MLURI

Annual Report 1990-91

THE MACAULAY LAND USE RESEARCH INSTITUTE
Craigiebuckler Aberdeen and Pentlandfield Roslin

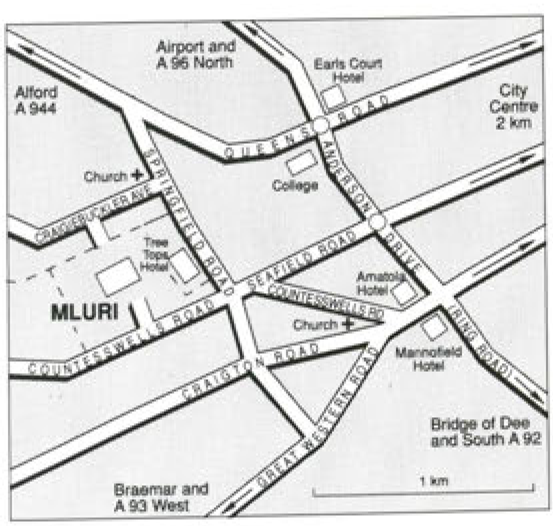
MLURI

The Macaulay Land Use Research Institute came into being on 1 April 1987 by a merging of the former Macaulay Institute for Soil Research (MISR) at Craigiebuckler, Aberdeen, with the Hill Farming Research Organisation (HFRO) at Bush near Edinburgh. The Institute is currently based on two sites. The administrative headquarters is at Craigiebuckler, on the site of the former MISR, where there are laboratories, offices and glasshouses.

The former staff of HFRO are based at Pentlandfield near Edinburgh, where there are offices and laboratories, and an animal house and laboratories nearby at Bush Estate.

It is the intention that by April 1992 all the laboratories, offices and staff will be established in the new building currently under construction at Craigiebuckler.

In addition, the Institute has five field research stations: Sourhope, Roxburghshire; Glensaugh, Kincardine; Hartwood, Lanarkshire; House o' Muir, Midlothian; and Rahoy, Morvern. It also participates jointly with the AFRC Institute of Grassland and Environmental Research at Bronydd Mawr at Brecon in Wales.



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THE MACAULAY LAND USE RESEARCH INSTITUTE

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Craigiebuckler Aberdeen AB9 2QJ
Pentlandfield Roslin EH25 9RF

Research Stations
Glensaugh, Laurencekirk, Kincardineshire
Hartwood, Shotts, Lanarkshire
Sourhope, Kelso, Roxburghshire
House o' Muir, Easter Howgate, Midlothian
Rahoy, Morvern
Bronydd Mawr, Trecastle, Powys
(with IGER-WPBS)

MLURI

MLURI

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The Howe of the Mearns near Laurencekirk

Remit

To undertake research, in the context of rural land use and resource management, with the objective of assessing the environmental, economic and social impacts of agriculture and related land uses, and the consequences of changes resulting from factors and influences such as policy, management, effects of climate, and pollution.

Mission

The Institute undertakes research for the Scottish Office, other agencies of central and local government and private contractors, to identify and characterize land resources, investigate the effects of land use policies, and the potential effects of alternative land uses in rural areas. The Institute is concerned with rural land use issues in Scotland, and with hill, upland and marginal areas which predominate in Scotland but which are also important in other parts of Britain, as well as in Europe and elsewhere.

The Institute aims to be internationally recognized for research in the following topics:-

1. Land use information and modelling systems and environmental impact assessment
2. Acidification and pollution of soils and water, organic matter turnover and soil mineralogy
3. Soil-plant relationships, including microbiological aspects and nutrient cycling on acid soils of high organic matter and low fertility
4. Vegetation dynamics and foraging strategies of grazing animals

The research demands a holistic and integrative approach calling upon the Institute's skills in land capability assessment and evaluation, remote sensing, geographic information systems, systems research and modelling, and socio-economics. The aim is to describe and quantify the inter-relationship between soil, plant, animal, economic and human resources, how these function, interact and change over time and what the development opportunities and their potential impacts are.

The Institute seeks to become a lead centre for interdisciplinary fundamental and strategic research with emphasis on soils, pastoral agriculture, farm forestry, pollution, and for developing methodologies to bring together and interpret information on land use. To achieve this the Institute uses and develops its expertise in strategic and underpinning research in soil science, soil-plant relations, microbiology, nutrient cycling, vegetation dynamics, foraging behaviour, the physiological ecology of animals, and resource use.

The Institute seeks collaboration in many areas of its research and links into a wider network of information and databases. It collaborates closely with AFRS Institutes and the Scottish Agricultural College, the Universities, and other relevant national and international organizations in Europe and elsewhere.

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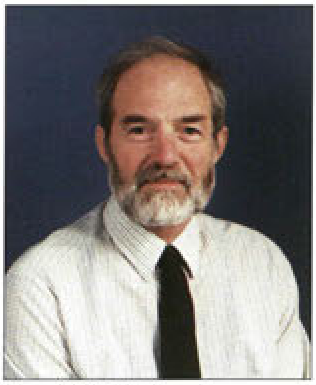
Director

Peter Newbould
Assistant Director



Donald W. Futty
Director's Scientific
Administrator

Susan P. Bird
Public Relations Officer

Robert B. Devine
Secretary

Change is something which permeates every aspect of life: if it is to be positive and constructive it needs to be planned carefully and at a rate which allows adaptability, flexibility and adjustment to take place. In the context of MLURI, the only institute in the UK with a specific remit for land use, change has dominated its own short life no less than the land use industries and the policies affecting the social, economic and rural environment with which it is concerned.

The Government White Paper *This Common Inheritance* defining Britain's Environmental Strategy was published in the autumn of 1990 with an emphasis on finding ways towards the integration of environmental considerations with economic activities in the countryside. An outcome of this policy was the creation of the Nature Conservancy Council for Scotland (NCCS) and the intention to merge NCCS with the Countryside Commission for Scotland (CCS) to form the Scottish Natural Heritage in 1992. The UK Government also supports strongly the reform of CAP, and the need to move towards more satisfactory world trading arrangements which is a major objective of the GATT negotiations. These are policy developments which already are having, and will continue to have, wide ranging economic and social effects on those who live and work in the countryside.

Nevertheless, the Government and EC economic and social aims for agriculture still appear to be oriented towards the stability of rural communities. But during 1988 and 1989, which was a relatively favourable period for world marketing, both EC surplus stocks and budget costs were reduced significantly; however, for various reasons this trend has not continued. Of particular significance to the hills and uplands is the fact that production of beef is increasing and stocks are fast approaching the record level of 1987; production of sheep meat continues to increase and its budgetary requirements have doubled over a four-year period. It is clear that schemes to take land out of agriculture, and diversify and extensify production, have not got to the root of the problem, which is that support to agriculture remains proportionate to the quantity of commodities produced: this factor preserves a permanent incentive to greater production and intensification. On the other hand a reduction in prices to re-establish market balance will require significant compensation measures not connected with volume of production if economic and social stability in rural areas is to be maintained. We will have to wait perhaps some time before agreement is reached as to how the CAP will be reformed and how farmers will respond to these reforms. There can be no doubt, however, that there is a determination to control levels of production through price control mechanisms, and incentives to extensify operations, coupled with the management of land in ways which also meet specific environmental objectives.

It is therefore not surprising that after the first three years of the Institute's existence it was judged apposite to review the remit and define more clearly its mission. Such a review was also necessary because of changes in R&D policy within Scotland, and in the UK as a whole, and the relative change in emphasis and funding as between basic, strategic, applied and developmental research which has occurred since the merger of the former MISR and HFRO to form the new Institute in 1987. Account had to be taken of other developments taking place for R&D in Scotland within the Scottish Agricultural Research Institutes and the Scottish Agriculture College, the increasing importance of environmental research, and the need to respond more urgently to some of the important socio-economic and policy issues on rural land use and resource management.

With respect to the management and development of the Institute's research programme there has been also a need to establish clear priorities within a declining budget, to continue to promote highly innovative and imaginative science to provide information relevant to the needs of agriculture, forestry, conservation and the general well-being of the countryside. This requires appropriate basic and strategic research in the soil, plant and animal sciences in areas where the Institute has special skills and an international reputation.

Our remit is built on the idea that change is an inevitable feature of rural land use and that there is a continuing need to undertake research to assess the impact and consequences of change with particular respect to policy, management, effects of climate and pollution. Such a remit cannot be fulfilled satisfactorily by pursuing research within isolated scientific disciplines nor by a purely reductionist approach. The mission statement describes the strategic areas of science which are central to the work of the Institute and how a holistic and integrative approach is being promulgated in developing an interdisciplinary, strategic and dynamic programme of land use research.

Such an approach requires that an increasing proportion of its research programme has to be developed on a collaborative basis. An emphasis during the last two years, therefore, has been the development of closer working relationships between the new Institute and the Universities, particularly Aberdeen and Edinburgh, other research institutes in the Agricultural and Food Research Service, the Institute of Terrestrial Ecology, the Institute of Hydrology and organizations such as the NCCS and the CCS. Equally, much effort has been directed towards forging links with relevant European and international centres for land use research, acquiring EEC R&D funding and participating fully in the SARI East European Initiative. The research contract and consultancy skills of the Institute have been developed through the newly launched Resource Consultancy Unit. Collectively these initiatives have resulted in a research and consultancy portfolio which encompasses a wide range of national and international land use issues.

The scientific vitality of a research institute is dependent upon the enthusiasm and intellectual vigour of its scientists and their innate desire to acquire new knowledge and have a deeper understanding of the processes which determine our ability to bring about and manage change for the good of mankind. It is also essential to pass on this knowledge and understanding in published works, and through the media. In this Institute it is important also that scientists have direct contact with those who live and work in the countryside as well as those urban dwellers who benefit from its recreational and conservation value. To this end many of the scientists have participated in national and international conferences as well as local meetings where their expertise and knowledge can have a significant influence.

The Institute's association with the Universities is important in the training which it can offer to both graduate and postgraduate students as well as the more versatile research that can be jointly undertaken. The benefits to the students in being able to participate first hand in research which is relevant to current and future land use issues and having access to the excellent facilities of the Institute are important. But so also is the contribution that the liveliness and enquiring nature and perspective of the young mind makes to the intellectual life of the Institute. There are 28 postgraduate students currently working in the Institute.

The reports on progress to be found on pages 22-49 of this Annual Report indicate some of the highlights of the Institute's research over the last twelve months. These are presented within the framework of the programme commissioned by the Scottish Office Agriculture and Fisheries Department at the beginning of 1991 as a result of the review carried out by the senior scientists of the Institute and the Board of Management in the autumn of 1990. It is contained within five programme units:

Land Use Options and Impacts on Natural and Human Resources
Soil and the Environment
Plant - Soil Relations
Plant - Animal Relations
Ecology of Grazing Ruminants and Resource Utilization

The philosophy and rationale for this structure is that the output from land use research arises largely from the systematic analysis and modelling of information arising from the soil, plant and animal research which the Institute undertakes. This is research particularly relevant to determining land use options and impacts on natural and human resources, which is the subject of the first programme unit. This programme aims to establish, test and apply protocols for the objective assessment of land use changes and options and their potential physical, and socio-economic impacts within a wide range of geographic scales. The overall programme is designed to complement, and integrate with research going on elsewhere and provide an essential continuity between basic, strategic, applied and developmental research.

The testing of options and impacts on land use cannot be done wholly within a conventional field- or laboratory-based research programme. Thus the first article in this Annual Report examines the 'Role of Mathematical Modelling in Land Use Research'. Whilst plant and animal physiologists, agronomists, ecologists, economists and sociologists all do research related to land use, it is argued that the integration of the information flowing from this research can be more effectively utilized and explored if expressed within a modelling context.

As an example of how the multidisciplinary nature of the Institute can give a depth and breadth of research to an important environmental issue the second article addresses 'Soil and Surface Water Acidification in Relation to Afforestation'. Whether trees are planted as forests or in farm woodlands it is vital that the interactions between forestry and forestry practice, atmospheric inputs, soils and waters are well understood so that potential problems of soil and/or water acidification can be predicted and, if possible, avoided. It is also important to understand all of these relationships in the context of the natural acidification processes in the soil.

Though it is generally accepted that the amounts of nitrate in drinking water supplied from groundwater sources is less of a problem in Scotland than in central and eastern areas of England, these geographical differences with respect to nitrate loading in river systems are much less clear cut. Nitrite, ammonium and organic nitrogen compounds may also contribute to the total nitrogen load. Thus, 'Nitrogen Transformations and Nitrogen Leaching in Scottish Soils', is discussed in the third research article of this report, in relation to the land use practices which dominate the river catchments in Scotland.

The fourth major contribution to the Annual Report comes from Dr I.J. Graham-Bryce of Shell International who gave the 15th Macaulay Lecture on 'Managing the Impact of Human Activities on the Environment: practical possibility or unrealized ideal?' The perspective of this lecture was that of a company covering industrial activities in oil and gas, chemicals, metals, coal and forestry. The conclusion, backed by a declared intention 'to implement a policy of continued improvement in operations to reduce effluents, emissions and discharges of waste known to cause a negative impact on the environment, with the ultimate goal of elimination', was that 'managing the impact of human activities must be, and is a practical possibility' even if such management 'is still an imperfect art - a mixture of science and pragmatism'. But as Ian Graham-Bryce said, 'it is a truism to state that we as yet have only a rudimentary understanding of how the environment works, at least for the purpose of precise management. It seems unlikely that such understanding will ever be complete, and hence the pragmatism, ... but it is essential that we continue to strengthen the science, both by making observations and understanding the processes *of change*, through work of institutes such as MLURI'.

T. JEFF MAXWELL, Director

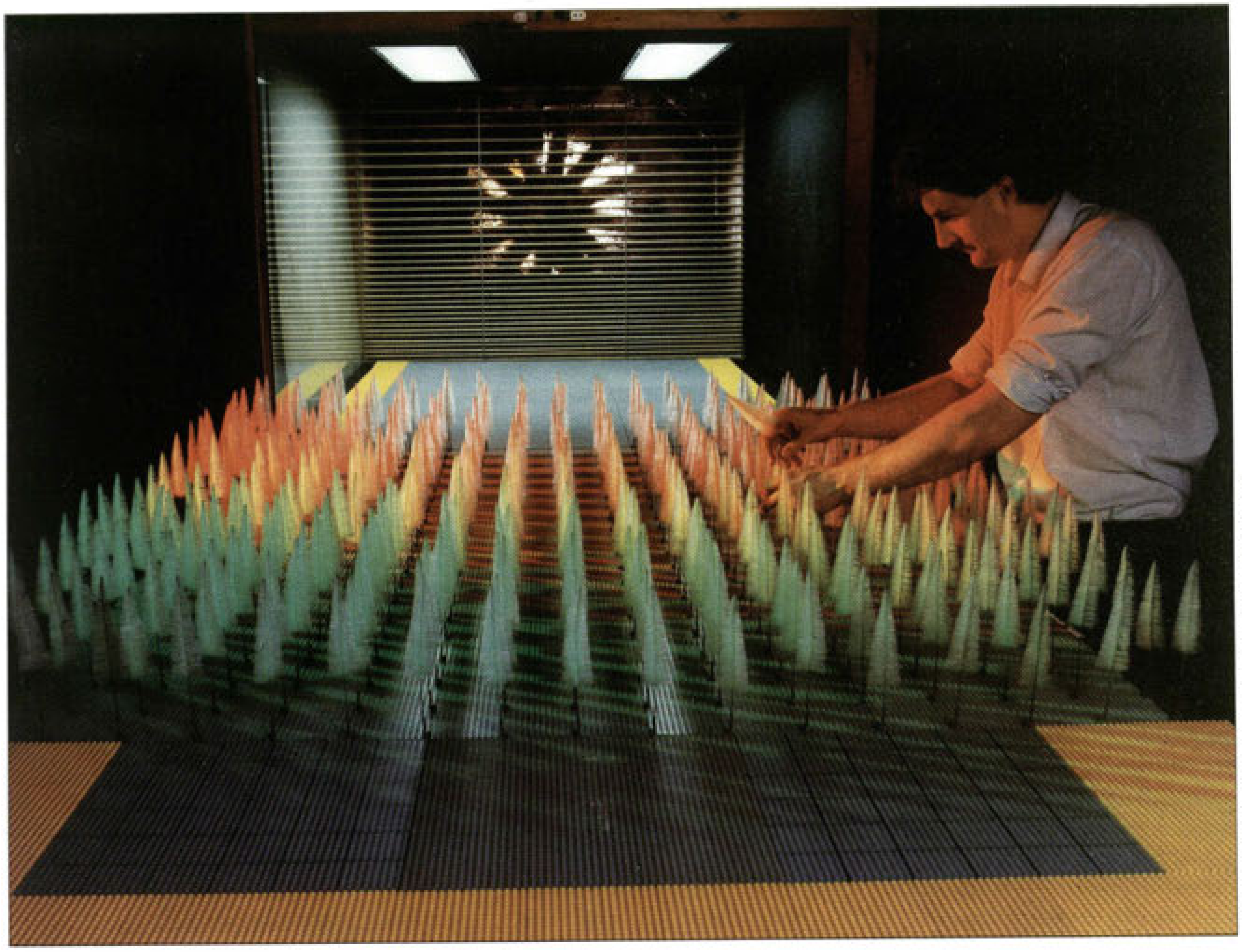


Photo: P. Tuffy, Physics Dept., University of Edinburgh

The ROLE of MATHEMATICAL MODELLING in LAND USE RESEARCH

R.V. Birnie, D.A. Elston and J.A. Milne

Issues in land use research

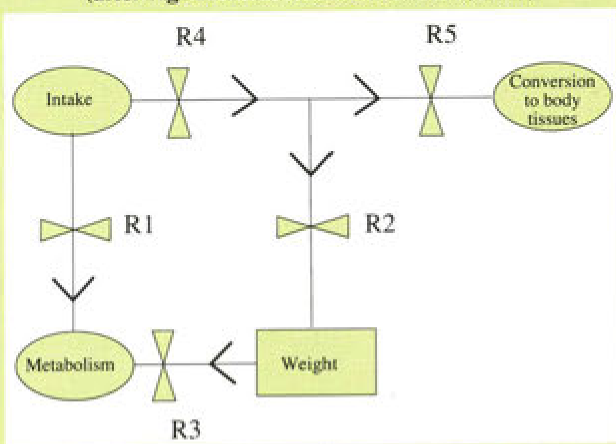
Land use research is concerned with understanding the relationships between land management systems and their environment with a principal aim of anticipating the effects of change. This change may be internal to the systems themselves (e.g. plant varieties, animal species/breeds, husbandry techniques) or in the system's environment (e.g. changes in climate, economic conditions, cultural attitudes). The effects of change may be general or specific to either a particular management system (e.g. sheep production) or geographic region (e.g. differential impact of set-aside policy across Europe or more locally across Scotland). The outcome of such land use research is to provide both improved explanations for phenomena and a framework within which informed judgements may be made about various land management options. Such judgements might be made in terms of a range of goals, such as economic viability, sustainability, complementarity, animal welfare, environmental impact and cultural acceptability.

