in the faeces increases as the carbon chain-length increases. Thus, estimates of diet composition may be biased in a manner dependent upon the chain-lengths of the predominant alkanes in each component plant. If the faecal recoveries of dosed even-chain alkanes follow the same relationship with chain-length as do the herbage odd-chain alkanes, it would be possible to adjust the faecal patterns of herbage odd-chain alkanes according to faecal recovery, by dosing with a mixture of even-chain alkanes; this would not only allow unbiased estimates of diet composition to be made, but also intake to be determined. In order to validate the technique direct estimates of faecal recovery of both dosed and herbage alkanes are required. It is also necessary to compare diet composition estimates with actual composition. These aspects were examined using housed adult goats fed differing proportions of perennial ryegrass and rush

Figure 5. Effect of chain length on faecal recovery of alkanes in goats.



(Juncus effusus). Goats can be used to remove rushes from grass swards and, therefore, it is important to know whether diet composition can be assessed from faecal alkane patterns.

The faecal recoveries of dosed and herbage alkanes were compared in 16 housed adult feral goats given rush/ryegrass mixtures ranging from 0% to 60% rush at two different feeding levels (600g DM and 900g DM per day). The animals were dosed daily with a pellet of shredded filter paper containing 80mg each of C_{24}, C_{28}, C_{32} and C_{36} n-alkanes for 18 days, with total faecal collections carried out over the final 10 days.

Figure 5 depicts the mean faecal recoveries of the dosed and herbage odd-chain alkanes. Clearly, the recoveries of the dosed alkanes follow a well-defined curve; the herbage

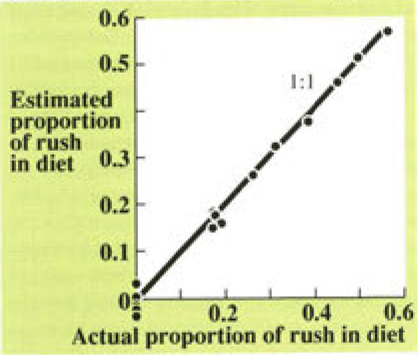


Figure 6. The relationship between estimated and actual proportions of rush in diet of goats (Alkanes used: C_{25}, C_{27}, C_{29}, C_{33}, C_{35}).

odd-chain alkanes deviated slightly from this relationship.

Since, in practice, absolute faecal recoveries cannot be estimated, the relationship between C-chain length and dosed alkane recovery relative to that of C_{36} was used to adjust the faecal patterns of natural alkanes such that the diet composition could be estimated. Figure 6 shows the relationship between estimated and actual proportions of rush in the diet.

These results suggest that n-alkanes can be effectively used to estimate the composition of the diet from two plant sources. However, the efficacy of the technique is dependent upon the degree to which the alkane patterns of the component plants in the diet differ. Rush and ryegrass have alkane patterns which are sufficiently different to allow good estimates of diet composition to be made.

Contact name: **Bob Mayes**

Develop and test foraging strategy theories for ruminants grazing mixed indigenous hill communities

In order to be able to advance our understanding of the foraging strategies of herbivores ranging across mixed hill plant communities we need to determine the factors affecting relative preference for these communities on offer. We predict that the preference between communities will be related to their relative forage biomass and nutrient availabilities. Testing this prediction requires an experimental approach offering animals, in the first instance, relatively simple choices.

A previous experiment showed that the sward height on the preferred species of a community *(Agrostis/Festuca)* affected the proportion of time that sheep spent foraging on a less preferred species *(Nardus)*. When the sward height on the *Agrostis/Festuca* community was maintained at 3cm, the sheep spent a greater proportion of their time on the *Nardus* community than where the *Agrostis/Festuca* community was maintained at 4.5cm. Previous research had also shown that the level of utilization of *Nardus* community affects the proportion of live leaves and digestibility on that community in the following year; high utilization in one year increasing the proportion of digestible forage in the next year.

An experiment conducted in 1988 at Sourhope Research Station examined further the factors affecting relative preference between two major hill communities by investigating the effect of varying the proportion of digestible material on a less preferred *Nardus* community while maintaining the height of the preferred *Agrostis/Festuca* community at 4.5cm.

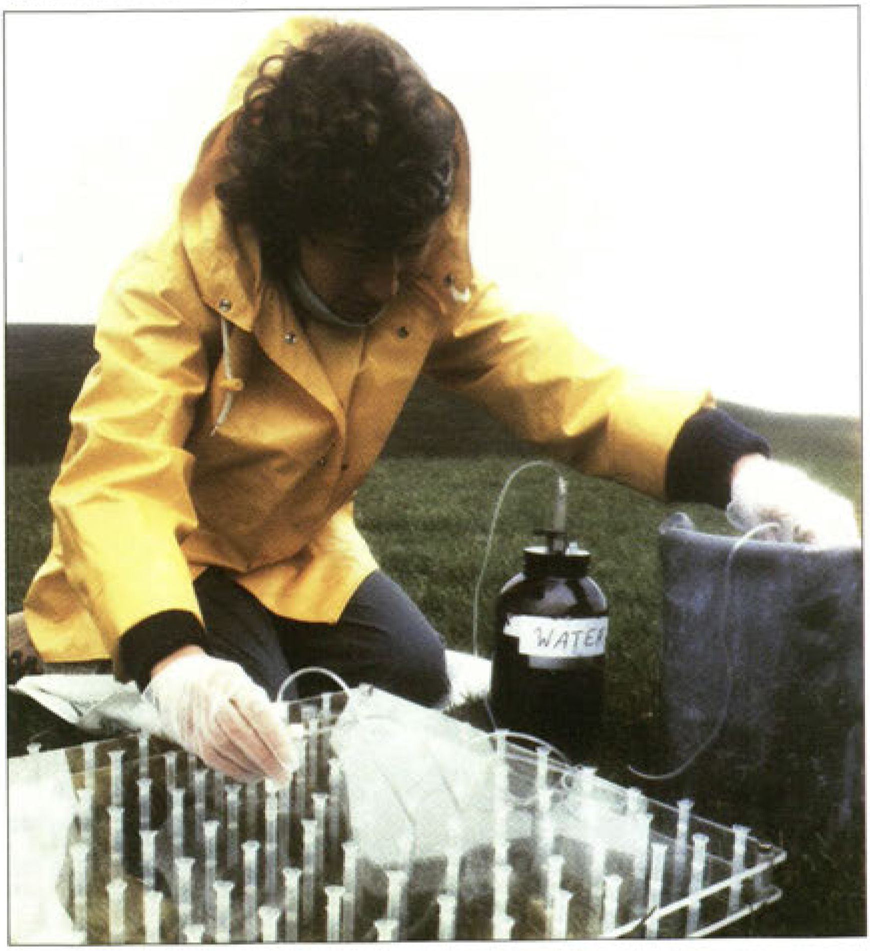
The experiment was conducted on plots established across two hill grassland communities, namely *Agrostis/Festuca* and predominantly *Nardus*, which each occupied separate halves of a plot. Measurements were made of the distribution of sheep across the two vegetation communities using time-lapse photography. Measurements were also made on the extent (proportion of leaves grazed) and severity (length of lamina remaining after grazing) of grazing on the *Nardus* community in the middle and end of the grazing season.

The results are presented in Table 1. The sheep spent a greater extent of their time on the *Nardus* community and grazed a greater proportion of *Nardus* leaves on plots in which the *Nardus* community had been heavily utilized in the previous year. These results provide evidence in support of the hypothesis that nutrient density alters foraging choices, even when it is the nutrient density of the normally less preferred species that has been changed.

Contact names: **Iain Gordon, Murray Beattie**

Nardus treatment	Sightings of sheep on *Nardus* community (%) June	August	Proportion of *Nardus* leaves grazed June	August	Mean length of *Nardus* leaves after grazing (cm) June	August
Previously lightly grazed	24.5	22.5	24.6	17.1	10.3	6.5
Previously heavily grazed	39.6	31.0	38.3	27.3	6.4	5.1

Table 1. Proportion of sightings of sheep on the Nardus *community and grazing records for* Nardus *tillers.*



The effect of grazing management strategies on cattle performance and floristic composition in *Nardus*-dominated swards

Nardus stricta (white bent) is currently estimated to dominate 5% of the hill and upland areas of the UK and it is generally accepted that this area is increasing. *Nardus* is a grass of relatively low nutritive value for grazing livestock and if unchecked can dominate large areas of hill land, leading to a reduction in species diversity. Previous work at MLURI has indicated that sheep avoid *Nardus* but with cattle the proportion of *Nardus* in the diet increases with grazing pressure, and the proportion of *Nardus* in the sward declines with time. Present evidence indicates that inter–tussock sward height can be used as an objective criterion on which to base the management of these plant communities. However, if cattle have a role in the management of these communities there is a need to quantify the levels of performance that can be sustained.