Complex biological, economic and social systems comprise organized hierarchies of interactions. At a high level are land use management systems; beneath are biological systems which may be controlled to a greater or lesser extent; these in turn have component sub-systems at an internal plant or animal level. This continues to the cellular or even sub-particular level. At what level do we seek explanation? Dawkins (1986) provides a philosophical answer to this through reference to 'hierarchical reductionism' where a complex entity, at any particular level in its hierarchy of organization, is explained in terms of entities only one level down in the hierarchy. This answer is compelling; the workings of a car can be explained to a driver in terms of steering wheel, accelerator, brake; to a mechanic in terms of bearings, driveshafts; and to a design engineer in terms of material composition and strengths. This concept is clearly mirrored in our hierarchical organization of scientific disciplines.

Land use research is thus concerned with explanations at several levels. More particularly, it is concerned with how these different levels interact. This concern is central to land use research and separates it from more conventional discipline-orientated research. Whilst plant and animal physiologists, agronomists, ecologists, economists and sociologists all do research related to land use, the interdisciplinary nature of land use research enables a better understanding of how the different levels link and interact. To return to the car analogy, it may be sufficient to explain the workings of a car engine in terms of carburettors but it may require a knowledge of the interaction between the lubricants and the bearings to explain why it breaks down. In the same way, a knowledge of the links between animal nutrition and reproductive physiology might open up an unforeseen management opportunity which could in turn impact on the quality of grazing resources and have implications for policy options for agricultural output.

Since an important role for land use research is understanding the links between different levels of organization, and since it transcends conventional scientific discipline areas, then there has to be a new common ground, a new way of communicating. The MLURI is taking two major steps in this direction. The first is to create a common-to-all computer information system. This will allow access to a wide range of environmental, biological and socio-economic data covering the whole of Scotland. The second is to simultaneously develop computer facilities which will provide the modelling tools considered essential for progressing understanding of complex systems. Taken together these comprise the elements of the Macaulay Land Use Information and Modelling System (MLUIMS). The computer hardware required for this system is documented elsewhere in this report.

A simple flow diagram, energy requirements for cattle growth (after Agricultural Research Council, 1980)



The simplest form of this model assumes an animal's body weight as being the only relevant information about the animal. Body tissues are treated as a store of energy, and hence are the only state variable. It is assumed that energy enters the system on food, and is lost, due either to maintenance costs of existing body tissues or to the cost of converting food energy to body tissues. The routes and directions of energy flow round the model are shown in the diagram. Note that the routes of flow are not independent. Since maintenance costs have to be met, the equation

$$R1 + R3 = M$$

must hold true. Equations for the rates of flow R1, R2, R3, R4 and R5 determine how energy moves round the model, and hence how fast cattle grow.

The aim of this article is to describe mathematical modelling and to illustrate its role in MLURI's research programme.

Mathematical modelling

Models are the essence of science. They describe our beliefs about how the world around us functions. There is no single type (France and Thornley, 1984). Rather they range from physical scale models through empirical descriptive models to more theoretical mechanistic models which attempt to give a description with understanding (see box).

Many scientific models are expressed in mathematical equations. Mathematics is attractive to scientists because of its lack of ambiguity. It allows a concise description of our understanding, which can be manipulated to arrive at logically consistent conclusions. It is therefore the natural language for scientists to use for their models.

Mathematics has long held the centre stage of the physical sciences. Experimenters have observed that simple systems, in closely controlled environments, change in a repeatable way. Theorists have proposed mathematical relationships which describe the observations and used these relationships to predict the behaviour of the system under new conditions. A crucial test is whether, under the new conditions, future observations match these predictions. Thus the role of mathematics is to pass from past observation to future predictions in a precise way.

Historically, mathematics has played a relatively peripheral role in the biological sciences. The emphasis in research has been on observing complex systems, such as genetically variable living organisms, in variable environments. One of the most important early applications of mathematics to biology was in the study of variability,

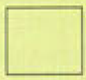
Symbol	Technical Name	Notes
	Source or sink	Entry or exit points for material
	State variable	Material store
	Material flow	Paths and directions of flow material
	Control on flow rate	

Figure 1. Symbols for use in flow diagrams (after Forrester, 1961).

	Empirical	Mechanistic
Deterministic	Prediction of cattle growth from a regression relationship with feed intake	Prediction of shelter effects based upon physical airflow models
Stochastic	Analysis of variance of variety yields over sites and years	Genetics of small populations based on Mendelian inheritance

Table 1. Broad categories of models.

and the statistical assessment of the evidence for consistent, average behaviour, as against random variation (Fisher, 1925). However, as understanding of the basic processes of biological systems increases, so the potential for applying mathematics as a descriptive tool has increased. Furthermore, the ready availability of computing power has paved the way for the numerical solution of linked equations which arise from studies of complex systems.

Once the objectives have been clearly defined, mathematical modelling can conveniently be regarded as consisting of four distinct phases, namely building, studying, testing and use. Although these follow closely the scientific method in general, a study of each stage in turn is illuminating, showing how scientific understanding blends with modelling techniques.

Building a mathematical model requires a qualitative understanding of the system. The most important features of the system must be identified, as well as the way in which these interact. Simplifications made should be stated as assumptions. A successful model should be as simple as circumstances allow. The model structure can then be conveniently displayed in a flow diagram using standard symbols (see Figure 1, after Forrester, 1961). Flow diagrams are most effective for models which consider the transfer of a conserved resource (e.g. energy) between components of a system. A quantitative understanding of the interactions of the system must also be achieved. This requires the selection of functional forms for equations, and estimation of parameters in these equations. Note that the equations may express probabilities when outcomes are essentially random. The full model, consisting of both structure and equations, then needs to be solved. The solution can sometimes be obtained algebraically using mathematical analysis or more usually by iterative computational methods.

Once a model has been proposed, it is important to study it and establish whether it predicts the same qualitative features as the system being modelled. This is often an integral part of building a model. In exceptional circumstances, studies of model predictions have corresponded so closely to observations of unexplained phenomena that new causal theories have been developed (Murray, 1989).

Testing models is important for increasing confidence in their predictions and for estimating the likely discrepancies between predictions and observations. This testing can be done internally, by considering the combined effect of uncertainties in the parameter estimates, or it can be done externally by comparing model predictions with data that were not used to build the model. Internal testing of models, which is the equivalent of calculating estimation errors in fitting statistical models, can only give a lower bound on the prediction errors because it takes no account of simplifying assumptions made in building a qualitative model. External testing is more rigorous, but will be limited by our ability to conduct enough new experiments or observe enough cases of the system to test the model in the full range of conditions for which it is required. Indeed, with many land use situations rigorous external testing of models may be impractical because of the scales involved.

In some scientific models, testing predictions is also the prime use for the models, because we can then identify cases where our understanding of the system is insufficient. In other cases, model use may be completely removed from the testing environment. This is particularly true of models which are designed as decision aids. However, it is important to follow up the outcome of decisions, so that serious discrepancies between models and predictions can be addressed.

Classification of models

It is helpful to classify models into broad categories. This tells us some essentials of their structure.

One system of classification divides models according to:

a) the outcome they predict

b) the level of understanding upon which they are based.

Models which predict only a typical outcome, ignoring random variation, are termed deterministic. Stochastic models, on the other hand, predict a distribution of possible outcomes.

The classification of models according to the level of understanding on which they are based links back to our opening comments about explanation being linked to hierarchies of organization. A model which uses a large amount of theoretical information generally describes what happens at one level in the hierarchy by considering processes at lower levels. These are called mechanistic models because they take account of the mechanisms by which changes to the system occur. Alternatively, empirical models are based solely on observed relationships. Thus empirical models add less to scientific understanding, and are likely to give poor predictions when they are applied to new situations where there is no reason to believe that observed relationships will continue to hold.

Table 1, on the preceding page, provides examples of the four broad categories of models relating to combination of the above classifications.

Further classification of models can be based on their treatment of either time and space. Time may be ignored (static models), or included (dynamic models), using either discrete units (often year to year) or in a continuous fashion. Models without a spatial component implicitly assume that interactions take place at a single point in space or that variables are distributed uniformly. Alternatively, models with a spatial component may describe variation in one, two, or three dimensions.

Models of complex systems often consist of several linked sub-models, where each sub-model is a model of some particular part of the whole system. Structural complexity introduced by linking together different sub-models has important consequences for model performance. In general, those models which are structurally simple have two desirable properties. Firstly, parameters in these models can be estimated simultaneously from a single dataset. Secondly, it is possible to monitor and experiment with all relevant aspects of the system simultaneously, hence rigorous testing of all aspects of the model is possible. Conversely, structurally complex models tend to have neither of these desirable properties. Parameter estimates are obtained independently from different datasets, a feature which loses the robustness property of simultaneous estimation. Furthermore, simultaneous monitoring of and experimentation with all aspects of a complex system may be impractical, making it impossible to test and identify weaknesses in the model.

Modelling applications in land use research at MLURI

Table 2, on pages 8 and 9, provides a summary of a selection of the modelling initiatives in the MLURI research programme. The list is neither exhaustive, nor does it include those experimental research projects which aim to develop, test or elaborate existing models. It illustrates: a) the broad range of modelling activities and b) the variety of modelling applications, from improvement of scientific understanding at a process level, to development of decision-aids for planning at farm, regional or national levels.

There is a close correspondence between model type and the research objective. Most models are empirical and deterministic, reflecting an emphasis within the research of the Institute towards development of predictive models.

Conversely, process level models tend to be mechanistic and deterministic. The appeal of mechanistic models is that the underlying processes which control system behaviour over a wide range of conditions are encapsulated in the model. Hence the models are free of some of the limiting assumptions of their empirical counterparts. A fundamental challenge in land use modelling is how to use process level models at the higher levels of organization in biological systems, in a way which achieves the high levels of predictive ability normally only associated with the empirical approach.

Whilst mechanistic understanding of complex systems may be a distant goal across the wide span of the MLURI research programme, some steps have already been made towards it. For example, through close collaboration with researchers in the UK (NERC Institute of Hydrology), Scandinavia, and North America, a mechanistic model describing hydrochemical fluxes within river catchments has been applied to a range of sites. This model, whose name has the acronym MAGIC, utilizes an understanding of input/output chemistries and chemical processes to predict future long-term changes in water quality under different land use and anthropogenic deposition scenarios (Cosby *et al.* 1990; Jenkins *et al.* 1990). The model framework can be applied at a specific site level to produce a deterministic outcome, or on a regional basis with generalized environmental data to produce a stochastic outcome. A particular feature of current developments is the application of a regional analysis on catchments incorporating detailed individual watershed soil information and land use histories. The required spatial data manipulation has been carried out within the context of a Geographical Information System (GIS). The coupling of GIS technology, high resolution spatial data and process models, offers new opportunities for developing mechanistic models which operate at different levels in the organizational hierarchy and at different geographic scales (Aspinall *et al.*, 1990).

A further example of how mechanistic models are being incorporated at a land management level is in a model being developed to describe the impact of grazing by large herbivores on hill vegetation. Here a predominantly mechanistic model, (Illius and Gordon, 1987) has been incorporated as a sub-model for predicting offtake of vegetation by ruminants. It is intended to develop this model further by the use of a GIS approach to predict the spatial element of grazing in the heterogeneous environment typified by the semi-natural vegetation of the upland areas of the UK.

The key role of modelling in land use research at the MLURI is further emphasized by the challenge of current land use issues: sustainability, environmental impacts, climate change. These issues provide themes around which land use science can be organized. For example, what are the potential effects of climate change on agriculture and land use in Scotland? This question is central to a major SOAFD programme on climate change. This involves the MLURI in partnership with the Scottish Agricultural College (SAC) and the Scottish Crop Research Institute (SCRI) and is essentially an attempt to model the effects of climate on management systems. At MLURI work is being directed towards modelling relationships between general climatic patterns (as predicted from General Circulation Models) and agriculture and forestry (see Table 2 on pages 8 and 9). Since many of these effects will be transmitted through soil processes (see also Table 2), climate-soil interactions are also being modelled. This work is revealing a lack of knowledge concerning key processes and indicates how modelling, hypothesis generation and experimentation are inexorably linked.

Towards the future: issues for research

Land use research is concerned with understanding the relationships between land management systems and their environment in order to anticipate the effects of change. This concern inevitably leads to a need to develop techniques for understanding systems in a dynamic and spatial manner. It is our contention that modelling is a key to this. As Peterson *et al.* (1990) put it, 'a model provides a paradigm for organizing systematic thinking about complex and baffling topics'.

Currently modelling is a major activity for around 15 MLURI scientists with their research spanning a wide range of topics. At the process level, models are mainly mechanistic and concerned with improved scientific understanding. At the higher levels of organization the models tend to be empirical and concerned with prediction in order that they can be used to aid management decisions.

There is growing evidence of linkages being made between research groups working at different levels in the organizational hierarchy (e.g. the use of sub-model on herbage intake and diet selection within a predictive model looking at consequences of herbivore grazing on indigenous vegetation communities). New initiatives in modelling in relation to land assessment, multiple-objective planning, and impact assessment (environmental, economic and social) indicate a genuine concern with developing holistic understanding. The development of the Macaulay Land Use Information and Modelling System (MLUIMS) will provide standard datasets and modelling tools for future modelling applications.

Continued in-house research in the fields of GIS, spatial statistics and artificial intelligence techniques, and geostatistical techniques combined with the modelling expertise provided by the Scottish Agricultural Statistics Service (SASS), will ensure that issues central to developing modelling applications are properly addressed. Examples of these issues are: use of fuzzy logic; error-handling procedures; expert systems/artificial intelligence; combination of data at differing spatial resolutions and modelling spatial changes over time.

Like all developing areas of science, research on modelling needs to be constantly reviewed. Questions concerning the objectives and span of the modelling effort, its technical currency and its management need to be addressed.

There is presently a bias in the modelling effort towards empirical approaches. However, there is a commitment to increase effort on coupling mechanistic models with management models. In some areas (e.g. vegetation dynamics and foraging strategy) mechanistic models can be based upon available results from long-term research programmes. In other areas, particularly those concerned with rural socio-economics, both observation and theory are limited. Here modelling efforts may initially be more conceptual than mathematical but research is already beginning on identifying processes and process controls (e.g. in joint work with University of Aberdeen, Department of Land Economy on development of a typology of rural land use decision-makers).

Advances in the uses of modelling will depend partly upon theoretical developments and partly upon availability of mathematical skills and computing tools. In such terms, the quality of our models depends upon our level of understanding about how the world around us functions. That depends upon our experience and our synthesis from the knowledge of others. But we have to recognize that many issues we address are outside our common experience. Modelling should be seen as only a part of the scientific process but a part which is fundamental to effective knowledge synthesis. In a complex, uncertain and data-poor environment it would be a mistake to believe that models can predict reality. In many situations, the best we can hope for is to attach probabilities to alternative patterns of events.

Innovation in modelling may be largely conceptual but implementation requires appropriate tools. Between MLURI and SASS there is a commitment to provide comprehensive mathematical and computing support based upon networked workstations with standard modelling and expert-system software. This facility reflects a trend towards open architectured, user-friendly computing systems with an emphasis on communication and data-sharing.