An experiment was started at the Sourhope Research Station in 1988 to measure the level of performance that can be achieved from lactating cows and their calves when grazing *Nardus*-dominated grassland at two grazing pressures, and to investigate the long-term changes that occur in floristic composition.

Each summer lactating Blue-Grey cows and Charolais-cross calves graze plots where the inter–tussock sward surface height is maintained at either 4-5 cm (high grazing pressure) or 6-7cm (low grazing pressure). These heights are maintained by the addition and removal of non-experimental cows and calves.

The cattle are put on the plots when the appropriate heights are reached in spring (usually at the end of May) and numbers are gradually reduced in late summer to maintain inter–tussock sward heights. The last cattle are usually removed in late August or early September.

	Inter-tussock sward height	
	4-5cm	6-7cm
Cow live-weight gain (kg/day)	0.02	0.39
Milk yield (kg/day)	5.7	6.5
Calf live-weight gain (kg/day)	0.70	0.83
% *Nardus* in diet (1988 data only)	22.1	18.9
% *Nardus* leaves grazed		
July	51.9	22.8
September	44.4	11.5
Grazed leaf length (mm)		
July	70.2	111.8
September	59.4	85.6

Table 1. The effects of inter–tussock sward height on cattle performance and Nardus *utilization*

Some results, obtained in 1988 and 1989, are given in Table 1. The cows on the 4-5cm inter–tussock sward height treatment gained virtually no weight over summer, while those on the 6-7cm treatment gained 0.39kg/day. Similarly the calf live-weight gain was reduced by 15% on the 4-5cm treatment, mainly as a consequence of reduced cow milk yield. A much higher percentage of *Nardus* leaves was grazed on the 4-5cm treatment, and those leaves which were grazed were grazed to shorter lengths. This was reflected in the diet of the cows, with those on the 4-5cm treatment having a higher percentage of *Nardus* in their diet.

The preliminary results from this experiment suggest that whilst the amount of *Nardus* consumed by cattle can be increased by increasing the grazing pressure, this can only be achieved at the expense of animal performance, particularly in terms of cow live-weight gain.
Contact name: **Iain Wright**

Modelling land and feed resource use by weaned suckled calves

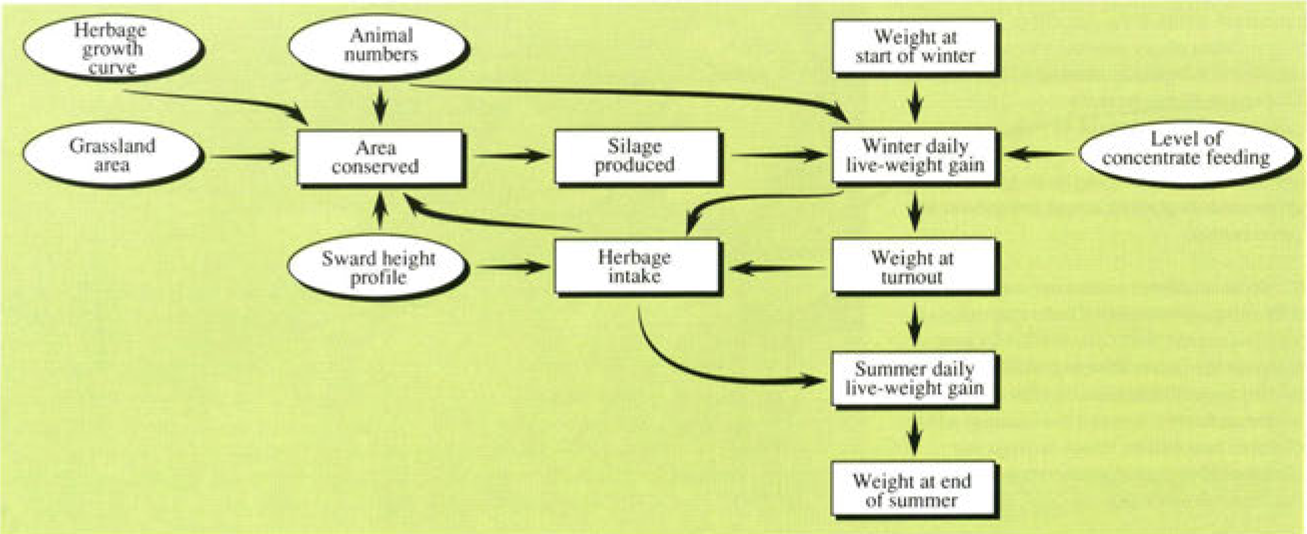
Information currently available on resource use by weaned suckled calves is mainly restricted to the responses of individual animals to feed inputs during discrete parts of the year, and, although relationships exist between level of individual animal performance at different times of the year, they take no account of the consequences for land use. For example it is difficult to assess the effect of changing animal numbers, in relation to the ability of the system to produce feed on a year round basis, on individual animal performance and total output.

To help examine some of these relationships a model of land and resource use by weaned suckled calves has been developed. A simplified version of the conceptual model is illustrated in Figure 1. The model assumes weaned suckled calves coming in to the system at the start of the winter feeding period, being overwintered on silage and concentrate, and then grazed at pasture during the following summer. The winter rationing part of the programme is based on standard rationing procedures. During summer, sward height is maintained at 8cm by weekly adjustment of the area available to the herd and two cuts of silage are removed from the remaining area in June and August. This silage is then fed to the next batch of cattle during the following winter. Currently a fixed herbage growth curve throughout the summer is used. Herbage intake and live-weight gains are calculated from relationships derived from experimental data.

The model can currently operate in one of two modes - it can predict either a) the number of animals of a given type that can be kept for a given set of resources and inputs or b) the amount of additional feed that needs to be brought in to the system (in the form of concentrate feed in winter) to sustain a given number of cattle at a specified level of performance on these resources.

Table 2 shows some output from three runs of the model. For a given area of grassland

Figure 1. Simplified model of resource use by weaned suckled calves.



	Number of cattle 200	225	250
Winter live-weight gain (kg/head/day)	0.90	0.75	0.50
Live weight at end of summer (kg/head)	565	553	500
Total live-weight gain over winter plus summer (t/50ha)	53	57	50

Table 2. Predicted response to keeping 200, 225 or 250 weaned, suckled calves on a grassland area of 50 ha with 128t concentrate being brought in.

(50ha) and a fixed total amount of concentrate to be fed in winter (128t) it is possible to keep different numbers of animals of 300kg live weight at the start of winter. Table 1 shows that as more animals are kept, the lower the level of individual live-weight gain in winter and the lower the individual live weight at the end of the summer. However, maximum live-weight gain from the system is higher when 225 cattle are kept compared to keeping either 200 or 250.

The model can be further developed to alter the seasonal level and pattern of herbage growth and so simulate different land classes or levels of fertilizer input. Consideration of the removal of cattle for slaughter at different dates is also possible. The model is currently a biological one, but in order to relate the value of different inputs and outputs a financial element requires to be imposed. However, it is clear that with these additions the model will have the potential to predict the ability of land to be used for the rearing of weaned suckled calves and how that ability may be influenced by altering the level of inputs to the system.

Contact name: **Iain Wright**

Comparison of two varieties of oilseed rape in feeding trials with red deer and sheep

There have recently been reports from some parts of Europe that the mortality of roe deer has increased in areas where oilseed rape crops are grown. These reports have coincided with the introduction of new 'double-low' varieties of oilseed rape, which were introduced to meet new EEC regulations on reduced levels of glucosinolates allowed in rape seed, since the seed residues are subsequently processed for animal feed.

To test the hypothesis that double-low varieties of oilseed rape might be more palatable, and thus potentially more harmful to ruminants than the single-low varieties, voluntary intakes of two different varieties of oilseed rape were compared with male red deer calves and Scottish Blackface wether lambs. A double-low variety (Ariana) and a single-low variety (Bienvenu) were each offered *ad libitum* to eight deer calves for 5 weeks and to four lambs for 3 weeks in February and March 1989. Whole rape plants were harvested daily and offered to the animals fresh. Twice weekly blood samples were taken and packed cell volumes measured as an indication of anaemia.

Voluntary intakes of both varieties of oilseed rape increased throughout the feeding period for both the deer calves and the lambs. Initially the voluntary intakes of the double-low variety were higher, but after a few days voluntary intakes of the single-low variety increased above those of the double-low and remained consistently higher throughout the rest of the feeding period (Figure 2). Intakes of oilseed rape by the deer were low and after the first week the deer were also offered hay, so that oilseed rape formed between 0.50 and 0.65 of the diet for the red deer as intakes increased.

For both varieties of oilseed rape the proportion by weight of stem increased over time with the growth of the plants, and during the last two weeks of the feeding period the deer selected a higher proportion of lamina and lower proportion of stem than the material offered for the double-low variety. The lambs consistently selected a diet with a higher proportion of lamina than the material offered for both varieties of oilseed rape.

Chemical analyses of the plant material demonstrated higher concentrations of s-methylcysteine sulphoxide (SMCO) and total glucosinolates in the double-low compared with the single-low variety of oilseed rape. Within

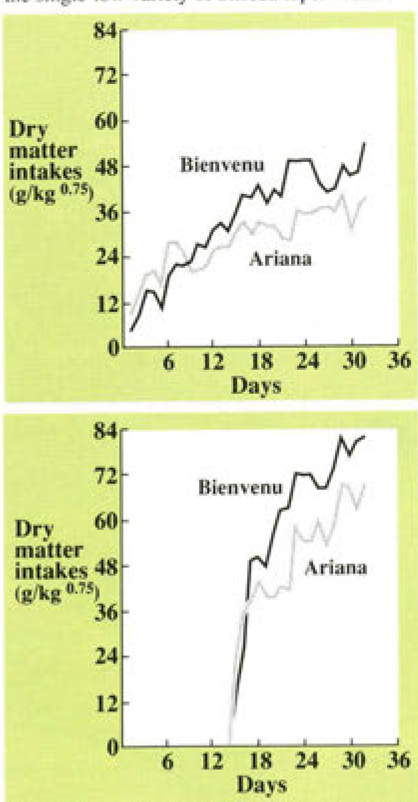


Figure 2. Intakes of oilseed rape by red deer (top) and sheep (bottom).

the double-low variety, there were higher concentrations of SMCO and total glucosinolates in the stem compared to the lamina. The higher concentrations of these sulphur-containing compounds were associated with lower intakes by both animal species, when comparing the different oilseed rape varieties and also when considering selection between plant components. In contrast, there were no differences in nitrogen, soluble carbohydrate or fibre content associated with these differences in intake.

There were signs of the development of anaemia in the deer calves after 5 weeks of oilseed rape ingestion, with the mean packed cell volumes reduced by 7.5% and 12.4% for the single-low and double-low varieties respectively. However, the evidence presented above lends no support to the hypothesis that the intake of double-low varieties of oilseed rape by ruminants will be higher than that of single-low varieties, with a consequently more rapid development of pathological conditions. The evidence does however indicate a negative relationship between SMCO and glucosinolate content of oilseed rape and intake by both sheep and red deer.

Contact name: **Angela Sibbald**

Compensatory growth in lambs: the trade-off between feed inputs, carcass composition and finishing date

Hill and upland environments are characterized by seasonality of climate and plant growth. Animal production under such conditions has

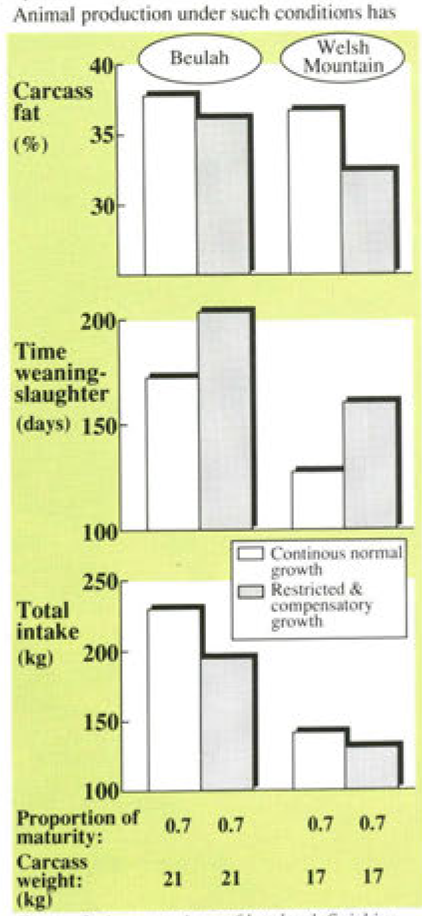


Figure 3. A comparison of key lamb finishing characteristics of Beulah and Welsh Mountain lambs reared to 0.7 of maturity with and without a period of food restriction.

traditionally required additional inputs or conservation of forage for overwinter use. Following periods of food restriction as would occur seasonally under natural conditions, growing animals often undergo compensatory growth, during which food intake and efficiency of conversion of food to body tissue increase. Natural cycles of food supply provide conditions suitable for exploitation of this phenomenon.

Factors that affect compensatory growth include the nature of the food restriction, i.e. whether it is energy or protein supply which is limiting, the duration of restriction, or its severity. When considering the growth of weaned lambs from a range of genotypes, many of the differences in growth characteristics and body or carcass composition arise due to differences between them in mature adult size. Thus at a given date and age, lambs may be at different stages of growth. Most of these differences disappear when comparisons are made at the same proportion of mature live weight. An experiment has recently been conducted which controls for all the above factors whilst investigating the nature and extent of compensatory growth in two Welsh genotypes of lamb, the Beulah and the Welsh Mountain, with contrasting adult mature body size.

Results show that when a 3-month period of body weight stasis in the autumn is incorporated into the feeding regime, then the subsequent compensatory growth period results in greater daily live–weight gain than on normal growth during continuous feeding. This increased LWG persists for longer after realimentation in Welsh Mountain lambs than it does in Beulah lambs. It is not accompanied by a correspondingly higher level of food intake during this longer period of enhanced live–weight gain.

The Beulah lambs have a larger carcass relative to live weight than the smaller Welsh Mountain genotype when compared at the same proportion of maturity. The composition of the carcass also differs between the two genotypes, being leaner in the Welsh Mountain than in the Beulah (Figure 3). The proportion of protein in the carcass weight gain was greater in the Welsh Mountain lambs during compensatory growth (CG) than during normal growth (NG) (NG:0.098, CG:0.123, $P<0.05$), but was not significantly greater in the Beulah (NG:0.106, CG:0.118, NS).

When reared to slaughter at small carcass weights or proportions of maturity, the total food intake of both genotypes was higher in the restricted and realimented groups than in the continuously fed lambs. However, when reared to larger carcass weights or proportions of maturity, then the total food supplied to achieve equivalent carcass production was lower for the restricted and realimented lambs than for those undergoing continuous growth. Although carcass composition of the two genotypes is similar during normal growth, under conditions of compensatory growth the Welsh Mountain lambs become relatively leaner and less fat than the Beulah lambs. The results demonstrate the need to make careful choices of genotype and to consider the desired carcass composition and timing of finishing when using compensatory growth to maximum effect.