The management of the modelling effort at MLURI is based on the view that those with relevant modelling skills should operate within the framework of groups of scientists with a common goal, such as in relation to the study of climate change, acidification, production systems at an enterprise level or moorland management. Such a team approach is a powerful means of making rapid and effective progress. There is also a need for those with modelling skills to meet as a group to consider issues which are common to a range of applications.

In conclusion, modelling provides us with a common ground which is essential to progressing land use research. It will take time to make significant progress because modelling still depends upon the scientific process and the quality of our knowledge-base. It is our belief that by

MATHEMATICAL MODELLING

Programme Unit (PU) Research Objective (RO)	Purpose of model	Level of understanding	Outcome	Application	Development	Contact person
PU11 Develop and test land use suitability models (011148)	To describe relationships between bio-physical conditions,management, and crop yields	Empirical	Deterministic	Decision-aid for regional/national land use planning	Based on ALES package. In-house add GIS and geo-statistical components	Gordon Hudson
Assessment procedures in wide area conservation evaluation (011150)	To describe relationships between wildlife distributions/populations and key habitat descriptors (e.g. vegetation patch size, connectivity, context)	Empirical	Deterministic	Increase scientific understanding	In-house, based on application of Bayes Theorem	Richard Aspinall
Modelling and field testing of silvo-pastoral systems (011151)	To describe i) links between annual herbage production, tree canopy dimensions and sheep performance ii) shelter effects of tree canopy development on seasonal patterns of herbage production	Empirical/ Mechanistic	Deterministic	Increase scientific understanding	In-house based upon component research validation against long-term field experiment	Alan Sibbald
Modelling upland sheep systems (011152)	To describe complex inter-actions between soil, plant and animal processes under different management/climatic conditions	Mechanistic/ Empirical	Stochastic	Increase scientific understanding	In-house based upon component process and field systems research	Nick Hutchings
Decision-support systems for assessing land use options at the farm level (011153)	To describe land use options based on biophysical and economic constraints, but capable of satisfying multiple objectives (e.g. conservation, amenity)	Empirical	Deterministic	Research tool and potential farm level/management unit decision-aid	In-house development of Hill Farm Forestry and other models	Cathy Butcher
Economic effects of land conversion to forestry from agriculture with special reference to environmental effects and the development of multiple-objective forestry policies at regional and national levels (011155)	To extend forestry investment appraisal (FIA) models to include assessment of wider environmental and social costs and benefits	Empirical	Deterministic	Regional/national planning decision-aid	Elaboration of existing FIA model in collaboration with University of Stirling	Douglas Macmillan
Use of GIS techniques with proccess-based environmental assessment procedures for water quality modelling (011157	Through use of spatial data in a GIS extend the application of catchment-based process models to regional/national levels	Mechanistic/ Empirical	Deterministic	Tool for use in producing environment impact assessment in association with proposed land use changes	Combination of existing spatial modelling facilities (GIS) and hydrochemical process models (e.g. MAGIC) see PU12	David Miller
PU12 Water resource modelling: the effect of land use change and atmospheric deposition (012173)	To describe hydrochemical budgets in relation to patterns of deposition, land use and soil processes	Mechanistic/ Empirical	Deterministic	To increase scientific understanding/ underpin policy formulation on atmospheric pollution	Based on international development of MAGIC model combined with in-house developments in GIS for regional modelling (see PU11)	Bob Ferrier

Programme Unit (PU) Research Objective (RO)	Purpose of model	Level of understanding	Outcome	Application	Development	Contact person
Investigate interaction between heavy metals and the fine-grained constituents of mineral soils (012181)	To describe the role of surface reactions in the response of soils to pollutants	Mechanistic	Deterministic	To increase scientific understanding in general area of pollution	In-house modelling effort	Ed Paterson
Soil response to climate change (012181)	To describe the relationship between climate and soil properties	Mechanistic/ Empirical	Deterministic	To underpin policy development in relation to impact of climate change on Scottish Agriculture	In-house development using existing soils data-bases	Alex Macdonald
Assess the critical loads of acid deposition to soils and determine the distribution of acid-sensitive soils in Scotland (012172)	To identify areas at risk from strong soil and surface water acidification	Mechanistic/ Empirical	Deterministic	Decision-aid for land use of sensitive catchments; to increase scientific understanding	Based upon model PROFILE and existing MLURI soils database	Simon Langan
PU13 Analysis of the effects of climate change on tree crops in Scotland using indicator species (013176)	To decribe the relation-ships between tree crop growth and climate	Empirical	Deterministic	To underpin policy development in relation to tree crops under altered climate conditions	Based upon in-house development of existing empirical growth/yield predictive models	Stuart Allison
Seasonal internal cycling of nitrogen in evergreen and deciduous trees and the consequences for nutrient use efficiency (013189)	To describe processes of nutrient storage and nutrient cycling in perennial plants	Mechanistic (conceptual)	Deterministic	To increase understanding of nutrient use efficiency in relation to manage of low input systems	In-house modelling effort	Peter Millard
PU14 Develop and test foraging strategy theories for ruminants grazing mixed indigenous hill vegetation (014209)	i) to describe intake rate of ruminants of different sizes ii) to describe digestive strategies in herbivores	Mechanistic/ Empirical	Deterministic	To increase scientific understanding	In-house	Iain Gordon
Modelling the agricultural and environmental consequences of sheep and red deer grazing heather moorland (014120)	To describe impact of grazing by large herbivores on hill vegetation	Empirical	Deterministic	Management decision-aid	In-house development of existing "heather" model	Helen Armstrong
PU15 Effect of shelter on grazing behaviour, nutrient intake, energy expenditure and welfare of sheep in farm forestry sytems (015222)	To describe airflow around spaced trees	Mechanistic	Deterministic	To increase scientific understanding	Application of PHEONICS fluid dynamics package	Nick Hutchings

Table 2. Examples of modelling applications in land use research at MLURI

taking a holistic, multidisciplinary approach we will be more able to capitalize on existing knowledge. The approach draws upon a long established genetic principle - hybrid vigour.

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Photo: The Scottish Picture Library, Strathpeffer, Hugh Webster

Forestry plantation, Loch à Ghridma, Sutherland

Photo: Highlands and Islands Enterprise

SOIL and SURFACE WATER ACIDIFICATION in RELATION to AFFORESTATION

H.A. Anderson, J.D. Miller and M.J. Wilson

Soil acidification is a natural phenomenon resulting from the removal of basic cations from the soil by leaching or uptake into the biomass at a rate faster than can be compensated for by mineral weathering. In recent years, however, it has become apparent that the deposition of anthropogenic acidic pollutants from the atmosphere has, in all probability, led to an accelerated acidification of natural and semi-natural ecosystems. In such cases, it seems that the natural acidification processes are exacerbated by the transfer through the soil of mobile acid anions such as sulphate and nitrate, which may to a large extent derive from pollutant inputs, leading to the release of protons and aluminium from the soil exchange complex into soil waters. This acidity may eventually find its way into surface waters and lead to declining fish stocks in streams and rivers.

Because more emphasis is now being placed on afforestation, whether as plantation or farm forestry units, as an option for land being taken out of agricultural production, it is vital that the interactions between forestry and forestry practices, atmospheric inputs, soils and waters are well-understood so that potential problems of soil and/or water acidification can be predicted and, if possible, avoided. This review discusses recent MLURI work relating to acidification processes that are connected or likely to be connected with forestry, but firstly, it is important to place this work in the context of natural acidification processes in the soil.

Sources of soil acidity and proton turnover

Soil acidity arises where hydrogen and aluminium ions adsorbed on the soil exchange complex (clays and organic matter) greatly exceed adsorbed bases such as calcium, magnesium and potassium. This aluminium, when released to the soil solution, reacts to release hydrogen ions in very acid soils, (pH <4.2) and the same process takes place to a lesser extent in moderately acid soils (pH 4.2 - 5.0). The acidity associated with the exchange complex may be thought of as a capacity factor which interacts and balances - in other words buffers - the acidity in the soil solution which represents the intensity factor. Forest soils are naturally acid because they are often developed on base-poor materials, occur in areas of high rainfall and are therefore heavily leached. Inherently acidifying soil and vegetation processes include the microbial decomposition of organic matter, the respiration of soil organisms and roots leading to the production of carbonic acid, excess cation uptake by plants with replacement of these cations by hydrogen ions, application of certain acidifying fertilizers, etc. An important concept in soil acidification studies is that of the Acid Neutralizing Capacity (ANC) of the soil. The ANC of a soil is related to the rate of weathering of the primary soil minerals, both in terms of the release of neutralizing cations and the formation of fine-grained secondary products which are highly reactive as sites for ion exchange and chemisorption. Both primary and secondary minerals act as proton sinks, but operate via dissolution and adsorption reactions respectively. The secondary minerals, along with organic matter, respond much more rapidly to episodic acidification 'events', although the slow dissolution of the primary silicates is likely to be an important determinant of the overall chemical characteristics of the soil. However, it should be stressed that following the generation of acidity in the soil through internal processes or acid deposition, the transfer of protons or soluble aluminium into surface waters will only take place if (a) the soil basicity has been sufficiently depleted or is insufficiently reactive and (b) mobile anions, derived from strong acids (usually sulphate or nitrate) are present. In their absence, organic anions, silicate and bicarbonate, all derived from weak acids, are the only available accompanying species. Of these, only organic anions form Al-compounds sufficiently stable to the pH ranges (4.6 - 6.5) of the soil solutions and surface waters. Most organic-Al compounds are relatively non-toxic to aquatic biota compared with the monomeric Al species associated with sulphate and nitrate.

	PARTICULATE & COLLOIDAL		SOLUBLE	
	Coarse sediment	Humic acid	Fulvic acid	Hydrophilic acid
Control plot	15.2	7.8	34.4	19.9
Planted plot	17.3	14.8	37.2	19.2

Table 1. Comparison of organic carbon (kg/ha) in drainage waters from control and planted plots on deep blanket peat at Bad a' Cheo, Caithness during 1989 (ploughed and drained Dec 1988 - Jan 1989, planted and fertlized May 1989.)

	Na^+	Cl^-	Total Al	Si	Total S	SO_4^{2-}	NH_4-N
Control plot	11.5	18.7	0.046	0.156	2.26	2.00	0.68
Planted plot	12.0	20.3	0.083	0.214	4.95	2.36	2.11

Table 2. Comparison of drainage water chemistry (mg/l) from control and planted plots at Bad a' Cheo, Caithness during March 1991.

Forest effects

It has been suggested that forestry and its concomitant operations may have a variety of effects on soil and water quality and in the following section these are discussed with specific reference to current MLURI work.

Site preparation

Sitka spruce is likely to remain the species of choice in the paper, pulp and construction industry markets. It is grown on poorly drained, highly organic soils, the preparation of which involves drainage to dry out the rooting zone and cultivation to create an upturned plough ridge for competition-free establishment. Following the cultivation and planting of a 5 m deep peat at Bad a' Cheo in the Rumster Forest of the Flow Country in Caithness, various physical and chemical effects in drainage waters have been studied. Increases in the turbidity and colour of the drainage waters were observed and could be attributed to a mixture of particulates and dissolved organic matter, the latter encompassing a range from soluble small organic molecules to colloidal particles. The drainage water from unploughed control plots contained a similar amount of soluble organic matter to that of the planted plots, although the latter contained larger quantities of both sediment and colloidal humic substances (Table 1). Mineralization of N and S has also occurred in the drained and cultivated peat (Table 2). N mineralization has proceeded to the ammonium production stage with little evidence of nitrification, possibly as a result of the acidity of the system (pH 4.0-4.3). Increased concentrations of sulphate were also evident and possibly this could add to net soil acidification by removing exchangeable cations, or to surface water acidification in the case of aluminium being removed from the exchange complex.

Fertilization

Forest establishment often involves the regular application of fertilizers during growth to canopy closure. Some of these fertilizers can be regarded as acidic and, for example, nutrient uptake (K, NH4-N) from potassium sulphate or ammonium sulphate and ammonium nitrate fertilizers may release the 'mobile' sulphate and nitrate anions (Nilsson *et al.*, 1982). However, if no additional acidifying inputs are present, it is debatable whether forest fertilization causes extensive acidification. Thus, the immobilization of N, S and P into organic matter is normally rapid in undrained organic soils, although forest drainage systems, when associated with high rainfall, can be efficient routes for the loss of fertilizer sulphate and nitrate. At Fetteresso Forest, for example, there is evidence that high application rates of ammonium sulphate fertilizer have led to acidification of the soil solutions with an increase in soluble aluminium (Table 3).

Uptake of cations

During forest canopy formation, excess cation uptake may occur from the exchangeable pool leading to enhanced soil acidification. However, in this respect all plants may be regarded as acidifying and in Figure 1 the rates of Ca uptake over 50 years for grass, barley, *Calluna* and Sitka spruce are compared. This illustrates the greater potential for soil acidification under crops compared with trees, although nutrient export in the crop is replenished by periodic fertilizer and liming treatment. The export of basic nutrients during forest harvesting can be minimized by adopting methods which leave debris on-site. A comparison between stem-only removal and whole-tree harvesting was made on an experiment conducted near Balquhidder in the Central Highlands (Table 4 overleaf). Marked species differences were observed, with the harvesting of Norway and Sitka spruce removing two to three times the amounts of nutrients removed by harvesting pine or larch. Whole-tree harvesting removed a large extra quantity of basic cations, particularly potassium and calcium compared to the traditional method. The adoption of a method whereby the stems were debarked on site and only the wood removed would reduce base cation export by about 25%, which could be important in highly acidified sites.

		Feb.	July	Nov.	Feb.
Control plot	H. horizon	0.85	1.20	0.24	0.07
	Mineral soil (20 cm)	0.40	0.68	0.23	0.66
Fertilized plot	H. horizon	1.65	4.00	0.37	0.51
	Mineral soil (20 cm)	0.90	1.65	14.8	2.16
	Rainfall	0.4	0.1	0.1	0.1

Table 3. Comparison of total aluminium content (mg/l) of soil and rainfall water in control and ammonium sulphate fertilized plots at Fetteresso Forest in 1982-1983 (30 year old Sitka spruce on brown forest soil; fertilizer applied in May 1982 at 200 kgN/ha).

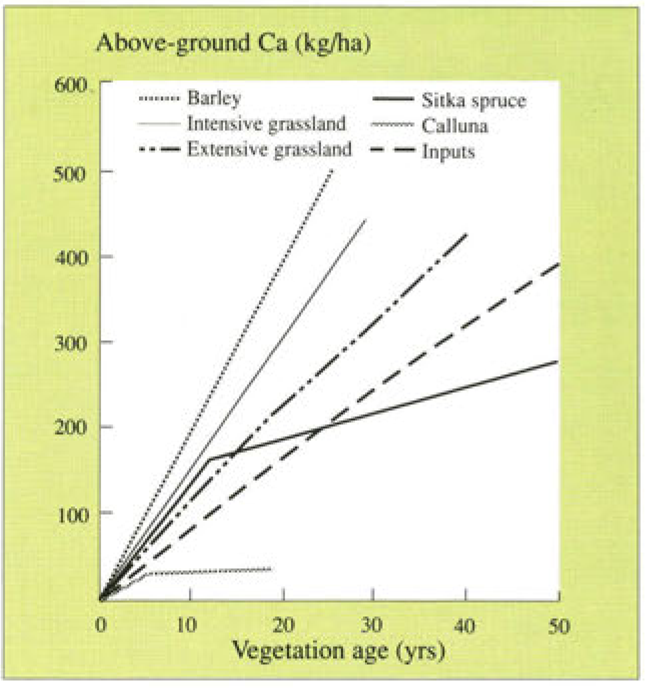

Figure 1. Cation uptake by various forms of vegetation. Barley and grassland data from J.D. Miller & B.L. Williams (unpublished results) and Perkins et al., *(1978).* Calluna *data from Robertson & Davies (1965) and* Sitka *data from Miller* et al., *(1991b). Inputs are means from Robertson & Davies, and Miller* et al., *(1991b).*

Canopy processes

Forests are efficient interceptors of atmospheric components, whether present as dusts, salts or reactive gases, because of the turbulence induced by their canopies. Relative contributions from wet and dry deposition vary enormously and evaporation of intercepted inputs from forest canopies, proceeding concomitantly with both forms of deposition, can lead to chemical concentrations on canopy surfaces that are substantially larger than those measured in the inputs (Unsworth, 1984). Forest canopy interception is greater than that of moorland vegetation and, when accompanied by contributions from crown leaching can lead to enhanced chemical loadings to forest soils. Possible increased levels of sulphur cycling within Sitka spruce may contribute to the sulphate in throughfall, but the dominant process must involve the enhanced capture of pollutants. Recent results have demonstrated that significantly greater acidity reaches the forest floor under Sitka spruce compared with Norway spruce (Figure 2 overleaf). These and other canopy processes such as crown leaching are seasonal, with large pollutant inputs appearing during winter and with canopy exchange processes involving nutrients, such as input NH_4 exchanging for H^+ which appears in throughfall, occurring in the summer.

Species	Harvest method	Nutrient export (kg/ha) Na	K	Ca	Mg
Scots pine	SOR	22.0	54.5	68.3	26.2
	WTH	26.8	118.4	100.9	39.6
European larch	SOR	18.1	37.9	55.3	10.9
	WTH	20.6	63.7	86.0	18.7
Norway spruce	SOR	32.1	100.1	171.1	33.8
	WTH	44.7	199.8	313.7	63.0
Sitka spruce	SOR	24.8	91.9	165.6	28.8
	WTH	26.6	221.9	281.4	55.8

Table 4. A comparison between traditional stem-only removal (SOR) and whole-tree harvesting (WTH) based on data presented in Miller et al., *(1991b). The comparison is based on measured nutrient contents in bark, wood, needles and twigs of 50 year forest trees.*

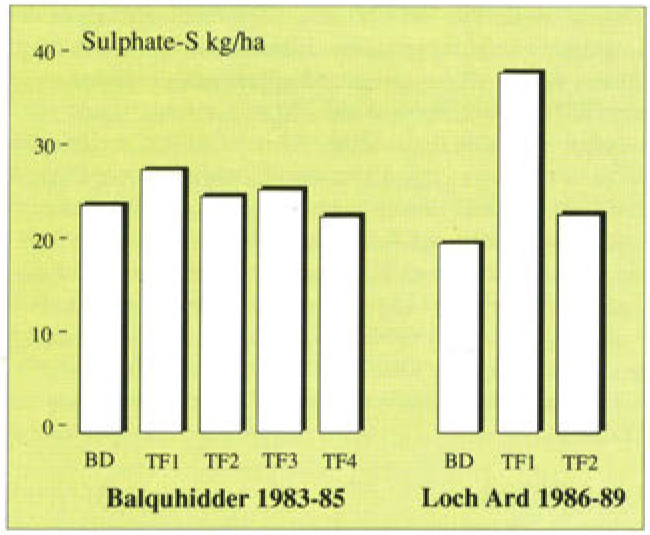

Figure 2. Sulphate concentrations in tree throughfall (TF) compared with rainfall (BD-bulk depositions) for several species:
1 - Sitka spruce, 2 - Norway spruce, 3 - European larch, 4 - Scots pine.
From Miller et al., *1991a.*

Clearfelling

In addition to the potential losses of base cations during harvesting, nitrogen losses may also occur. Tamm *et al.*, (1974) explained the appearance of elevated nitrate concentrations in clearfelled catchment streams as being due to the release of ammonium from brash, triggering nitrification in the soil. In a clearfell site in an experiment at Loch Ard, several point sources of nitrate production were identified, associated with areas of deep peat which had been disturbed during harvesting operations. An additional result (see also page17 of this report) of the clearfell was reduced sulphate and sodium chloride concentrations in the output, presumably because the canopy interception effect discussed above was no longer operative.

Conclusions

It is clear that plantation forestry and the operations associated with site preparation, establishment and harvesting have the potential to cause soil and surface water acidification. However, the extent to which such acidification actually occurs will be influenced by the interactions between many different factors, and not least by the nature of the soil itself. Much will depend upon the ability of the soil to buffer the effects of incoming acidity by the release of base cations ultimately from the weathering of primary minerals. Mineral weathering is, in fact, the basis of the recently formulated soil critical load concept. Provisional maps showing the distribution of critical loads of acidity to Scottish soils have recently been compiled at MLURI, as have maps showing the areas where critical load has been exceeded. Following validation and refinement, these maps should prove useful in indicating the areas where forestry is, or is not, an environmentally appropriate land use option.

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Photo: Words and Pictures, Aberdeen

NITROGEN TRANSFORMATIONS and NITRATE LEACHING in SCOTTISH SOILS

B.L. Williams, A.C. Edwards and H.A. Anderson

Introduction

Recent concern about the amounts of nitrate in drinking water supplied from groundwater sources has been focused on the central and eastern areas of England. This problem is caused primarily by the relatively low volume of effective runoff water combined with the effects of high amounts of nitrogen fertilizer used in intensive farming. The result is that nitrate-N concentrations in surface and ground waters exceed the EC limit of 11 mg NO_3-N/l during winter and late spring. In Scotland, nitrate concentrations in groundwaters can be close to or above the limit (Robins, 1986), but for rivers the picture is rather different with generally much lower nitrate concentrations in surface waters. If, however, we calculate the total fluxes or load (load = discharge x concentration) of nitrate in river systems these geographical differences are much less clear cut. Nitrate is not the only nitrogen-containing substance in natural waters and nitrite, ammonium and organic nitrogen compounds may also contribute to the total nitrogen load. The greater part of this nitrogen ultimately reaches the sea where it may have serious implications for the environmental conditions in coastal waters (Milne, 1989).

In many Scottish river catchments, there are wide ranges of land uses, cropping practices and soil types over relatively short distances. Wright *et al.* (1991) have correlated river nitrate concentrations with cropping practices and fertilizer use for a number of catchments in the north-east of Scotland. The nitrogen load increases dramatically as we move downstream from upland areas, rough pasture and forest to the more intensively used soils

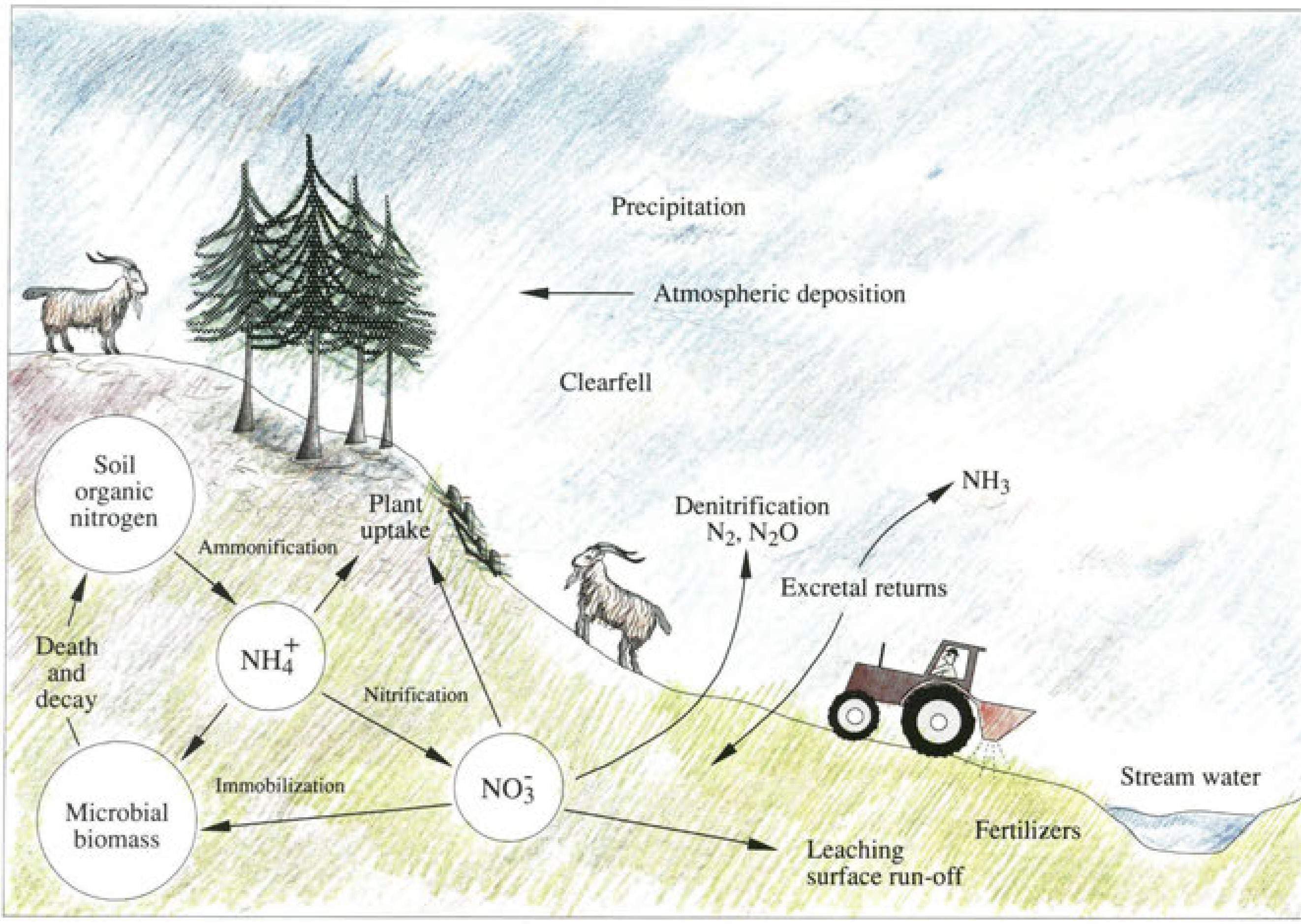

Figure 1. Nitrogen transformation processes, plant uptake and leaching, active in different land use systems.

in the lowlands (Edwards *et al.*, 1990). It doesn't follow, however, that the major source of nitrate is fertilizer nitrogen moving directly into the groundwater. Nitrate is a very soluble and mobile form of nitrogen and is produced by the microbial process of nitrification in many soils. For nitrate to be leached out of the soil, production of the anion should exceed its removal by processes such as plant uptake, immobilization in the microbial biomass and denitrification (Figure 1). Interruption of plant uptake is particularly important; for example, in arable soils, nitrate leaching occurs after harvest when crop uptake has ceased and autumn rainfall occurs. At this time, nitrification and the mineralization of organic nitrogen are still active. In this short article, we review the information available about the relative rates of different nitrogen transformations in soils in relation to land use and cropping practices.

Areas of natural or semi-natural vegetation

Nitrogen budgets for natural and semi-natural vegetation in upland areas show a substantial reserve of nitrogen, 6 to 25 t/ha, in the soil organic matter of predominantly peaty soils (Batey, 1982). The largest inputs of inorganic nitrogen to these ecosystems are in precipitation and dry deposition which total around 10-30 kg N/ha/yr. Net mineralization of the soil organic nitrogen is in the range 20 to 60 kg N/ha/yr. Immobilization probably has an important influence on the seasonal pattern of net mineralization in these soils being closely linked to the decomposition rate of plant litter. These highly organic soils are invariably acid and nitrification appears to be limited to those containing an appreciable quantity of inorganic material (Williams, 1984). Annual outputs of nitrogen from these soils to streamwaters are of the order of 3 to 6 kg N/ha (> 50% as nitrate) (Edwards *et al.*, 1985) compared with 10 kg N/ha from acid grassland in Wales (Roberts *et al.*, 1984). The additional contribution of organic nitrogen to these losses has not been measured but could well be significant either in particulate or in soluble forms which could be degraded and nitrified downstream. It follows that the large reserve of organic nitrogen in these soils could be mobilized following disturbance such as ploughing for afforestation and the potential for nitrogen losses to surface waters is great.

Forest soils

Forested catchments leaching 10 kg N/ha/yr have been reported (Stevens and Hornung, 1988) in Wales whereas net losses from nitrogen-deficient forests are negligible (Miller *et al.*, 1979). Fertilization with nitrogen is not generally practised in UK forests with an average of only 2,000 ha out of 2 million ha treated annually (Taylor, 1991). Nitrogen deficiencies occur mainly in pure stands of Sitka spruce planted on peaty soils and can be corrected by applications of 150 kg N/ha which may be repeated at 3 year intervals until canopy closure. A significant annual input of nitrogen is derived from the interaction between the trees and the ammonia and nitrate in the atmosphere. These inputs of nitrogen in wet and dry deposition are derived mainly from combustion of fuels and ammonia volatilized from animal wastes. Their geographical distribution is extremely variable and a cause for concern, particularly, where leaching of nitrate to ground waters occurs beneath tree stands (Stevens *et al.*, 1990). This phenomenon has generated the term 'nitrogen saturation' implying that all additional nitrogen inputs pass through the system unchanged (Skeffington, 1990) but this view is over simplified. The atmospheric input of nitrogen is secondary to that mineralized from the litter and humus. Studies at Glen Tanar (Grampian Region) have shown that the quantity of nitrogen mineralized from the forest floor depends on the age of the trees and the species (Table 1). Nitrate production both within and between sites is extremely variable and at present there is no satisfactory explanation why nitrification is active at some sites and absent from others. Forest soils have been considered too acid for nitrification to occur, but there is increasing evidence that acid-tolerant microorganisms actively nitrify in litter and soil, (Killham, 1990). Soil pH, C:N ratio and total nitrogen content may each have a regulatory role on nitrification at particular sites, but none can be used to predict the occurrence of the process (Robertson, 1982).

Trees	Organic matter	Mineral - N NH_4^+	NO_3^-	Total
Old Scots pine	97.1	35	2 (5)*	37
Young Scots pine	34.6	8	0.5 (6)	8.5
Sitka spruce	43.7	16	8 (33)	24
Larch	19.5	20	13 (39)	33

* Values in parentheses expressed as a percentage of the mineral

Table 1. Organic matter content (Mg/ha) and ammonium and nitrate-nitrogen (kg/N/ha) released by the litter and humus horizons beneath four conifer stands during incubation in situ for 12 months at Glen Tanar, Grampian Region.

One of the most dramatic increases in nitrogen flux occurs after forest harvesting (Stevens and Hornung, 1988). Forests in which ammonification is active, but not nitrification, prior to harvest, can release a large part of the nitrogen reserve as nitrate in catchment drainage. Tamm *et al.* (1974) explain the appearance of elevated nitrate concentrations in clearfelled catchment streams as being due to the release of ammonium from mineralized organic N in harvest residues. In the denuded landscape, with little vegetation cover to utilize the released nutrient, nitrification is triggered in the soil by the excess ammonium (Figure 1). In addition to incurring the loss of a major plant nutrient from the catchment, the injection of the mobile nitrate anion into soil solution actively increases soil acidification, and leads to increased surface water acidification (see Anderson *et al.*, this Report).

In a comparison between a clearfelled site and a forested control at Loch Ard (Burns 10 & 11 respectively, Harriman *et al.*, 1990), Freshwater Fisheries Laboratory (Pitlochry) are monitoring hydrochemical changes in the main catchment output stream, including the enhanced output of nitrate. Collaborative work at MLURI has concentrated on identifying and quantifying soil sources of nitrate production. The catchment, forested largely with Sitka spruce, either alone or in admixture with lodgepole pine, was felled during 1987-90 and harvested using both conventional methods (stem-only removal (SOR), leaving brash scattered over the compartment) and whole-tree harvesting (WTH). In both cases, the crop was removed from the site by cabling using machinery that minimized surface soil disturbance. In WTH, the branches were piled at the top of one side of the catchment (Figure 2), prior to removal as chip for energy use. This removal took place *ca.*, 12 months after the initial harvest, allowing the needles to fall and accumulate at that point. Miller *et al.* (1991) have shown that Sitka spruce can contain approximately 250 kg N/ha in needles compared with 70, 90 and 60 kg N/ha in twigs, bark and stemwood, respectively. Thus, needles and branches from the piled harvest residues form a major input of N concentrated over a relatively small area.

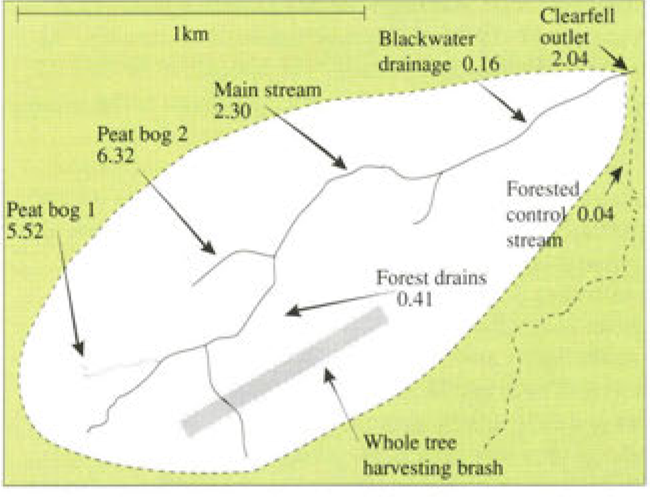

Figure 2. Nitrate concentrations in surface drainage at selected points within the Loch Ard clearfell catchment; values are as mg NO_3-N/l.

Although both laboratory and *in situ* field incubation techniques had indicated that the major soil types of the catchment were all capable of nitrification, analyses of water samples taken from a series of soil water samplers, forest drains, riparian zone outputs (stream bank), the main stream and its tributaries, showed that elevated nitrate concentrations did not occur over the catchment in general (Figure 2). The drainage waters from the area immediately below the WTH brash consistently showed small concentrations of nitrate, as did most blackwaters draining under brash in the SOR. Large concentrations of nitrate were evident only occasionally, in either tributaries, surface drainage or riparian pipe-flow at the stream bank. On following these occasional sources back from the stream the enhanced nitrate production was traced to areas of peat (60-120 cm depth) which had been disturbed during the harvesting operations.