Contact name: **Glenn Iason**

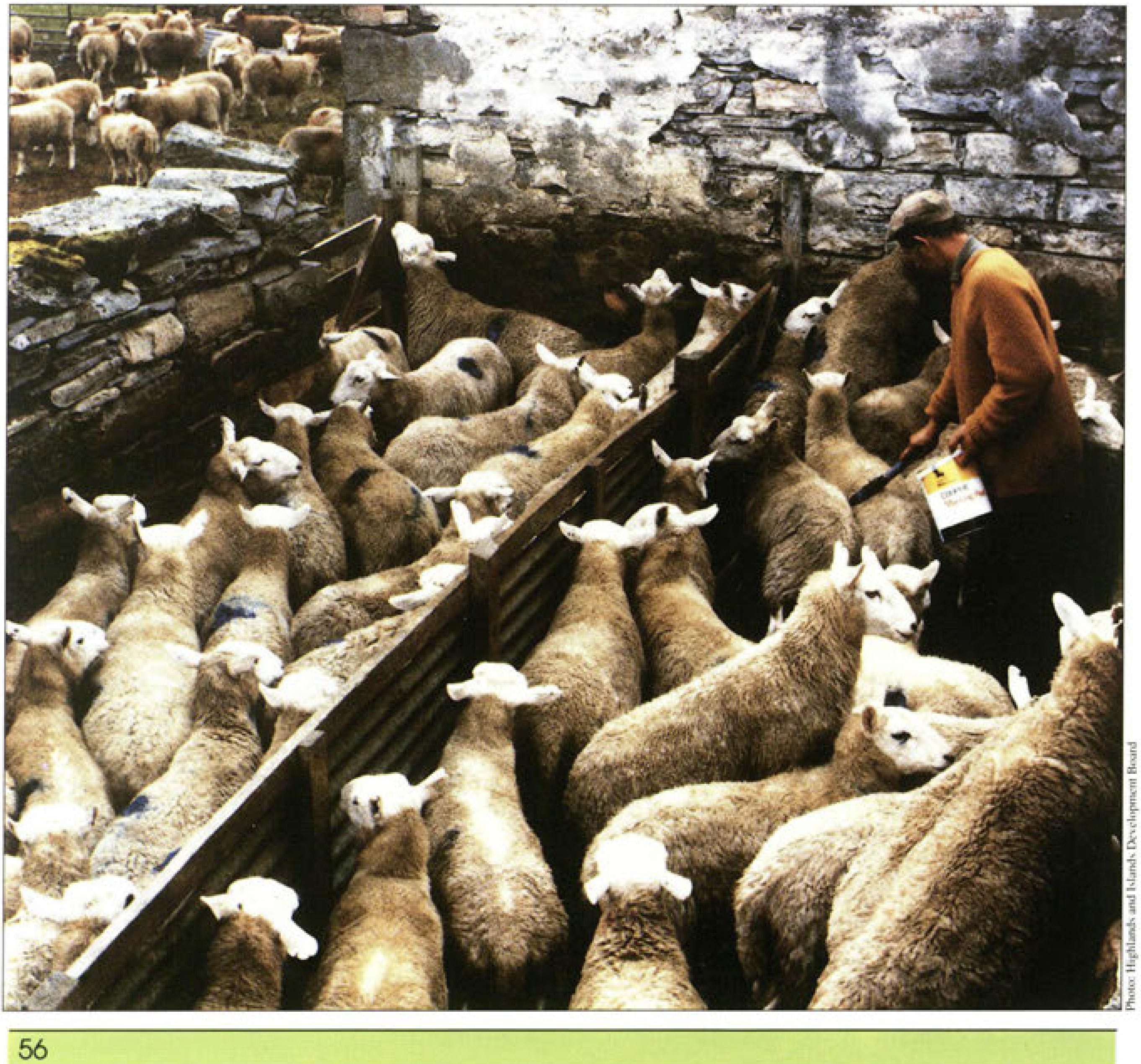


Photo: Highlands and Islands Development Board

Factors influencing reproductive performance in beef cows

Reproductive performance is one of the most important factors determining the efficiency with which beef cows utilize resources. However, all too often, the reproductive performance of beef cows is less than desirable with the mating period, and hence the calving interval, having to be extended to ensure a low proportion of barren cows. Also the consistency and predictability of reproductive performance is not high. The factors determining reproductive performance are, as yet, not clearly identified. Research in this area is difficult, not least because of the large numbers of animals required. Within any one herd in a year under UK conditions there are rarely sufficient animals with which to show statistically significant effects. However, by pooling data over a number of years, it is possible to produce data sets with sufficient observations to allow relationships between management and nutrition and reproductive parameters.

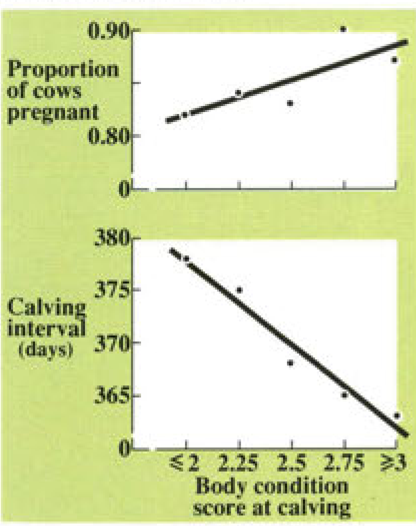


Figure 1. The effect of body condition score at calving on calving interval and proportion of cows becoming pregnant.

To assess the effects of a number of factors on reproduction, data were available from 321 spring–calving cows used in a series of grazing experiments between 1984 and 1987 at MLURI. For all cows, details of age, breed (237 Hereford x Friesians and 84 Blue-Greys), calving date, body condition score and live weight at calving and calf birth weights were available. For 226 cows data were also available on body condition and live weight at the start and end of the mating period and calf live-weight gain until the end of the mating period. Cows had been maintained indoors during winter and turned out to pasture in mid-May. Mating to Charolais bulls lasted 9 to 10 weeks and started within one week of turnout.

The overall pregnancy rate was 84% and the calving interval of pregnant cows was 370 (SD 18.9) days, with the mean interval from the start of mating to conception being 25 (SD 16.9) days.

There was a tendency for cows in higher body condition at calving to have a higher probability of becoming pregnant (Figure 1) and cows which were fatter at calving had shorter calving intervals. Body condition at the start of the mating season explained less of the variation in calving interval than that at calving and live weight at calving was not related to reproductive performance. Cows which were fatter at calving lost more weight between calving and the start of the mating period and gained less weight during mating, but live-weight change did not affect reproductive performance.

Calf birth weight and live-weight gain had no effect on cow reproductive performance but after adjusting for body condition and calving date 90% and 83% of the Blue-Greys and Hereford x Friesians became pregnant. In Hereford x Friesian cows above 7 years of age there is a significant decline in the number of cows becoming pregnant. There was no effect of age on reproductive performance in Blue-Grey cows (age range 4 to 10 years) nor in 4- to 7-year old Hereford x Friesian cows.

Although it was possible to relate reproductive performance to a number of factors and body condition at calving in particular, only 42% of the variation in reproductive performance was accounted for by these factors. This suggests that a number of as yet unidentified factors influence reproductive performance.

Contact name: **Iain Wright**

Studies on the manipulation of cashmere growth and shedding

One of the main difficulties facing cashmere producers in the UK is how best and when to take the annual harvest of fibre.The fine undercoat of cashmere produced from the secondary skin follicles is considered to stop growing in response to increasing daylength following the winter solstice, and is shed from the follicles at some subsequent stage. The mechanisms which cause shedding are not fully understood, but are likely to be influenced by both genetic and environmental factors, the latter including nutrition, body condition, physiological state and general health. In practice, the timing of the moult varies considerably between individual animals and, in a herd comprising different breeds and crosses and with animals of different ages and in varying condition and physiological states, can extend over a period of months from late January until May (Figure 2).

If cashmere is to be harvested by combing, the timing of the operation for each animal is critical. The undercoat cannot be combed out until the individual has started to moult, but if left too long there is the risk that a substantial proportion of the fibre will have fallen out and been lost. Thus the operation of combing can continue over a period of some months.

The alternative method of harvesting is shearing. Ideally this should be done before shedding starts to avoid any loss of fibre. In practice this means that shearing is carried out in late January or February and thus entails a period of inwintering until May with consequent high feeding and housing costs.

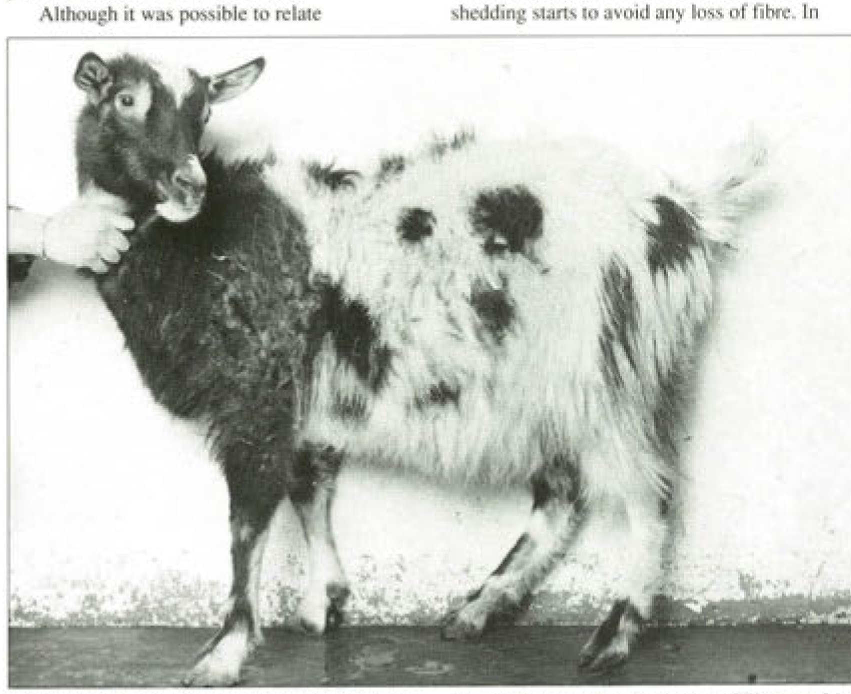


Figure 2. Assessing the degree of fibre moulting in studies on the growth and shedding of cashmere.