Within the catchment area (90 ha), two peat bogs (forming in total *c.*, 3 ha) form the most influential point sources. The first of these (2 ha, mean depth 100 cm), in the valley bottom near to the stream source, was extensively disturbed during harvesting in 1988 and, following standard forestry practice, the drains were renovated in 1988 prior to restocking the site in 1990. The nitrate concentrations in the drainage waters reached peak values of 25-40 mg/l NO_3-N after drainage, and in 1991, still formed a major source of nitrate in the main stream (3-5 mg/l). The second area of peat (area 0.75 ha, mean depth 60 cm), perched above the stream on an indented shoulder, formed part of one of the last compartments to be felled. This second bog drained into the main stream either directly, or via a lower bankside bog (*c.*, 0.05 ha), and released similar concentrations (3-10 mg/l NO_3-N).

Several aspects of this work remain to be confirmed, but the broad conclusions are that, in this Scottish catchment, nitrification was most evident after the physical disturbance of organic soils. Although the processes suggested by Tamm *et al.* (1974) may still be active, it appears that the mineralization of soil organic-N is stimulated in a similar way to ploughing-up pastures and contributes to the overall nitrification output from point source areas.

Denitrification is a process that could remove surplus nitrate from soil and prevent its transfer to surface waters, provided the nitrogen is completely reduced to N_2 and not released as N_2O. Measurements of this process in coniferous forest soils indicate that it may account for about 3 kg N/ha/yr beneath standing crops of trees increasing to 10-40 N/ha/yr during the first two years after felling (Dutch and Ineson, 1990). In a forest soil that did not normally nitrify, denitrification was not active and on adding urea only very small pulses of NO_3 - N and denitrification were measured (Hulm and Killham, 1988). This process of denitrification is not very active in the surface horizons possibly because of the acidity of the organic layers.

Grassland

Nitrogen budgets and transformations on grassland are strongly influenced by the rates of fertilizer inputs and the level of grazing. On reseeded areas of blanket bog, annual net mineralization of nitrogen (64 kg N/ha) appears to be similar to that on unimproved areas (50 kg N/ha) (Martin and Holding, 1978). On the limed peats, however, the rate of immobilization is appreciable and predominates over net mineralization in the spring (Williams and Wheatley, 1991) with rates reaching 1.2 kg N/ha/day. This period of immobilization coincides with a very poor uptake (less than 25%) of the urea nitrogen applied in spring. During the summer months, net mineralization reached 1.1 kg N/ha/day which compared favourably with rates of 1.2 kg N/ha/day measured on mineral soils beneath grass (Barraclough, 1988) and recovery of available N in herbage was much greater than in spring. There seems little potential for nitrogen losses from cut grassland during the growing season, but leaching may occur at the end of the winter when accumulations of up to 40 kg N/ha present as ammonium have been measured in the surface soil (Marriott, 1988; Williams and Wheatley, 1991). This accumulation of mineral nitrogen is caused either by a steady accumulation in the absence of plant uptake over the winter or else by rapid freeze-thaw effects on the microbial biomass in the surface soil.

On less acidic soils in mid-Wales beneath *Nardus-Agrostis-Festuca*, nitrate concentrations in the soil solution were greater after the soil had been cultivated, limed, and fertilized or ploughed (Hornung *et al.*, 1986). Grazing has a marked effect on the nitrate content of the soil compared with cutting largely through the effects of excretal returns. Thomas *et al.* (1990) showed that under upland conditions the nitrate content of the soil was increased by about 4.5 kg N/ha by excretal returns from sheep. Grazed grassland receiving 114 to 194 kg N/ha as fertilizer lost 17.5 and 48.7 kg N in drainage water in successive years (Haigh and White, 1986). In intensive grassland receiving 420 kg N/ha the nitrate content of the soil profile was 5.6 times greater where the grass was grazed than where it was cut (Ryden *et al.*, 1984). The potential for losses of nitrogen to occur by nitrate leaching or by volatilization are therefore much greater in intensively grazed areas where only 26% of the nitrogen return in cattle urine may be retained by the plant and soil (Whitehead and Bristow, 1990).

Under upland conditions, substantial losses of nitrogen occur when swards are ploughed up and 67 kg N/ha more nitrogen was leached from ploughed grassland than from undisturbed areas during the first 3 years (Roberts *et al.*, 1989). This release of N is presumably caused by accelerated decomposition of organic matter and the total amount leached would be expected to increase with the age of the pasture and the quantity of nitrogen accumulated beneath the sward.

Losses of nitrate by denitrification can occur in grassland provided moisture conditions are suitable with rates of up to 1.8 kg N/ha/day measured in poorly drained clay soils (Ryden *et al.*, 1987). In highly organic peat soils the potential for denitrification exceeded 6 kg N/ha/day during April and fell sharply in June and July to less than 2 kg N/ha/day (Wheatley and Williams, 1989). However, nitrification was not active in this peat and denitrification was confined to nitrate from rainwater and fertilizers.

Arable soils

Lysimeter studies at Aberdeen (Hendrick, 1930) showed smaller annual leaching losses (3-24 kg N/ha) than at Rothamsted (30-45 kg N/ha) (Addiscott, 1988) suggesting that under Scottish conditions losses of mineralized N from arable soils could be smaller. Recent measurements of mean leaching losses in the range 15 to 30 kg N/ha/yr at Bush, Midlothian support this (Vinten *et al.*, 1991). The potential for leaching nitrate is greatest in arable rotations at the end of harvest when plant uptake has ceased and mineralization of organic nitrogen continues to be active. More than 90% of the mineral nitrogen in soil at this time has been derived from the soil organic fraction (Goulding *et al.*, 1989). Leaching is greatest under fallow areas and decreases as the degree of tillage is reduced (Goss *et al.*, 1991). Incorporation of decomposing straw residues promotes nitrogen retention in the soil by stimulating immobilization into the microbial biomass (Ocio *et al.*, 1991). However, the use of winter cover crops and green manures appear to have little effect on nitrate leaching (Vinten *et al.*, 1991).

Denitrification is active on the heavier clays, but the very texture and structure of these soils make direct measurements of the process difficult (Vinten *et al.*, 1991).

Alternative land uses

The consequences of taking land out of agriculture through set aside, or by establishing farm woodlands, on nitrate leaching can only be speculation at present. The importance of maintaining plant uptake probably means that the risk of nitrate leaching is low in areas set aside though when such an area is ploughed up there could be a flush of decomposition and nitrate leaching which would be greater if clover had been present in the vegetation (Sinclair *et al.*, 1991).

With a change in land use to farm forestry new factors could be introduced. For example, nitrate leaching could be enhanced by planting trees on relatively fertile soil where nitrification is active and concomitantly increasing the annual input of nitrogen from the atmosphere. Information on nitrogen transformations in these soils is required to predict the overall effect on nitrogen leaching. The same arguments apply to agroforestry or silvopastoral schemes where nitrogen fertilizers are also added.

Conclusions

Nitrate concentrations in Scottish rivers are presently well below the EC limit of 11 mg NO_3-N/l and values reported for rivers in eastern England. However, some samples of groundwater from agricultural areas of lowland Scotland have moderate to high nitrate concentrations. The nitrogen fluxes in Scottish rivers represent a significant economic loss as well as a source for potential eutrophication in coastal waters. Nitrogen loads correlate with the area of agricultural land and fertilizer use in a catchment and in different land uses and cropping practices there are circumstances which promote nitrate leaching. In arable soils, the potential for leaching is greatest at the end of harvest, whereas in fertilized grassland the potential is increased by excretal returns from grazing animals. In upland areas, conditions suitable for nitrate leaching to occur are created by ploughing-up or disturbing peaty soils and by clearfelling tree crops. Whether nitrate leaching occurs or not depends on the activity of the nitrification process, and at present there is insufficient information about the factors that control this process to predict its occurrence in acid soils.

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Photo: Words and Pictures, Aberdeen

Mixed woodland on the upper Don near Corgarff, Aberdeenshire

Land use research is fundamentally concerned with improving our awareness of how we can utilize land resources to achieve a range of different goals. These are concerned not only with production but now increasingly they include other so-called environmental goods such as conservation, landscape, amenity, recreation and access. In parallel with these changes in emphasis, concerning our use of rural land resources, changes are occurring also in the way we measure the success or otherwise of our management systems. Conventionally, measures of output have been used to gauge success. However, these provide no real indication of the true cost of rural activities in terms of resource depletion, social or environmental impact. In order to make more balanced judgments it is necessary to develop methods which allow these hidden costs to be quantified.

Our research programme on 'Land Use Options and Impacts on Natural and Human Resources' therefore addresses two fundamental issues:

(1) how do you identify management options when given different resources and different management goals, and

(2) how do you assess the impacts and true costs associated with these options?

The programme aims to draw together physical, biological and socio-economic information and examine it in an integrated way. It recognizes that there are few if any established protocols for doing this and therefore considerable emphasis is being placed on developing these. Central to this is the creation of a national land resource database for Scotland and the development of new skills in computer modelling. Further, the programme aims to develop and apply techniques from the evolving discipline of environmental economics in order to facilitate procedures for auditing potential impacts.

Dr. R.V. Birnie, Head of Land Use Research

The structure of the programme encompasses these initiatives within three main research topics:

1. *Multiple-objective rural land use management and planning*

This covers the development and testing of new methods of land suitability assessment, for specific crops and conservation; the field testing of alternative management systems for low-input, extensive pastoral agriculture and silvopastoralism; and land use decision-support systems for use at farm and regional levels. There are also projects concerned with the economic evaluation of land use options and the significance of non-farming income on farm businesses.

2. *Impact assessment*

Environmental impact assessment techniques seek to establish the degree of risk associated with specific land use or environmental change and to quantify this in terms of social or economic costs. In this programme the techniques are being developed and the principles are being applied in the context of four topics:

i) acidification
ii) heavy metal pollution
iii) climate change and
iv) land use change.

This work links closely with the strategic research being done on these topics elsewhere in the Institute's programme.

3. *Information technology development*

The ability to acquire, handle and utilize relevant information from a wide range of diverse sources (e.g. maps, farm surveys, population census data etc.) is fundamental to an effective land use research programme. In view of this there are three projects which focus on:

i) use of remote sensing techniques for monitoring land use change,
ii) development of a national computer-based land use information and modelling system (known by the acronym of MLUIMS) and
iii) use of knowledge-based procedures and geostatistical techniques in land use modelling.

A number of new initiatives have been introduced into the programme which was commissioned by SOAFD in April 1991. Several of these have evolved from previous work on topics of 'land resources and information systems' and 'land use systems and socio-economics' (MLURI Annual Report 1990). The following research summaries represent work relevant to the direction that this programme unit will take in the next two to three years.

Field testing of low input upland sheep systems

Background

Extensification of livestock production systems is seen as a way of reducing agricultural surpluses and of minimizing environmental problems by reducing levels of applied fertilizers. Grass/clover swards are seen as a basis for such systems but these must be proved to be biologically sustainable and their economic viability must be assessed.

The aims of this project are to measure the effects on grass/clover swards of the amount of nitrogenous fertilizer applied (on an annual basis) for a range of flock size of Greyface ewes, on individual performance and total output of ewes and lambs, the amount and quality of winter fodder produced and the amount of supplementary feeding supplied. Lambs are retained after weaning on separate areas within treatment plots until they reach a live weight of 40 kg when they are removed as 'finished' lambs. All lambs remaining below 40 kg at the end of September are removed. Grass and clover contents of swards are measured at the start, middle and end of the growing season. Nitrogen content of herbage and soil is determined at the start and end of the growing season and immediately before each fertilizer application.

Treatments must necessarily involve a range of level of N-fertilizer in combination with a range of flock size. The design matches flock size with fertilizer level over a realistic range of treatment combinations. In each case where N-fertilizer is to be used, 50 kg N/ha is applied as a spring dressing to encourage early season grass growth.

The treatments are:

Flock size (ewes+lambs/ha)	Fertilizer level (kg N/ha/annum) 150	100	50	0
10	x			
6	x	x	x	x
4				x

Each treatment is replicated three times. The swards are grass/clover mixtures of equal proportions across treatments at the start of the experiment. The project will run for three years to April 1993.

Results

There were no significant differences between treatments in the growth rate of lambs from birth to weaning or in the weight of individual lambs at weaning (Table 1a). There were no significant differences between treatments in the percentage of lambs finished by the end of September (89% of all lambs were finished). There were slight differences in ewe live-weight change throughout the grazing season so that there were significant differences in ewe condition score ($P<0.05$) at mating (late October) (Table 1b).

On the ewe-grazed areas, the sward height on treatment N150/10 was significantly lower than on the other treatments until the middle of May; thereafter there were no treatment differences. There were no significant treatment differences between mean sward heights on the weaned-lamb-grazed areas.

	N150/10	N150/6	N100/6	N50/6	NO/6	NO/4	±SE (if $P<0.05$)
a. LAMBS							
Live-weight gain (g/d) birth-weaning	281	249	270	253	262	285	ns
live weight (kg) at weaning	36.2	33.1	35.2	33.2	34.2	36.3	ns
b. EWES							
Condition score at mating	3.31	3.37	3.47	3.44	3.56	3.67	0.062

Table 1. Treatment mean values for individual animal performance.

The treatment means for proportions of plots cut for silage on two dates are shown in Table 2a. The proportion conserved on treatment N150/10 was significantly less than the other treatments at the first silage cut, otherwise the differences within cutting date are not significant.

	N150/10	N150/6	N100/6	N50/6	NO/6	NO/4	±SE (if $P<0.05$)
a. Proportions of plot areas cut for silage at two dates							
Early June	0.50	0.82	0.78	0.80	0.74	0.79	0.032
Early August	0.48	0.59	0.45	0.52	0.50	0.65	ns
b. Silage yields (kg DM/ha) at two dates and final yields of silage (kg DM/ewe)							
Early June	3170	5173	4724	4924	2938	3769	296
Early August	2747	2718	3082	2740	3614	3396	
Final yield per ewe	295	971	845	876	651	1296	59

Table 2. Treatment mean values for silage yield parameters.

Silage yields per unit area are shown in Table 2b for the two cutting dates. The treatment mean yields for the early-June cut show significant differences ($P<0.001$). The treatment mean yields for the second cut are not significantly different. The yield of silage per ewe, resulting from proportion of plot cut, yield of silage and flock size, is also shown in Table 2b. Treatment mean yields per ewe show significant differences ($P<0.001$).

Mean values for grass and clover content, measured at the end of the growing season, are shown in Table 3 for pasture consistently grazed and consistently closed for silage between May and August. There are significant treatment differences for all three parameters as shown.

There were no differences between treatments in the amounts of concentrates fed at pasture during lactation. No concentrates were fed at pasture around mating.

	N150/10	N150/6	N100/6	N50/6	NO/6	NO/4	P	±SE
Grass tiller number (n/m²)								
Grazed areas	14787	17153	14064	13779	10444	14568	<0.05	569
Silage areas	9294	6838	7601	6734	4511	6088	<0.01	394
Clover stolon length (cm/m²)								
Grazed areas	2187	1657	2227	1749	6761	3088	<0.05	517
Silage areas	1309	4094	6667	10668	11634	8189	<0.001	719
Clover growing point (n/m²)								
Grazed areas	2482	1034	2081	1564	5843	2301	<0.01	422
Silage areas	789	2107	3813	4007	6192	3917	<0.001	370

Table 3. Treatment means for grass tiller numbers, clover stolon length and clover growing points per unit area for grazed and ensiled areas at the end of the growing season.

Discussion

No treatment differences in individual performance to weaning are evident. This is consistent with the maintenance of sward height across treatments and the fact that there were no significant treatment differences in the clover content of the treatment swards at the start of the experiment. The difference in ewe condition at mating, though unlikely to result in differences in lambing performance next year, could be due to differences in diet quality resulting from the differences in clover content between treatments that developed during the season; differences at the start of the experiment were not significant.

The consistent levels of concentrates fed at pasture during lactation indicate that rates of herbage production were similar across all treatments. The complete absence of feeding around mating indicates that, at all levels of flock size and applied fertilizer, rates of herbage production were adequate.

All treatments produced large surpluses of silage after winter feeding requirements are accounted for. The silage yields produced on the low-nitrogen treatments are particularly surprising. These may be explained by the presence of a residue of nitrogen remaining in the soil from previous years or by the contribution already being made by the clover to the nitrogen balance of the low-nitrogen treatments. Results from analyses of soil and herbage nitrogen status throughout the season are awaited.

The differences in clover content between the treatments and between the consistently grazed and consistently ensiled areas, which themselves represent significantly different proportions of the treatment areas, could contribute to greater differences in pasture and animal performance in subsequent years. Measurements over the next two years will further help to resolve these matters.

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Decision-support models for assessing land use options at the farm level

Decisions affecting land use are ultimately taken at the farm or other management unit level. Evaluation of the consequences of these decisions is important (i) to provide objective assistance in the decision-making process at the management unit level, and (ii) to enable models and decision-makers working at higher levels of aggregation to take account of management level decisions.