The manipulation of the cycle of cashmere growth and shedding could have important implications for harvesting by either method. Results of recent research indicate that such manipulation may be possible. It has been shown, for example, that the increase in plasma prolactin concentrations which occurs naturally in response to increasing daylength is associated with the initiation of the moult. Administration of endogenous prolactin has been demonstrated to advance shedding and in theory could be used to synchronize the moult and thus allow

combing to be carried out over a short and predetermined period. Prolactin, however, could not be used in commercial situations, but it is possible that some other treatment may be found which would have a similar effect.

The research results have also shown that bromocriptine, a dopamine agonist, has the opposite effect on fibre shedding, as might be expected from its known inhibitory effects on endogenous prolactin secretion. The administration of bromocriptine has been shown to delay the moult to the extent that in theory shearing could be carried out in May without any risk of losing valuable fibre through shedding and hopefully without the need to house the animals for longer than a few days. As with prolactin, the treatment of herds of goats with bromocriptine is impracticable, but the results nevertheless indicate the potential for manipulating fibre growth and shedding and highlight the need to investigate alternative, less expensive and more practicable means of achieving the same ends.

Contact names: **Angus Russel, Pamela Lynch**

Cashmere production from goats and its improvement by cross-breeding and selection

The Institute acts as managing agent to Cashmere Breeders Ltd. (CBL), a co-operative currently comprising 11 farmer members plus the Institute, and expected to expand to 18 members in the current year. The group's objective is to breed and market goats producing high levels of quality cashmere, and as part of its responsibility as managing agent the Institute advises CBL on its breeding programme and manages its élite herd.

The breeding programme is being pursued in two stages. The first is the cross–breeding of native feral goats with imported genetic material. The native stock is hardy and produces significant but non-commercial quantities (<100g) of high-quality cashmere (14µ mean fibre diameter). To increase the level of production while maintaining a high quality of fibre the feral goats are being mated with stock from Iceland, Tasmania, New Zealand and the USSR. The Icelandic goats have greater quantities of relatively fine cashmere (<16µ) and a thick guard coat which would appear to afford the protection required for outwintering on Scottish hill farms. The Australasian stock are largely white, the desired colour, and produce around 300g of moderate-quality fibre, while the Altai Mountain goats from southern Siberia have very high levels of production

Figure 3. Does and cross-bred kids in Cashmere Breeders Ltd. élite herd at Sourhope Research Station.

(>500g) of generally poorer-quality dark-coloured fibre.

The breeding plan involves the establishment of 16 three-way crosses with 25% native and 75% exotic material. These cross-breeds are currently being produced on members' farms, with modern breeding methods being used to increase the numbers of improved cross-breeds. Fibre samples from five-month kids and yearlings from each of the crosses are evaluated in the Institute's fibre laboratory.

The results to date indicate a large degree of variation between the crosses in the important production traits which should enable effective selection to be made on the second phase of the breeding programme - the establishment of a group breeding scheme with stock being supplied from members' farms to form a nucleus or élite herd at MLURI, Sourhope Research Station. Selection lines will be created, firstly, to maximize financial returns from fibre by placing the emphasis on weight of cashmere with a constraint on increase in fibre diameter, and secondly to establish a line in which quality is given greater emphasis than quantity.
Contact name: **Angus Russel**

Figure 4. Tasmanian fine wool Merino x Shetland lambs are being evaluated for their hardiness and wool characteristics at Sourhope Research Station.

The biological and economic possibilities for wool production in the hills and uplands

Current pressures on livestock farming may change the relative importance of traditional products, with greater emphasis being placed, for example, on animal fibre production and less on meat production. Against this background a desk study was undertaken with Mr Geoffrey Saul, a visiting scientist from the Pastoral Research Institute in Hamilton, Australia, to examine the likely biological and economic consequences of changing the breed structure of sheep enterprises in the hills and uplands to give increased emphasis to the production of fine and semi-fine wool.

The study examined the probable effects of mating Australian Fine-wool Merino rams with hill North Country Cheviot ewes, and of using European Merino rams on either pure or Australian Merino x North Country Cheviot ewes on upland farms. Other simulated systems examined included extensively and intensively (housed) managed self-replenishing flocks of pure-bred Australian Fine-wool Merinos, and also a 3/4:1/4 Fine-wool Merino-Shetland fixed breed. These possible systems were considered under wide ranges of costs and prices.

The results indicate that even with the payment of a substantial premium for ewe lambs and subsidies on wethers, the use of Fine-wool Merino rams over North Country Cheviot ewes is not likely to increase gross margins on hill farms. The need to purchase replacement stock in what have been traditionally self-replenishing flocks would more than offset gains from the sale of higher priced breeding females. Increased returns from wool from extensively managed Fine-wool Merinos would not be sufficient to make up for the reduced income due to lower weaning percentages. With intensive Fine-wool Merino systems, where weaning percentages might be maintained, the benefits would most probably be insufficient to cover the high costs of long periods of winter housing. Problems with feet and wool disorders would also be likely to add to costs.

Fine-wool Merino x North Country Cheviot wether systems were calculated to be 50-60% less profitable than hill ewe systems.

None of the range of probable new systems considered for upland farms was considered likely to yield better gross margins than traditional systems and indeed most were likely to result in substantial reductions. Neither was there likely to be any benefit from the inclusion of Fine-wool Merino genotypes on low ground farms where two- to three-fold improvements in wool returns would probably be offset by lower lamb outputs and higher wool preparation costs.

The system which the desk study identified as showing most promise is on hill farms and involved the use of a 3/4:1/4 Fine-wool Merino-Shetland cross which could be established as a fixed breed. The Shetland is probably the finest-woolled of the native breeds and, although small, is reported to be hardy and reasonably prolific. This particular cross-breed is currently being established at Sourhope Research Station to obtain quantitive information on its wool characteristics, its lamb and wool production, and its suitability to hill farms.
Contact name: **Angus Russel**

Photo: Hugh Webster Photography Strathpeffer

FARMING, FORESTRY and the ENVIRONMENT

trying to achieve an integrated approach to rural development in the Highlands and Islands

Sir Robert Cowan

1: Introduction

Not since the days of Sir Thomas More, Francis Bacon, or even as far back as Thomas Aquinas, has it been possible for one person to know all there is to know. From their time onwards we have been increasingly at the mercy of specialists - including those who eventually end up knowing everything about nothing.

I for my part have always been too idle to be a specialist, and so I try to make a virtue out of being a "jack of all trades". You could argue perhaps that I know nothing about everything.

Recognizing this unavoidable truth it is with some anxiety that I come to this distinguished institute of learning which has, over many years, established a reputation for knowing a great deal about land and how it can be used. The subject is, of course, a very large one and at this time, when attitudes and practices related to land use are going through profound changes, the amount that is being thought, said and written about it is more than usually daunting. I therefore rapidly gave up aspirations to saying anything original this afternoon. It has all been said before.

So why do I presume to ask you to stay and listen to me? If there is any reason it is because I believe that we in the Highlands and Islands have for some time now been living in the future. I find myself a little like *Le Bourgeois Gentilhomme* who suddenly realized that though he might not be a poet he could at least speak prose. Perhaps the day of the generalist is at hand. Perhaps the work of the Highlands and Islands Development Board, which has the powers to take a broad spectrum or generalist approach to alleviating the problems of its area, has acquired experience that is now becoming more widely fashionable or relevant. You can see therefore why the word "integrated" is prominent in the title of my paper - and this at a time when the Board itself is facing a measure of disintegration.

2: The current Highlands and Islands land scene

Patterns of land output and employment

Though I am sure that most of you will know the Highlands and Islands, perhaps very well indeed, please forgive me if I set the scene for what I am going to say. I propose to summarize the current pattern of land use in our area and describe its economic significance.

The figures (Table 1) underline that most of the Highlands and Islands are classified often euphemistically, as "rough grazing": that forestry is still quite small (13% compared with the UK average of 15% and the European Community's 25%). National Nature Reserves in total are also small, though about one third of the whole area has some form of conservation designation, in particular National Scenic Areas and Sites of Special Scientific Interest.

	'000 hectares	Percent
Agriculture		
Rough grazing	2 848	
Crops/grass	245	84
Forestry		
Commission	257	
Private	211	13
Nature reserves	80	
Built up areas	19	3
	3 660	**100**

Table 1. Land use pattern in the Highlands and Islands.

Use of the term "rough grazing" highlights the traditional view of land as an agricultural resource. Much of our rough grazing is also a resource for often rather smooth sport, as well as for other forms of leisure and recreation. We do not reliably know the value of these activities, but I would estimate the other figures to be approximately as shown in Table 2.