The overall research objective is to develop a working model that through a series of production sub-models in conjunction with a hierarchy of decision rules can evaluate land allocation patterns according to single- or multi-objective criteria. On the farm, the consequences of land use decisions frequently have medium- to long-term effects and computer modelling provides a way of evaluating the consequences of land use change.

In model development, relationships between the physical properties of the land found in the uplands and production from a range of crops (arable, tree and livestock) have been collated and programmed to produce working sub-models illustrated below by describing the gean (wild cherry) and barley production sub-models. In addition, the model will also be developed to take economic, fiscal, sociological and environmental factors into account.

1. Interest in planting wild cherry (*Prunus avium*) is associated with its multi-purpose nature. Cherry timber can be valuable and on reasonable sites tree growth is rapid, the tree is a native of the British Isles and this is often associated with a higher conservation value, and cherry blossom and foliage are aesthetically pleasing.

For many of the coniferous species grown in the UK and some of the broadleaves, look-up yield class tables are available. If available and if the yield class of a site is known, tree growth can be quantified in terms of increases in height and timber volume. The cherry sub-model predicts approximate yield class for each potential site (represented spatially by a matrix of grid cells) and by using yield class tables, estimates production. In running the model, site suitability and yield class are predicted from the farm's physical characteristics and these are read in for each grid cell from a file holding date for the farm in question. Altitude is adjusted for geographical location of the farm and an exposure class is estimated from topex (a measure of geomorphic shelter) and aspect. Retained water capacity is estimated from soil texture and wetness class. According to adjusted altitude, soil depth, soil pH, major soil group, frost proneness, wetness class and exposure, each cell is evaluated as suitable or unsuitable for the planting of cherry (Table 4).

Site factor	Lower limit	Upper limit
Altitude		300 m
Rainfall	250 mm	1500 mm
Soil depth	40 cm	
Soil pH	4.0	7.0
Soil wetness class		III
Exposure class		3

Table 4. Site factor limits to cherry tree growth.

For suitable cells an initial yield class is estimated according to a yield class zone map based on mean July temperature. This initial value is adjusted according to soil texture, the medium loams giving best growth with sandy soils giving poorest growth. As with ash, cherry growth is poor from shallow soils and the model adjusts cherry growth according to soil depth. Yield class is next adjusted according to exposure rating with best growth in the most sheltered sites to give a final estimate of yield class.

Having estimated yield class for each suitable grid cell, the model, using yield class tables, reads mean annual increment of timber and timber volume per hectare for a rotation length chosen by the user and a given planting and spacing regime. Using regression equations, canopy diameter and percentage canopy closure are estimated to be used in mixed stand models. A similar approach is used for predicting growth and timber production from a range of tree species.

2. In estimating barley production, it is assumed that on an upland site that barley will be for the animal feed market and will be of a spring variety. Spring barley in contrast to winter barley, is less vulnerable to frost and flood damage and allows for more late summer/autumn grazing or a second cut of silage within a largely grass-based farming system. The model assumes that seed will be sown at 190 kg/ha and that fungicides will be used where necessary.

Site factor	Lower limit	Upper limit
Altitude		350 m
Rainfall	250 mm	1250 mm
Soil depth	25 cm	
Soil wetness class		IV
Soil pH	5.8	7.0
Stone or gravel as % of soil		35
Slope (%)		25
Field capacity		200 days

Table 5. Site factor limits to barley production.

As in the other crop models, the model first eliminates grid cells that are unsuitable for barley planting or growth. Relevant site factors include altitude, rainfall, soil depth, type and pH, stoniness and slope (Table 5).

The country is zoned according to number of days of field capacity and in zones where field capacity is greater than 200 days per year, except on soils of sandy texture, sites are evaluated as unsuitable for barley production. This results in much of the west of the country being classed as unsuitable for barley production.

For those cells which are suitable for barley production, nitrogen status of the soil is assessed from cropping history. The user is then asked for the rate of nitrogen to be applied ranging from 0 to 230 kg/ha and an initial approximation of yield is read from fertilizer response curves, according to N index, soil type and kg N/ha. Where average springs are wet and fertilizer is applied, grain yields are reduced to represent loss of fertilizer by leaching. Yield is further reduced for decreases in summer temperature associated with increases in altitude to give a final estimate of grain yield. Amount of straw produced is assumed to be constant at 2.5 t/ha.

Having developed a method for estimation of yield from relatively easily measurable farm characteristics, conversion of yields of timber, grain or lamb into common units will initially involve translation into monetary terms and a discounting procedure will be applied to allow comparisons over different rotation lengths. However alternatives to using economic returns have been investigated and might include employment opportunities, species or enterprise diversity and conservation or landscape values.

The number of possible land use combinations generated by the model is potentially very great and appropriate decision rules are critical to limit the number of possibilities generated. In planning decision rule development, incorporation of socio-economic, conservation and landscape interests is again thought to be important, and the priorities of the user can be reflected by altering the order of the rule hierarchy. The rules and order of the hierarchy must be clearly available to the user so that their effect can be assessed.

Integrated with other models being developed at the Institute, likely land use patterns will be objectively assessed over different scales of land area, for example from Regional scale to the on-farm scale.

Contact name: **Cathy Butcher**

Economic effects of land conversion to forestry from agriculture with special reference to environmental effects and development of multi-objective forestry policies at regional and national levels

Agricultural support mechanisms are undergoing rapid change and it is likely that significant areas of land will no longer be required for agricultural production in Scotland. Tree planting is, in many cases, the major alternative land use to agriculture and the potential for further planting has therefore to be assessed, particularly in relation to economic and environmental constraints.

The aim during the current year was to assess the commercial potential for new planting on agricultural ground within the context of changing land use policy.

The forestry investment model was expanded to include the new grants available for tree planting under the Farm Woodland Scheme, Set-aside Scheme and the Woodland Grant Scheme (WGS). A sub-model to predict the yield class of Sitka spruce (*Picea sitchensis* (Bong.) Carr) on better quality land, based on a principal component analysis of over 120 sample sites, was also incorporated. The major site factors affecting growth rate were elevation, soil type, soil moisture, shelter and aspect. With these developments, the model was better able to predict the rates of return to capital likely to be achieved by coniferous planting on good quality agricultural land qualifying for the Farm Woodland and Set-aside payments. Within the model's database these sites were identified from vegetation class (arable crops or improved grassland).

Application of the model has centred on the assessment of commercial planting opportunities in the preferred, potential and sensitive zones of the Regional Indicative Forestry Strategies. These can be described in the following way:

1. Preferred: Land which is likely to be attractive for forestry investment and where there are no major or only minor constraining interests
2. Potential: Land which is suitable for forestry but where at least one constraining interest has been identified
3. Sensitive: Land where the number, intensity or complexity of issues makes it extremely sensitive to forestry planting.

Results for Strathclyde and Borders Regions indicate that a relatively small percentage of land within each region is commercially attractive to investors based on a 6% return to capital and in a preferred area (Table 6). In both regions a relatively large proportion of the total

	Strathclyde	Borders
Total area (ha)	1 360 000	462 500
Preferred	32 500	15 000
Potential	67 500	52 500
Sensitive	67 500	35 000
Total	167 500	102 500

Table 6. Area of land with commercial potential in Strathclyde and Borders by strategy zone.

commercial area is located within the potential or sensitive zones. This implies that there is considerable potential for conflict between forestry and conservation, agriculture and other land uses. The introduction of a tiered grant system to reflect the environmental sensitivity of the three zones is one approach to minimizing conflict. A 50% increase in the basic grant available through the WGS in preferred zones, complemented by a 50% reduction in sensitive zones, significantly increases the proportion of the commercial area within the preferred zone (Table 7). Importantly, this approach would not

	Strathclyde	Borders
Commercial area (ha)		
Preferred	52 500	27 500
Potential	67 500	52 500
Sensitive	42 500	27 500
Total	162 500	107 500

Table 7. Effect of altering planting grant levels between zones on the commercial area.

significantly alter the total area of land with commercial potential in either region and hence could not be said to be altering the general attractiveness of forestry as an investment. Ongoing collaboration and consultancy with Strathclyde Regional Council, the Forestry Commission, the Countryside Commission and the Highlands and Islands Development Board is expected as more strategies are developed and refined in relation to national land use policy.
Contact name: **Douglas Macmillan**

Economic models in land use planning and policy development

Public policy may wish to intervene in the free market for land use through systems of incentives and controls in order to produce specific single or multiple objectives, such as economic development (including agriculture, forestry etc.), conservation and environmental aims and recreational objectives. In order to support the development of public policy it is important to identify and quantify the social and economic effects associated with different policies. These effects may be measured both in physical terms and also with parameters such as income, employment, public expenditure and cost.

Because of the public support associated with agricultural, forestry and a number of other land uses, any change in land use is typically associated with a change in public expenditure cost. The net effect of any change on public expenditure can be calculated by identifying, firstly, the public expenditure associated with the original land use, secondly, calculating the public expenditure support associated with the new land use and deriving the net effect as a difference. So, a policy development which encouraged the movement of land out of agriculture into woodlands would achieve a public expenditure saving through reductions in support expenditure on the agricultural activities displaced, but an increase in the expenditure associated with the grant structure for woodlands. Whether the latter change resulted in a net increase or decrease in public expenditure would depend on the difference between these two. New policy initiatives which impact on land use are not typically targeted in relation to specific existing land uses, and it may be difficult to predict the UK expenditure consequences of a new policy initiative such as a forestry grant scheme. A wide range of land using activities may be displaced and each of these would have an associated public expenditure saving.

The calculation of net expenditure changes associated with changes in land use is further complicated by the fact that some policies are strictly national whereas others are European, with a variable proportion of the costs derived from FEOGA (European Agricultural Guidance and Guarantee Fund). There is also a claw back arrangement which influences the net UK public expenditure of land uses for which there are common policies and common support in Europe.

A structure has been developed which, for all the main types of agricultural and forestry output, identifies the 1989 public expenditure support on a marginal basis. Each commodity's support arrangements tend to be different reflecting the differences and complexities of agricultural support. For example, with cereals the most useful assumption is that marginal output is exported with the cost associated with export refunds, whereas, with beef marginal output could follow a number of routes but intervention and subsequent storage and sale is the most likely one. Spreadsheet arrangements have been developed for the principal agricultural commodities, for which the physical output can be inserted and this is associated with a direct support expenditure and a calculated FEOGA and UK support expenditure. Similarly, for woodlands under the Farm Woodland Scheme or Woodland Grant Scheme, the European and UK public expenditure per hectare has been derived. It is the intention to expand this structure such that net effects of changing land uses can be identified.

The questions of additionality and displacement have also been addressed since it is not always evident that a substitution of land use necessarily saves the expenditure associated with previous output. The expenditure costs associated with a range of alternative land uses and policy initiatives, including set-aside and extensification, are being analyzed with a view to identifying the cost effectiveness of different land use policy instruments in public expenditure terms.

As an example of the public expenditure calculation, Table 8 shows the expenditure associated with new forestry planting under the Farm Woodland Scheme (FWS) in Scotland. The exchequer costs per year under this Scheme vary with land quality. On lowland farms, where a high proportion of broadleaves are planted, the annual cost is highest but savings on agricultural support are also considerable, as forestry

Land type	FWS cost £ per ha	Agricultural savings £ per ha	Net exchequer cost £ per ha
All land	157.50	99.30	58.20
Lowland	209.60	129.00	80.60
SDA improved	112.70	94.40	18.30
SDA unimproved	63.30	14.30	49.00
SDA refers to Severely Disadvantaged Areas			

Table 8. Annual average effect on UK Public Expenditure of Farm Woodland Scheme (FWS) planting, by each land type.

displaces farming. Overall the FWS cost of £157.50 per ha is reduced to a net figure of £58.20. In net terms forestry is cheaper to support on poorer Severely Disadvantaged Land. Much of this planting is, however, coniferous and in remote locations gaining little in the way of public benefit from improved landscape or environmental quality.

Contact name: **Bob Crabtree**

Modelling effects of rainfall variability on soil water regimes

The ability of a soil to store and transmit water has a profound influence on many land use issues. The soil water regime underpins many land capability, land suitability and hydrological models currently in use or being developed. However, all soils do not respond in a similar manner and in a collaborative project with the Institute of Hydrology and the Soil Survey and Land Research Centre, all UK soils have been assigned to one of 29 classes on the basis of their physical and morphological characteristics which influence the response of rivers to rainfall.

This HOST classification (Hydrology of Soil Types) presents an integrated model of water movement through the soil and substrate capable of predicting a range of river flow parameters. Based on three main soil criteria, hydrogeology and proximity to groundwater, the classification can be used at a wide range of scales to group soils and landscapes for a number of land use purposes. The model can be used to predict hydrological responses of rivers, particularly base flow indices and percentage runoff. It is also capable of being incorporated into other models such as slurry acceptance potential, erosion prediction and assessments of pesticide pollution risk.

Current work has been concerned with relating the individual HOST classes to their component soil types, associated landforms and vegetation, in an attempt to relate the abstract classification to specific environmental conditions. This will aid in understanding the complex relationships between the soils and hydrological parameters as well as placing the work in a context more readily understood by applied hydrologists. A summary of the soils, landforms and vegetation associated with each class is presented here. It should be noted that the classification is not hierarchical, instead there are complex inter-relationships between classes.

Due to the complexity of the Scottish landscape and soil pattern, individual HOST classes may have similar geographical distributions and landforms; this leads to a complex map contrasting sharply with the existing Winter Rainfall Acceptance Potential map which shows the Highlands to comprise largely one hydrological class. Of the 29 HOST classes, 18 are found in Scotland. Figure 1 on page 26 shows the distribution of the HOST classes in Scotland.

HOST class 3 comprises free-draining mineral soils and rankers developed on hard fissured limestones and sandstones. Much of the topography is rocky ranging from undulating lowlands of the Black Isle to the hilltops of Caithness and Sutherland. Covering only 0.6% of Scotland there is, however, a diversity of vegetation types from arable land to semi-natural grasslands and moorland with some coniferous plantation.

Developed on unconsolidated sands and gravels, HOST class 4 covers almost 5% of Scotland and is largely confined to fluvioglacial ridges in valley bottoms, coastal areas of links and dune sands, and fluvioglacial outwash in lowland areas. The soils are all freely drained and include brown forest soils, humus-iron podzols with alluvial gravels, regosols and brown calcareous soils. Although the dominant land use is arable or permanent pasture, semi-natural heather moorland or marram grass are also extensive.

HOST class 5 also comprises freely drained soils, mainly brown forest soils, humus-iron podzols and subalpine podzols, but the substrate is a loamy textured drift. It is one of the most extensive classes, covering around 16% of the land area, and is dominant in the north-eastern lowlands as well as Fife and the Southern Uplands.The land ranges in altitude from virtually sea level to around 900 m and encompasses a wide range of landforms and vegetation including arable and heather moorland.

HOST classes 9 and 11 have similar distributions alongside rivers and lochs as well as coastal areas of saline soils. Both classes are of limited extent (2.2% and 0.1% respectively) differing only in class 11 having a peaty surface layer. The largest single area of class 9 underlies the urban conurbation to the south side of the River Clyde and comprises poorly drained raised beach sands and silts. The dominant vegetation types are rush pastures and intensive arable. Floodplain is the most extensive landform.

Weakly gleyed soils such as brown forest soils and humus-iron podzols on permeable drift are placed in HOST class 12. This class amounts to 1.6% and comprises gently to strongly undulating topography with occasional steep valley slopes. Again, arable agriculture with improved and semi-natural grassland predominates. Soils with a greater degree of hydromorphism but overlying permeable drift are in HOST class 13. These mineral gleys cover only 1.7% of Scotland and are sporadically distributed, being confined to depressional and low lying sites in foothills and lowlands. Much of this land is under-drained and used for agriculture, although open moorland, rush pasture and coniferous woodland are also important land uses. The under-drainage changes the expected runoff response of these soils.

HOST class 14 is one of the most extensive, covering around 24% of Scotland. The soils have a peaty surface layer overlying permeable substrate. Although the most extensive landform is hummocky moraine, these soils also occupy lowland depressions and the glacially scoured areas of the Western Highlands. Permanent and rush pastures or conifer plantations predominate in lowland sites but the uplands are mainly bog or heather moorland and *Molinia* grasslands. Footslope springlines often occur on these soils but their extent is very limited.

Restricted to the high mountain tops, HOST class 15 comprises free-draining alpine soils on frost-shattered debris more than 1 m thick. The landscape is dominated by sparsely vegetated terracettes, boulder lobes and scree. Found primarily in the Cairngorm Mountains and only sporadically throughout the Western Highlands, this class covers only 0.6% of Scotland. Also of limited extent (0.5%) and composed of free-draining mineral soils, is HOST class 16. These soils have developed on water-modified lodgement till. The thickness of this layer is such that the soils have no hydromorphic characteristics within 1 m of the surface. HOST class 17 is similar except that the thickness of water-modified till is less, resulting in seasonal waterlogging of the soil. Together these classes account for 3.8% of the land area of Scotland. The gently undulating agricultural landscape is typified by Strathmore.

The common factors linking the soils of HOST class 18 are the presence of hard coherent rock within 1 m of the surface and their free drainage. The soils are brown forest soils, humus-iron podzols, subalpine and alpine podzols and are widely distributed in the Western Highlands and South-west Scotland. The vegetation is a semi-natural grassland or heather moorland. Covering around 5.7% of Scotland, this class is found in areas such as glacially scoured lowlands with well-developed roches moutonnées to high mountain summits with shallow frost-shattered debris and patterned ground. Where hard coherent rock is within 50 cm of the surface, mineral soils are

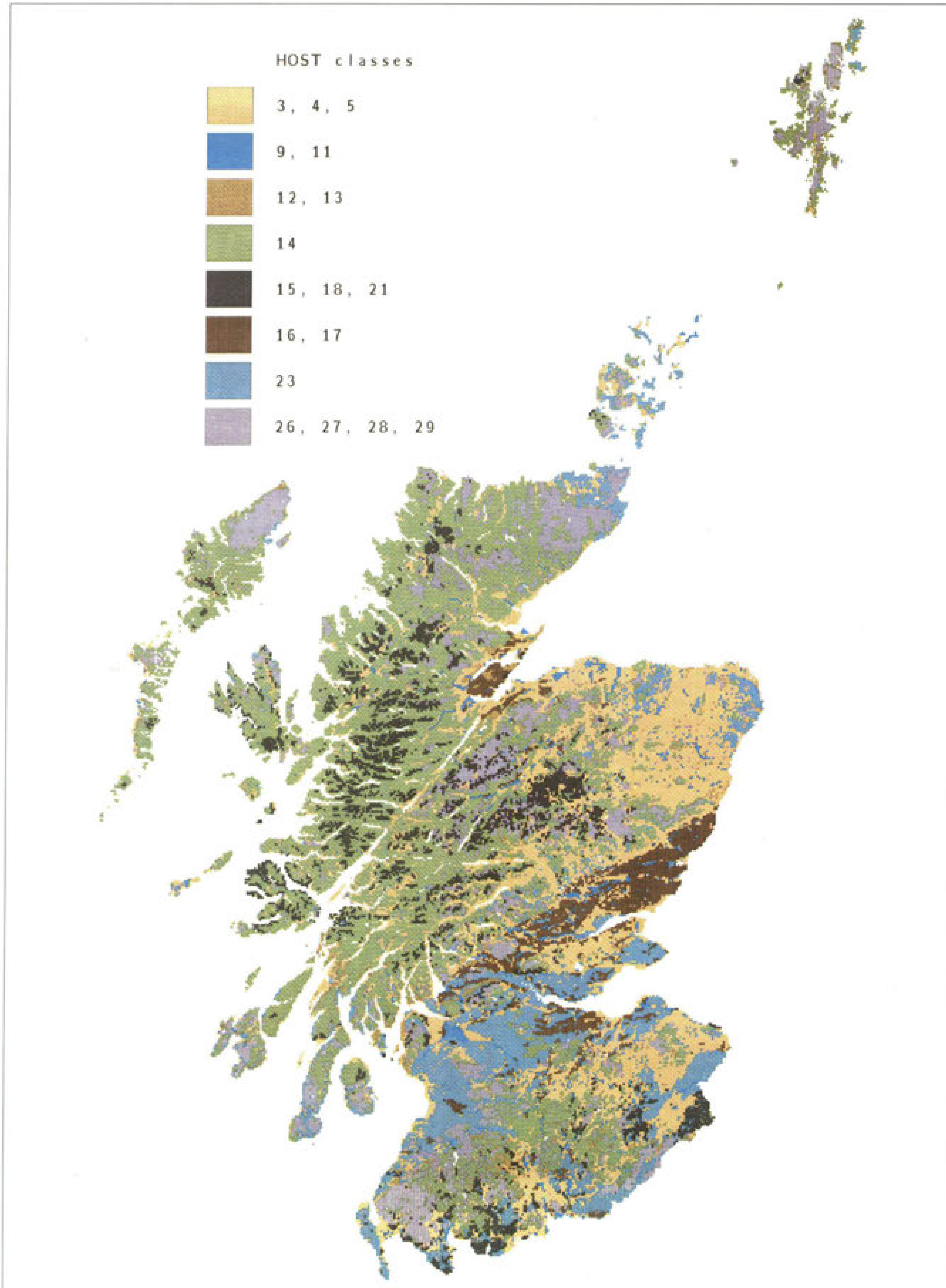


Figure 1. The distribution of HOST classes in Scotland.

assigned to HOST class 21. The land is rock-dominated and accounts for just over 1% of Scotland. The vegetation is often heather moorland, e.g. on Ardnamurchan or virtually non-existent, e.g. on precipitous rock walls.

Another extensive class, covering 9.9%, is HOST class 23. The soils are primarily gleyed mineral soils on fine-textured drift and are distributed throughout the Scottish lowlands and foothills. Till plains, till embayments and drumlin swarms typify much of the landscape though the level fields of the Carse soils are also included. The land is often cultivated but areas of *Molinia* grassland and rush pastures predominate in the foothills. The soils of HOST class 26 are related to those in 23 but here they have a peaty surface layer. This class is less extensive covering only 1.3% of Scotland and is confined to wetter, cooler areas.

Also with a peaty surface layer, the soils of HOST class 27 are shallow with hard coherent rock within 50 cm of the surface and consequently have high runoff rates and a low storage capacity. These soils occur in rock-dominated areas often in association with HOST classes 14 and 29, and, on its own, this class only accounts for about 2% of Scotland's land area.

Lastly, HOST classes 28 and 29 comprise eroded and uneroded basin and blanket peat and together account for around 25% of the land area of Scotland. These classes are widely distributed forming large areas on their own or as components of more complex landforms such as hummocky moraines. The vegetation is predominantly heather or *Molinia*-dominated moorland.

Contact name: **Allan Lilly**

Use of GIS techniques with process-based environmental assessment procedures for water quality modelling

Geographic Information Systems (GIS) provide a means for deriving and implementing different forms of geographical, inductive, knowledge-based or predictive models. An illustration of three of these models is in assessing the likely impacts of land use changes (principally changes in forest land use) within water catchments on water acidity as an input to strategic planning at a Scottish national scale.

Three stages are undertaken to identify indicator lochs in Scotland which will be most sensitive to changes in land use, where the MAGIC model is used as a calibration tool for water quality assessments on a catchment basis. Analyses of digital representations of terrain, land cover, soils and climate have provided a capability for prediction of where concentrations of atmospheric deposition may occur.

1. Geographical model - sensitivity of water quality model (MAGIC) to input map scales of spatially expressed model parameters (such as soil type dimensions)
2. Inductive model - derive a sample framework for Scottish national sampling of loch water
3. Predictive model - predict which loch catchments will be most sensitive to land use changes.

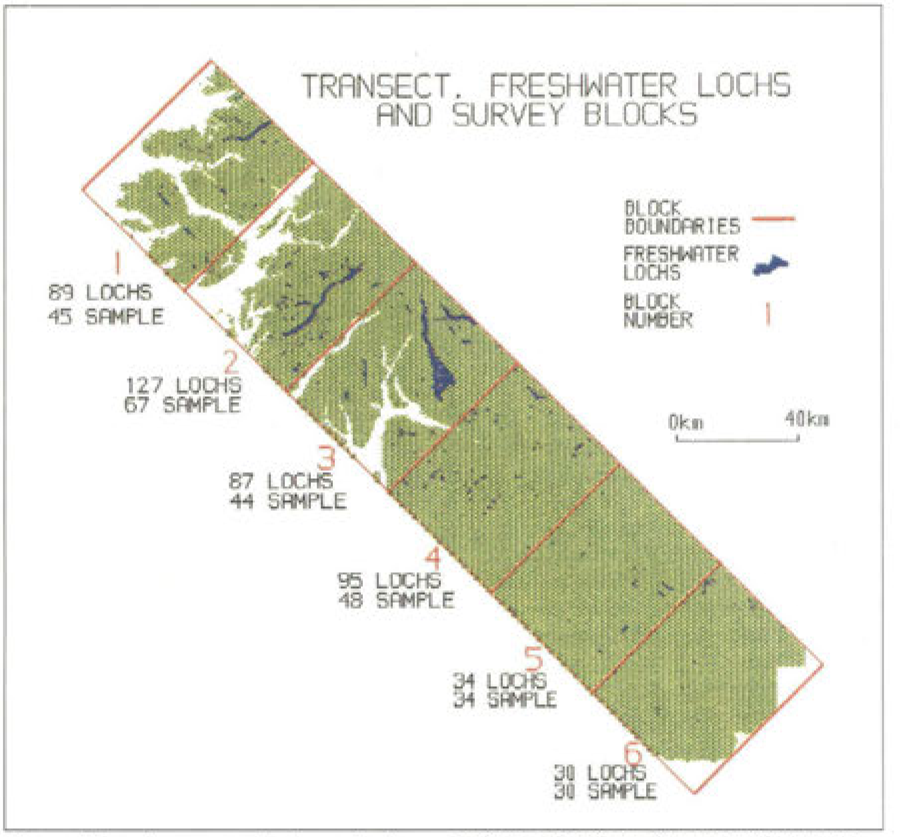


Figure 2. Sample transect of freshwater lochs.

MAGIC model sensitivity analyses are being tested in the River Feshie catchment, Cairngorm. The vertical and spatial aggregation of soil chemical information is an essential part of the initial parameterization of the model. GIS analyses are undertaken for the evaluation of three different hydrological scenarios:

(a) soils information weighted by area over the whole catchment
(b) flow pathway prediction
(c) proximity to soil units surrounding streams.

In the catchment there are 32 distinct soil map units identified by the Soil Survey of Scotland. Vertical weighting of soil chemistries was carried out for each soil type using horizon depths and bulk densities. Whole catchment assessments were calculated on the proportions of each dominant soil type within the catchment. Flow pathway prediction of a 100 random point sources of deposition was derived from a digital terrain model. The soil weightings were based on the last soil type encountered before reaching a stream. The final assessment summarized the soil weightings according to cumulative distance intervals of 25 m from the streams. The results of these analyses show the variation between soil characteristics dependent upon which hydrological scenario is used.

2. To measure the impact of land use change in water catchments, a reconnaissance survey of lochs occurring in a cross-section of geology, topography and land cover/uses was undertaken. This was of the form of a transect 480 km long by 60 km wide (Figure 2), running north-west to south-east, centred on Abbotsinch airport. Selection of the transect location and orientation was based upon a subjective assessment of the natural landscape and human intervention in west and central Scotland, with additional regard to wind direction over a year. A deposition gradient across the transect (SW/NE direction) can be compared with along-transect differences of air pollutant source - Glasgow, Ayrshire, Northern Ireland and north Atlantic.

The 1:250 000 soils dataset was scanned to identify the freshwater lochs, select a national grid coordinate for locational information and calculate their area. For convenience of comparisons between different parts of the transect it was split into six blocks, equal in dimension (47 km x 60 km). A sample was taken for each block based upon a minimum of 40 random samples per block, or half the number of lochs, whichever was the greater. From a total of 462 lochs, 268 (58%) were selected for sampling. Additional lochs were selected from 1:50 000 maps for the southern blocks to provide a higher sample population in this area.

From analyses of the water quality data and geographical datasets a model can be derived of the characteristics of those catchments which will be most susceptible to land use changes.

3.The predictive model requires expanded datasets across the country with which to apply both the inductive model of the sample transect and the sensitivity analyses of the calibration model.

Contact name: **David Miller**

Development of the Macaulay Land Use Information and Modelling System (MLUIMS)

Land use research and land use planning require the integration of a wide range of physical, biological and socio-economic information, and the necessary computing facilities to manipulate that information efficiently. An integrated land use modelling and information system is needed at MLURI as a basic tool for carrying out the Institute's research remit.

The aims are:

(i) To select a specific computer hardware processing platform, and to design and implement a suitable overall hardware configuration including processors, data storage devices, intra-system and extra-system communication links

(ii) To select specific computer software packages for Geographic Information System (GIS) applications, bearing in mind the need to be able to incorporate users' model code, and to tailor the packages to some extent, to meet MLURI's needs

(iii) To review the data needs for the new Institute research programme from April 1991, to negotiate costs and licensing arrangements, and enter data collected by MLURI

(iv) To develop a strategy for making MLURI's data available to other users

(v) To continue the cataloguing of spatially distributed data.

(vi) To explore the possibilities for use of the MLURI facilities by selected Scottish Office departments and other agencies.

The planned facilities are based on an easily-expandible network of SUN work-stations, together with x-windows, terminals and PCs. There wil! be several gigabytes each of magnetic, magneto-optical and optical disc storage. The PCs will be able to operate as independent processors, or as terminals managing processes in the work-stations. All equipment will be attached to a local area network, to which the VAX-based general computing facilities are attached.

A GIS package will be the principal software tool for much of the work concerned with spatially distributed data. A subroutine library forming part of this package will enable users to develop models using standard GIS data sets, without needing to code input and output operations. Other software is being developed at MLURI to supplement these facilities. One or more image analysis packages will be included in the system.

The ORACLE RDBMS holds attribute data for spatial data sets.

The CARTONET package is used for cataloguing all spatial data sets, both computer-readable and other.

A range of vector and raster data sets are being assembled for the whole of Scotland, with a preferred scale of 1:50 000. These cover soils, vegetation, topography, roads, rivers, climate, administrative boundaries and socio-economic data. Other data will be acquired, for particular projects, as needed.

Several staff will be available to provide a GIS service to staff. There will be a group of specialist users who will be available to advise other users

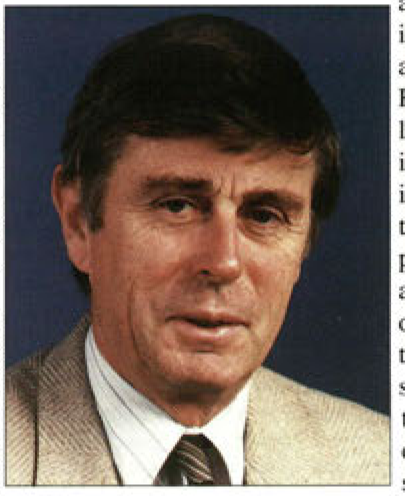
The facilities have been designed with a view to being usable by other organisations, as well as for the Institute's research programme and contracted projects. The system is designed to be able to be used remotely over a wide-area network.

Contact name: **Chris Osman**

Photo: The Scottish Picture Library, Strathpeffer, Hugh Webster

The Dornoch Firth from Struie, looking NW to Bonar Bridge in the middle distance

The programme of work on Soil and the Environment involves a strong element of continuity with previous programmes, particularly with regard to field-orientated research. Priority has been attached to studies of soil acidification, pollution of the soil by heavy metals and radionuclides and the likely effects on the soil of climate change. In general, the strategy adopted has been to coordinate field-based work with more fundamental work on soil characteristics and processes. In this way, it is intended that a coherent programme will develop so as to provide useful information that bears directly on the actual and potential interactions between land use, land use change, and pollution on the one hand and the quality of our soil and water resources, particularly in upland areas, on the other.



Dr. M.J. Wilson, Head of Soils and Environmental Research

Acidification studies are taking place in a variety of field sites ranging from the Flow Country of Caithness to Galloway in south-west Scotland. The reports below describe some of this work, particularly as it relates to the effects of afforestation on soils and waters and the effect of ameliorating acidified catchments by liming. Research into some of the soil processes that strongly influence the rates and consequences of soil acidification, such as cycling or transfer of sulphate, organic matter decomposition, aluminium retention or release, has been initiated: some results are reported on long-term weathering rates in catchments at Glensaugh and Sourhope on contrasting parent materials.

Heavy metal pollution of soils is a matter for public concern both in the context of direct application to land of urban sewage sludges and of atmospheric deposition from diffuse sources. The results of the field experiments described below indicate that these metals are strongly fixed in agricultural soils of relatively high pH, although these metals could become more mobile with the development of acid conditions and, for this reason, experimental sites have been set up on more acid soils including some under forestry. Research indicates that the high levels of lead found in some Scottish topsoils are indeed due to anthropogenic pollution and it will be important to determine the extent to which such metals are taken up by plants into the food chain. These studies are being reinforced by fundamental work on the effects of heavy metal pollution on the soil microbiology populations of the somewhat more acid soils typical of Scottish conditions and on the adsorption/desorption behaviour of individual metal species on fine-grained mineral and organic components.

Finally the results of an experiment aimed at elucidating the behaviour of radiocaesium in two organic soils under improved or indigenous vegetation are described. Surprisingly, it has been found that the caesium is to a large extent fixed by these soils, a result that emphasizes the need for a better understanding of ion exchange reactions occurring in upland soils.

Loch Ard with Ben Lomond, location of the Institute's studies on the effects of forestry practices on hydrochemistry

The effect of afforestation of blanket peat on water quality

Fears have been expressed that the afforestation of the deep peats of Caithness and Sutherland may have a deleterious effect upon the hydrology and hydrochemistry of the waters draining from these soils and, in collaboration with the Forestry Commission, experiments have been set up to obtain objective scientific information. The aims for the current year have been to establish the extent to which applied K and P fertilizers have been lost from forested plots and to determine the importance of losses in both soluble and particulate form from mineral and organic matter.