	£M
Agriculture	220
Forestry	25-30
Horticulture	5
Field Sports	60-65
Skiing	20
	£300 plus
Other recreation	**?**

Table 2. Estimated values of outputs from land use in the Highlands and Islands.

You will see that I have not even guessed at the total leisure and recreation element. It might be argued that few of the tourists who spent some £400 million in the Highlands and Islands this year would have bothered to come if it were not for our land resource, and uniquely beautiful and diverse landscape.

Our land therefore yields several major "crops". Fortunately they are not as a rule mutually exclusive alternatives. The same hillside can accommodate livestock, forestry, shooters, twitchers and orienteers, but only with goodwill and appropriate forethought.

To give a little more detail - Highland agriculture is dominated by livestock - just over 70% of total income with, perhaps surprisingly to some, beef being more important (40%) than sheep (32%). Cereals amount to less than 20% and milk 10%.

It is an area of small land holdings - 22,000 in total with an average of 6 cows and 50 ewes per holding of 165 hectares - but these averages include very wide variations. Nearly 18,000 of the holdings are crofts but only about 500 of these provide full-time employment for their occupiers. There are thus only about 4,500 farming units supporting people in full-time employment.

Employment in agriculture is declining with a switch from full-time to part-time. There has been relative stability in the 80s but the trend has probably again moved downwards in the last year or two, particularly in areas like Caithness and Sutherland.

There has also, during the period, been some increase in the number of spouses recorded as employed, though I suspect this has more to do with the taxman and the accountant than any shift in working pattern. The figures for spouses are additional to those shown.

	1970	1980	1985
Full-time			
Occupiers	2 881	2 753	2 999
Hired/family	4 567	3 321	2 925
	7 448	**5 984**	**5 942**
Part-time			
Occupiers	2 894	4 317	4 602
Hired/family	1 227	884	680
Seasonal	769	773	649
	4 890	**5 974**	**5 931**

Table 3. Employment in agriculture in the HIDB area.

Employment in forestry is less well documented, partly because it is often contract labour that is highly mobile. This has been used as a reason for denigrating the industry, but as the scale increases in an area, even contract labour is usually drawn from relatively local sources. Undoubtedly there has been a significant decline since the 1988 Budget but we estimate that around 2,000 full-time equivalent jobs are provided by forestry, not including the 500 or so in saw-milling and Highland Forest Products.

	Man years
Agriculture	9 500
Forestry	2 000
Estates	1 000
Public Sector	320
Approx	**13 000**

Table 4. Current employment - HIDB Area.

Estates are also poorly documented but we estimate that they account for about 1,000 man years of employment.

Then there is the public sector. All the agencies, Department and local authorities employ over 300. Our best estimate of current land-based employment in the Board's area is therefore as shown above in Table 4.

This represents 8.5% of the total Highland population in work

- whether employed or self-employed. For comparison we believe the figure for tourism employment would now be at twice this level with manufacturing and construction each about 25% more significant - and more so in money terms since agriculture is not renowned for high wages and profits.

Consider then the conclusions that may be drawn, and others that might wrongly be drawn, from a look at land-based employment.

The first is that agriculture is of declining and relatively minor employment-generating importance, even in areas as "truly rural" as the Highlands and Islands. If this is added in support of the prevailing backlash that is affecting agriculture generally just now, namely the perception that farmers are producing food that nobody needs by methods that nobody wants, with public money that could be better spent in other ways, you have a powerful lobby for abolishing support for our agriculture.

In the context of the Highlands and Islands however this view is wrong on all counts.

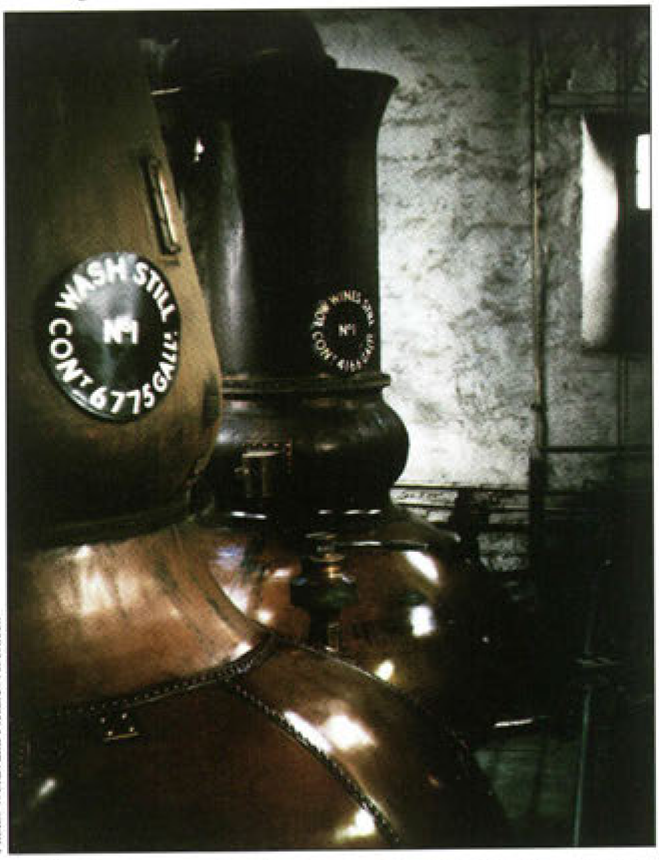


Photo: Words and Pictures Aberdeen

Firstly we are not producing surpluses but products that are in demand because they come from a "natural" relatively low input environment and can supply local and premium markets in a cost-effective way. There is, or can readily be created, a strong demand for, for example, malting barley, Orkney beef, or the specialist cheeses from island creameries.

The conclusion also undervalues the worth of the many who are barely classifiable even as part-time farmers but who derive income from the land, which is why they stay where they do. There may be as many as 15,000 people in this category though in the employment statistics they are classified in another sector. I could easily argue therefore that at least one in five of our economically active people are at least partly "land-based". These are the, often under-paid, managers of our countryside and the backbone of almost all the more remote communities. So in the Highlands and Islands agriculture support is doing very little harm and a great deal of good, to a wider cross-section of the population than may, on the face of it, be realized. It is absolutely essential to the well-being of the area.

Of course the agricultural subsidy is expensive - £81 million in the Highlands and Islands in 1988 - and one could argue that it might be spent in different ways - even transferred to the Highland Board's budget for example! But since this is not a realistic option I would argue for the continuation of present mechanisms, but with different priorities as appropriate, for without it there would be drastic loss of population from our remote farming areas.

The second conclusion you might be tempted to draw is that forestry and sporting estates are of little significance in terms of employment, and if you believe they are undesirable for other reasons, then they too should be discouraged. Here again I leap to the defence.

Certainly mistakes have been made in forestry. There have been undesirable side effects, as with most industries, but these we are learning to minimize and control. We now have a strong forest industry in Scotland, with enough investment in down-stream processing to ensure continued demand. It does produce valuable employment in rural areas, and would do so more effectively if it were allowed a stable régime to work within. I do not want trees everywhere, I do want them to be planted and harvested in environmentally friendly ways, and ways that accommodate other land uses. I do want modest expansion, for which space can be available at no detriment to the balance of interests, but to achieve it we need a consistent level of Government support. Forestry was beginning to employ a permanent force of local people in the Highlands till the Chancellor responded to those who don't like Terry Wogan getting any richer. It is sharp changes in policy, not foresters, who create the "gang labour" syndrome.

Then the estates. I must be careful what I say about the lairds if I am to escape the ravages of the West Highland Free Press, so I would only emphasize that most of the revenue derived from sport in the Highlands percolates through to local wages and local businesses, often in very remote areas.

Patterns of land ownership and control

Talk of lairds gives a cue for some points on Highland land ownership. This is both highly uneven, and inadequately documented. Official statistics are collated on the basis of farm units rather than ownerships. Nor does the official data reflect the true locus of control over land, for a single individual can own several units, some of which may be tenanted and one unit can incorporate both owner-occupied and leased land. These figures do show however that 82% of the land area in the Highlands and Islands is contained in about 25% of holdings. The difference is of course partly a reflection of the types of land use carried out, with hills and mountains predominant in our area. There is also the special factor of crofting tenure.

Nearly 60% of units in the Highlands and Islands are below 80 acres (c.32 ha). Land which is owner-occupied accounts for about half of our area, with the remainder equally divided between crofting tenure and leasehold tenure. Public land ownership extends to 650,000 hectares or 18% of the land area with the majority of this owned by the Forestry Commission.

There is therefore, a very varied mix of land ownership and tenure in the area involving many different kinds of people with very varied interests. This has added to the difficulties of achieving any coherent policies and controls.

Controls exist over most primary changes of land use through planning acts administered by local authorities, while changes from agriculture to forestry are controlled by the Forestry Commission - except for private forestry undertaken without grants.

Three difficulties in the present system of controlling changes in land use were referred to in the Highland Board's evidence to a Parliamentary Committee. First, the constraints presently applied tend to act as negative controls and not as a positive means of promoting regionally desirable developments. Secondly, decisions on changes in use tend to preclude a comprehensive approach and are usually made with reference to a choice between current use and the alternative under consideration. Thirdly, despite work by agencies like the Macaulay Institute, the Countryside Commission for Scotland, the Local Authorities and the Board, a coherent strategy for land use in Scotland is lacking. Such a strategy, in my view, is badly needed, but it should not be seen as any kind of rigid blueprint. Attitudes and needs change over time. As one example of this it can be recalled that NCC's review of conservation strategy in 1977 devoted only one short paragraph to the so-called Flow Country. Things were different ten years later!

It must also be remembered that plans and planners do not make things happen and they must bend though not capitulate to opportunity and those that do.

The Flow Country debate has however, provided the trigger for a momentous step forward. When the dust began to settle after the "moratorium of forestry" announcement, Highland Regional Council convened a working group of the various interested bodies, including both NCC and HIDB. That group did produce an indicative land use strategy agreed by all parties. It was an example of how compromise can be achieved by getting people round a table. The tragedy is that extremists not at the table can see agreement as a "sell out". However the Government has now recognized the need for indicative forest strategies, and these are being drawn up. We very much welcome this.

3: Culloden was not the last Highland battlefield

Probably the main reason why we do not have more widespread strategies for land use is because it is only comparatively recently that they have seemed necessary. When our remote areas were really remote, few people, except those who lived there, cared about them and there seemed to be very few uses to which the land could be put. Now that has completely changed as a side-effect of development and better infrastructure. Now there are increasing numbers of people, increasingly far-distant, who have increasingly diverse and divergent views on Highland land use. Some want change and others do not. I have attempted to illustrate this in Table 5. It is, of course, an over-simplification since people do not fit neatly into boxes, and at different times they change the box they fit in.

This is, in essence, a diagram of a battlefield with both attitude to change and degree of involvement in the local community giving rise to conflict. Being at opposite sides or ends of the matrix will tend to trigger the most vigorous conflict. Spot your enemies!

If we want to reduce the amount of blood that is being spilt on this battlefield then we have to seek ways of achieving a truce, or as far as possible devising a strategy that satisfies all interests. I would argue that all the interests have to be taken seriously, though the more "local", the more weight they should be given.

It is my belief in the importance of the local view and sensitivity to it that makes me strongly support the move to decentralize the NCC into Scotland. It is nonsense to argue that this need weaken the scientific base or concern for national or international issues. Communication technology can ensure that this does not happen. The simple truth is that NCC staff who live in the Highlands are widely respected, partly because they are prepared to set their concerns in the context of other local concerns. It may modify their views slightly but it gives them vastly more weight and acceptability.

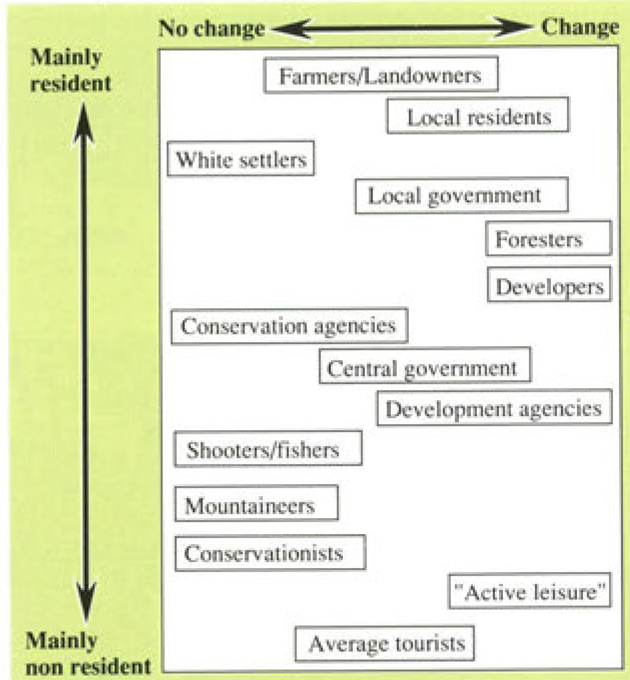


Table 5. Attitude to change in the countryside.

4: Integration from the bottom up

I said at the beginning that I thought that the HIDB was living in the future, that perhaps we can show the shape of things to come. Let me try to justify this comment.

Much of the administrative machinery of this country is designed in spokes that emanate from a single hub. Even regional local government has an element of this, but as far as central government is concerned we have different departments that deal with different aspects of life such as agriculture, health, industry and education. The further away from the centre, the more these functions are separated and the less the centre appreciates the needs of the periphery.

Those who set up HIDB recognized this, so we were created as a unique organization - a central government body but with delegated authority to deal with a remote area from a remote base, and across a broad spectrum. Of course we too are somewhat centralized in Inverness, and are not responsible for many functions of government, but we are responsible for the well-being of an area. We can deal with many aspects of social and economic activity at one hand and advise, facilitate and fill gaps in other sectors. I like to boast that in my job I can dabble in anything and justify it as being work.

It is generally accepted that the gamble taken in 1965 to set up a Highland Board has paid off. Since then, there has been a dramatic growth in the numbers in full-time employment - from about 130,000 to over 150,000. In 1965 employment was twice as high in the HIDB area as in Scotland as a whole, and four times the level of the UK. Now the level tends, if anything, to be lower than in Scotland as a whole.

Over the last ten years the Board has assisted over 11,000 individual businesses - farmers, crofters, horticulturists, deer farmers, auction marts, saw millers and wood processors, fishermen, boatbuilders, fish farmers, fish processors, hotels, guest houses, restaurants, visitor centres, engineers, craftsmen, builders, nursing homes, community co-ops, high and low tech industries, environmental projects and skiing.

In doing so, the Board has helped to create over 20,000 new jobs and protected 7,000 others at a cost which means that, by and large, each job created or protected was a net profit to the tax-payer provided that it lasted just one year. And most, of course, have lasted many years.

You see, I hope, why I said we had been operating in the future. One now hears much about rural diversification and integrated development. We have been doing it for nearly twenty-five years.

For small very rural areas the broad spectrum or integrated approach is particularly appropriate because these communities themselves are integrated not compartmentalized. People earn their living often through several different activities, and the same people are often involved in many different aspects of community life. It is convenient therefore, and cost-effective, if in these circumstances they can receive many services through one delivery mechanism. In fact, there is still a bewildering array of public organizations dealing with the rural areas - just try to list them! This is why I support the bringing together of the NCC and the Countryside Commission and the Training Agency with the HIDB, and I would even suggest there could be, with advantages, further mergers between organizations - please do not ask me to be specific on this one though.

Photo: Highlands and Islands Development Board

Although the HIDB itself can deal with, among other sectors, agriculture, food processing, tourism, fishing and community development generally - and has been involved in agricultural diversification long before it became fashionable, we have more recently worked with other organizations in more focused area development programmes. The first was the IDP which brought extra European money into the Western Isles but the process can be effective without significant extra funds, as we have demonstrated in Skye and now North West Sutherland.

The North West Sutherland Development Programme was set up in July 1988, led by the Board, but with a steering group involving a mix of agencies from the Area Tourist Board to the NCC. Its aims are to increase the income of the area and encourage a broader base through more varied and non-traditional activities. It expects to spend, in total public and private sector investments, about £5million over five years.

The key to any such programme, as we learnt first in the Western Isles, is the importance of communication. A series of public meetings to launch the programme were followed up by the project development officer in further more detailed meetings and discussions. A brochure describing the programme has been followed up by regular newsletters with the aim of keeping people involved and informed. Most importantly there is now a local community action group helping to maintain the momentum.

So far there have been over 200 enquiries from a population of fewer than 4,000 people and more than 100 plans have already been approved. Initially these were too much based on traditional agriculture, but this emphasis is changing.

Among other things the project has so far included:

- Training courses for B & B operators and for fish farmers
- Business counselling, both in general and specially tailored for small retailers
- The drawing up of a tourism development plan by the Area Tourist Board which is proposing projects from Crofting Life holidays to new interpretative centres.
- A variety of social development projects
- School liaison to encourage ideas from the schools and make children aware of local opportunities

All those involved, staff from the Region, the ATB, the North College and HIDB, and members of the community seem most enthusiastic and I believe lasting benefits are being generated.

The programme may seem very intensive in terms of both staff and money. It is. I learnt a long time ago, in my time as a management consultant in industry, that change does not happen because someone writes a report. Only by generating ideas from the bottom up - a process that takes time and effort - and by demonstrating the benefits that can be achieved, does one gain motivation and commitment and, one hopes, a change of attitude that will be self-sustaining.

5: In conclusion - a plea for breadth of vision

It used to be a cornerstone of military discipline that the subjects of Women and Politics were not to be discussed in the officers' mess. These are issues strongly rooted in emotion, and any discussion was likely to lead to quarrels that would break down the camaraderie of the regiment.

Land is just as emotional a subject, and always has been. Perhaps all discussion on it should also be banned! If that is not possible the alternative can only be to accept quarrels. Disagreements over land use are going to continue whether we like it or not.

Thus the most we can aim for is to increase the area of agreement and reduce the area of conflict, accepting that agreement tends to be constructive, while conflict and confrontation are usually destructive.

If we wish to follow this route and achieve an integrated policy and pattern of land use, then we must first appreciate that:

- Many different kinds of people have an increasing and (usually) legitimate interest in our countryside. Our own interest is not the only right one.
- The status quo is not a realistic option. We live in a moving continuum. Change is inevitable.
- The Scottish landscape is not a "wilderness" but an environment that man has shaped and will shape to his ends. When he stops doing so he creates dereliction, but he can produce equally undesirable effects by the pursuit of narrow and short term selfish interests. But working the land, in old and new ways must continue.
- Dogmatic, inflexible and "single issue" policies have no hope of succeeding. A framework of evolving guidelines that provide a wider context for individual decision making can only be helpful.
- Everyone will have to compromise to achieve such guidelines.
- In spite of the strength and diversity of opinions more agreement can be achieved, but only by individuals round a table, not by groups and organizations arguing their case from a distance.
- Such agreement can best be achieved at a local level, but only after determined efforts to involve and inform all elements in the community.

There is a role in all this for everyone concerned about the land. The "Doers" must adapt - but continue doing. The "Advisers" must facilitate change through communication and training. The "Administrators" must set strategies not just controls, and must provide incentives to the "Doers" who alone can implement the strategies.

I began this paper by lamenting the passing of the "complete man" and the growing inevitability of specialists. The trouble with becoming too closely focused on single subjects, single issues or single goals is that it leads to tunnel vision. Never more than now we need vision in the countryside, but it must be a broad one that can see our land from many points of view.

Photo: Highlands and Islands Development Board

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Photo: Words and Pictures Aberdeen

SCOTTISH AGRICULTURAL STATISTICS SERVICE

The Scottish Agricultural Statistics Service (SASS) has its headquarters in Edinburgh, with units in Aberdeen, Ayr and Dundee. It comprises 20 consultant statisticians, plus computer specialists and support staff. At the time of writing (August 1990), the staff based in Aberdeen provide a consultancy service to MLURI at both Craigiebuckler and Pentlandfield, the Rowett Research Institute, the Scottish Agricultural College (Aberdeen), Torry Research Station and the Institute of Terrestrial Ecology at Banchory. In addition SASS staff within other units are responsible for supporting specific areas of application across all DAFS institutes. Thus major projects within any of the fields of chemometrics, environmental studies, image processing, systems modelling, food science, molecular biology and variety and crop system trials can call on the expertise of the relevant SASS consultant. The areas of environmental studies, image processing and systems modelling have particular relevance to MLURI. Further support is given in the form of courses in statistics, developed around the statistical packages Minitab and GENSTAT, which are offered to scientists from the SARIs and SAC.

Staff based at Craigiebuckler are responsible for coordinating SASS statistical research in environmental studies. The group comprises three statisticians in permanent posts and one on a three year contract. The contract post was established to meet the demands of a growing number of external contracts won by SASS in the environmental field, and part of the remit of the post is to help provide computer support to MLURI scientists. A consultancy desk is staffed every Thursday at MLURI, Pentlandfield, where SASS have had extensive input to grazing trials and other animal experiments. During 1989, the Craigiebuckler group continued their commitment to designing experiments for monitoring root growth and analysing data from such experiments. This includes the conversion of root counts along minirhizotron tubes in the soil to root length per unit volume of soil, which is collaborative work with Plants Division and with the research group at SASS headquarters. The SASS research group also collaborated with Land Use Division on image analysis projects and Soils Division on microbiological work. Analyses for projects investigating the forest ecosystem continued throughout the year. A major new commitment in the land use area was initial development of GENSTAT routines which might eventually be used to model and predict distribution of land use, crops, an animal or plant species, plant communities, a plant virus or a farm or forestry pest, given incomplete survey data or under various scenarios of climate or socio–economic changes.

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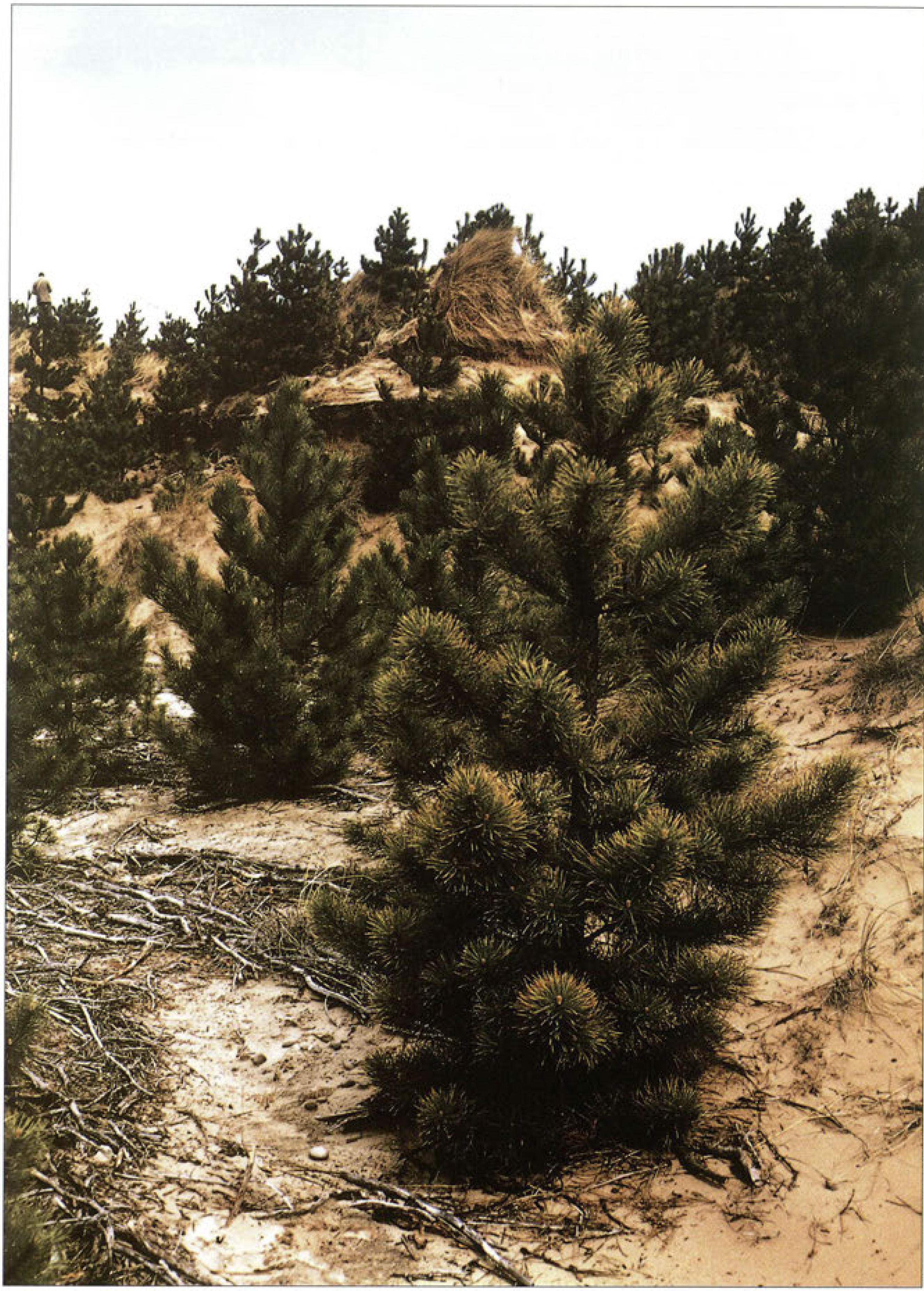

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