K and P losses were observed in fertilized plot drainage waters after rewetting of the peat in August 1989 following a dry summer (Figure 1). K again appeared in the outputs suddenly during February 1990 and elevated amounts of P were recorded in the spring. This led to algal growth in the furrows and drains of the P fertilized plots. In control plots, P losses were generally undetectable although high amounts of K (2.5 - 3 mg/litre) occur naturally in these drainage waters.

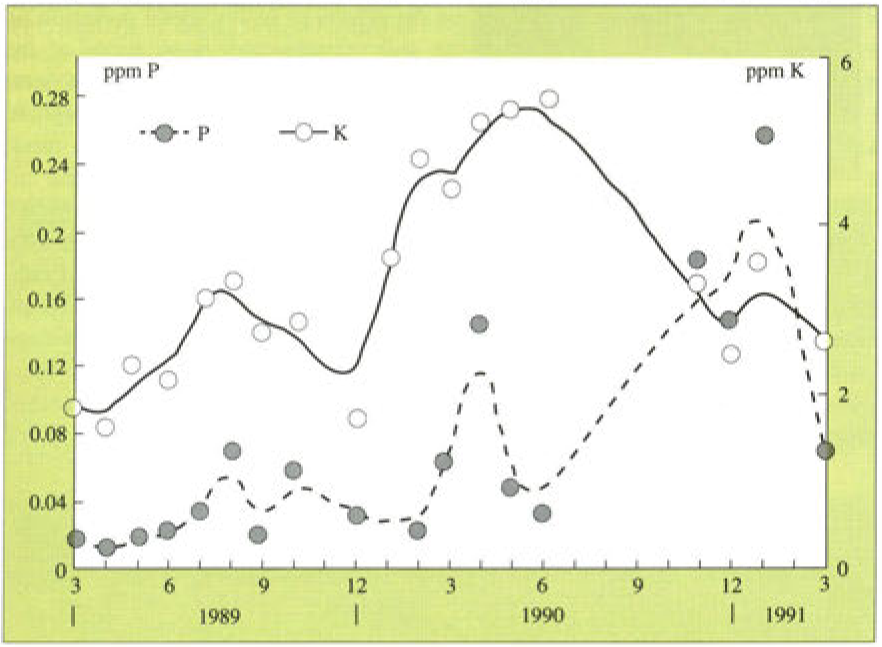


Figure 1. Fertilizer K and P concentrations in runoff from Bad a' Cheo Sitka plots.

Increased colour and turbidity of the drainage waters from the plots were observed and found to be due to soluble organic matter and finely divided peat. The latter probably derives from disturbance of the peat following cultivation. Carbon losses for 1989 were estimated at 6.5 kg C for the ploughed plots and 5.5 kg C for the control. Following ploughing there is an increased exposure of the peat, leading to increased amounts of soluble organics. Very low levels of nitrate are present in the outputs, the N losses being dominated by organic forms, with ammonium forming 25 - 35% of the N output. The significance of these observations is being further evaluated.
Contact name: **Hamish Anderson**

Harvesting consequences of various forestry practices at Balquhidder

A study was made of a forested catchment containing a variety of tree species to determine the nutrient content of the mature forest crop and the amounts of nutrients removed by harvesting the crop by various techniques. The catchment is at Kirkton, near Balquhidder in the south-west Highlands and the trees were planted between 1932 and 1936 with the overall species composition of about 40% Sitka spruce, 40% Norway spruce and smaller areas of European larch and Scots pine. A number of trees covering the diameter range at selected sites were felled to determine the above-ground component weights and nutrient amounts. The component weights for Sitka and Norway spruce amount to 300 and 254 tonnes/ha respectively, whereas for Scots pine the figure is 146 tonnes/ha and for European larch 112 tonnes/ha. However, the distribution of the various above-ground components is similar for all species, with wood comprising 70%, bark ~6%, twigs and branches 15 to 20% and needles ~6 to 8%. Figure 2 shows that nutrient amounts generally reflect component weights. However, spruce and pine contain large amounts of N and P in the needles and twigs whereas in larch there is a more even distribution between components. Sitka spruce contains more K than Norway spruce, but for both species the proportion of K is less than for pine and larch, where the wood contains >30% of the total K.

Table 1 illustrates the consequences for nutrient removal (including calcium) of two commonly used harvesting techniques, namely stem-only removal (SOR) where the brash remains at the felling site and whole tree harvesting (WTH) where the brash is removed from the site. The results again reflect the faster

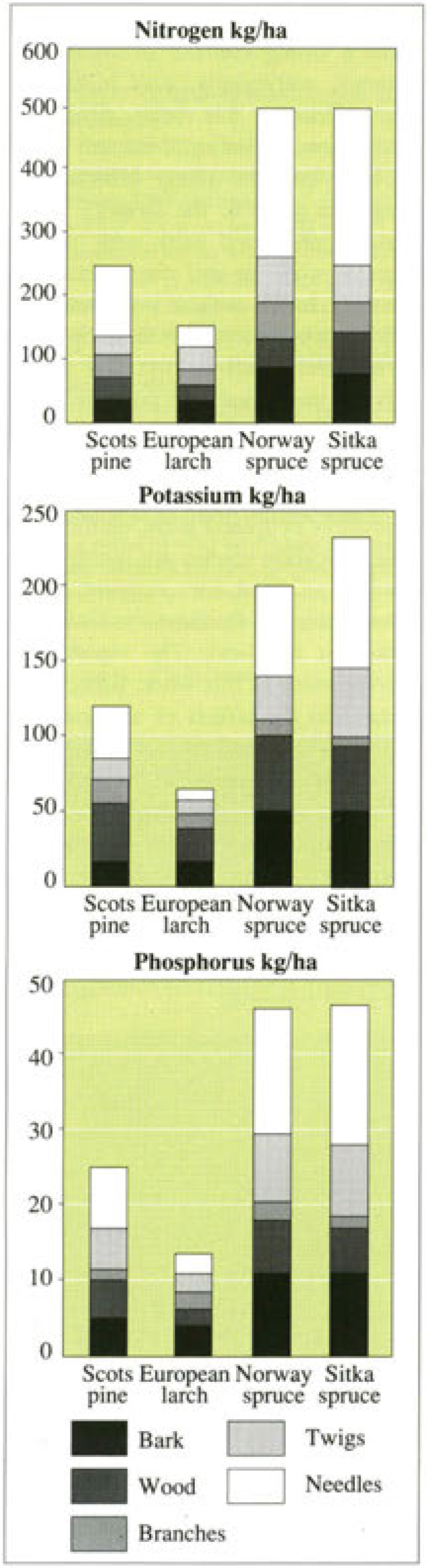


Figure 2. Distribution of nitrogen, phosphorus and potassium in the above-ground components of Scots pine, European larch, Norway spruce and Sitka spruce.

	Stem only removal					Whole tree harvesting				
	Biomass (Tonnes/ha)	N	P	K	Ca (kg/ha)	Biomass (Tonnes/ha)	N (kg/ha)	P	K	Ca
European larch	91	60	6	38	55	112	149	13	64	86
Scots pine	118	72	10	54	67	146	247	25	118	101
Norway spruce	201	140	18	100	171	254	498	47	200	314
Sitka spruce	237	149	17	92	161	300	498	47	222	281

Table 1. Comparison of different forest harvesting techniques for nutrient removal by different tree species in the Kirkton catchment.

growth rates and biomass accumulation of the spruces. For nitrogen, SOR accounts for the removal of ~30% of that removed by WTH for spruce and pine, rising to 40% for larch. These species differences are consistent for the other elements, but for calcium SOR accounts for ~60% of that removed by WTH. The results have implications for the nutrient depletion and acidification of forest soils with consequent effects upon the chemistry of surface waters.
Contact name: **John Miller**

The effects of selective liming of an acidified stream

Monitoring of the acidified Kelty Water catchment near Loch Ard has continued following heavy application of limestone in May 1990. Full details of application rates, limed areas and catchment areas are given in MLURI Annual Report 1989-90. Daily streamwater samples are being automatically collected to provide information on both the extent and duration of the treatment effects. The critical stream parameters necessary to sustain a viable fish population are generally accepted as; calcium to be maintained above 50 µeq/litre, pH to be greater than 4.5 and preferably above 5.0, and aluminium to remain below 250 µg/litre. The speciation of aluminium in water samples into labile inorganic and non-labile organic fractions is important for fish survival, with ideally the more toxic labile aluminium to be less than 70-100 µg/litre. These critical concentrations of calcium, hydrogen and aluminium are interdependent and are particularly important during the more vulnerable stages of fish development, that is for hatching eggs and very young fish (fry).

Figure 3 summarizes some of the hydrochemical results to date at a site about 1.8 km from the limed areas, and illustrates that stream conditions have been improved up to one year after liming. Calcium and hydrogen have been maintained at satisfactory levels, while aluminium has shown little response, with perhaps higher concentrations closer to the source areas, and with some indication of an increase in the proportion of the non-labile organic fraction, which matches an observed increase in the dissolved organic carbon concentrations. There are still, however, a few occasions when the critical levels are exceeded in these very dynamic stream systems during periods of high flow and under conditions representing a combination of surface and near-surface water flow. Because of the rapid water movement on or through the soil, it is very difficult to maintain the neutralizing effect.

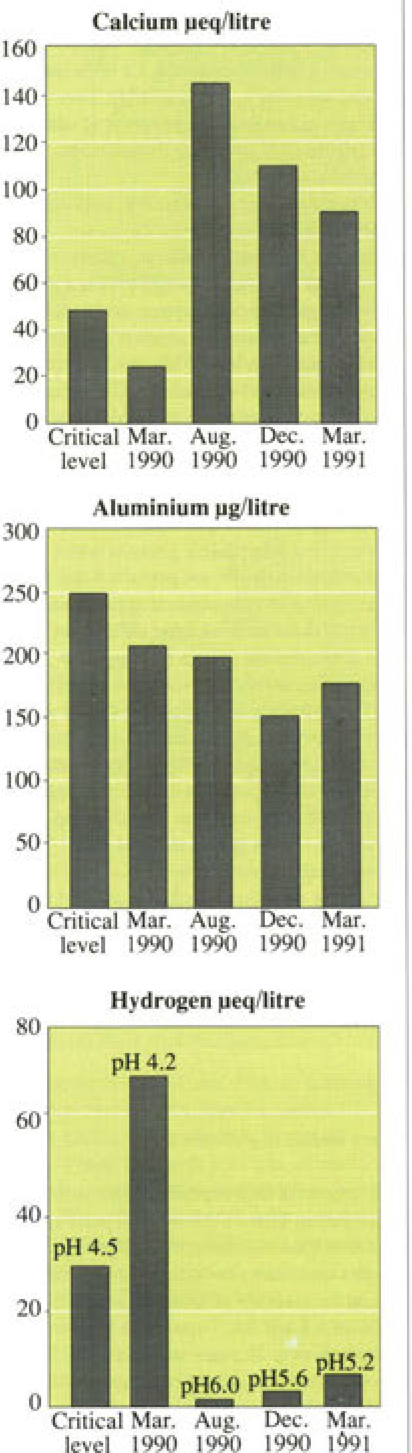
To test whether the streams are now capable of sustaining fish populations, salmon eggs were collected from fish taken from an adjacent, more alkaline river and batches of these eggs were installed into selected streams in December 1990 by the Freshwater Fisheries Laboratory. Initial results on egg survival were promising with around 70% success in the limed Kelty stream compared to no survivors in unlimed adjacent streams. However, this experiment was curtailed by severe losses of equipment in all streams due to a major winter storm. A further experiment on implantation of eggs at the particularly vulnerable eyed stage, which is about to hatch, was carried out in March 1991, again with promising results. Although the successful rate of hatching was low, around 20%, this was influenced by silting and the placement of the egg study chambers, as well as by problems of short periods of increased stream acidity.

Source area liming with heavy rates of fine limestone still seems to afford the best practical short-term solution to remedy the observed stream acidification problems in these forested catchments.
Contact name: **John Miller**

Inorganic nutrients from mineral weathering

In terrestrial ecosystems, the pool of inorganic nutrient cations in the soil is continually being depleted by uptake into the biomass, or by leaching. If the soil is not to become depleted in plant-available nutrient cations, this pool must be replenished, and weathering of minerals in the soil is the main mechanism by which this replenishment occurs.

The long-term rates of release of base



One year after limestone application the stream levels are remaining above the critical level for calcium and below critical levels for hydrogen and aluminium

Figure 3. Time diagram of stream hydrochemistry after liming in May 1990.

cations from the soils in two upland ecosystems on the Research Stations at Sourhope and Glensaugh have been calculated from chemical analyses of the various soil horizons. The most mobile base cation at Sourhope, where the parent rock is andesite, is Mg, followed by Ca, K and Na, whereas at Glensaugh where mica-schist is the parent rock, Ca is the most mobile, followed by Na, K and Mg. For Sourhope in particular, this order is at odds with that calculated from the catchment output, namely Ca>Mg>Na>K.

The mineralogy of the soils in both areas is similar in that the main constituents are plagioclase feldspar, K-feldspar, quartz, mica and chlorite, but the relative proportions differ. At Sourhope there is a decrease in chlorite and mica towards the surface which is consistent with the long-term loss of Mg and K. Although the two minerals also weather at Glensaugh, there is a greater decrease in the plagioclase feldspar content, perhaps explaining why Ca and Na are the most mobile base cations.

In the clay fractions at both sites, the most marked feature is the development of an interstratified vermiculitic phase in which the vermiculite interlayers are partially filled with polymeric hydroxyaluminium. It has been suggested from work on other catchments in mica-schist that the degree of aluminium interlayering depends critically on soil pH.

The phosphate solubilizing ability of a green, non-sporulating strain of a soil fungus isolated from an upland soil has been tested by incubating the organism with a rock phosphate composed of various forms of apatite and crandallite. Grains of this material were recovered after 4 months incubation and were found to be extensively etched compared with a control thus illustrating the ability of the organism to obtain phosphate from relatively insoluble material.

Contact names: **Derek Bain, David Jones**

Heavy metals in polluted soils

Two long-term field experiments set up in collaboration with ADAS over 20 years ago have now been concluded but soil profile samples taken last year are providing unique data on the mobility of metals in soils with pH values of 6.5 and 5.8. Topsoils (0-15 cm) taken at intervals over 20 years and held at MLURI provide a chronosequence of samples which are yielding valuable information on the long-term persistence of heavy metals and organic pollutants in sludge-treated soils.

Analyses of soil profile samples at Lee Valley show that most of the heavy metals applied in sewage sludge in 1968, particularly Cr and Pb, are strongly retained in the upper 30 cm of soil of pH 6.5 20 years later. There is evidence of some movement of Cd, Ni and Zn to a depth of 60 cm but these effects are small. Changes in the form of water-soluble copper with time have been studied using high performance/size exclusion liquid chromatography. Over a 17 year period copper becomes more firmly bound to higher molecular weight organic components.

The retention of organic pollutants in sludge-treated soils has also been investigated in collaboration with the University of Lancaster. Sludge applications in 1968 resulted in a four-fold increase in soil polynuclear aromatic hydrocarbon (PAH) concentrations. By 1972 some plots had lost up to 60% of the PAHs added and this increased to a 90% loss by 1989. Loss rates were related to PAH structure, the higher ringed compounds being more persistent. Half-lives varied from under 2 years for naphthalene to over 16 years for the seven-ringed coronene. Herbage species free from soil contamination are being analyzed for PAHs to quantify the uptake of these carcinogenic compounds from sludge-treated soils.

A first herbage cut has been taken at a sewage sludge field experiment set up at Craigiebuckler in 1989 with metal applications at the maximum permissible additions specified by the CEC and at twice these amounts. Target concentrations of metals in the soils have been achieved, and pot experiments carried out in collaboration with Aberdeen University have shown that the more mobile heavy metals will be taken up by vegetation. Thus, perennial ryegrass grown on these soils contains up to 400 mg Zn/kgDM and 20 mg Cu/kgDM.

Contact name: **Mike Berrow**

Atmospheric deposition of lead on Scottish hill and upland soils

Three small plots (1.5 m x 1.5 m) were set up at the Glensaugh Research Station in order to investigate the atmospheric deposition of lead in remote areas. One plot is directly beside the road on the climb to Cairn O' Mount whereas the other two are remote from the road, one on a reseeded area and the other on indigenous vegetation high on the hillside. The grass on these plots was allowed to grow throughout the summer and was cut in early winter, taking precaution to avoid soil contamination. Two grass samples were taken at each plot - one unwashed and the other washed on-site by immersion and agitation in Teepol solution followed by rinsing in distilled water. The solutions were filtered and the filtered material combined to give the particulate matter washed from the grass. The total lead content and the lead isotopic composition were measured for each sample collected.

Preliminary data indicate that although the roadside grass was visibly more contaminated than the grasses from the other plots and a greater quantity of particulate matter was washed off, the lead concentration (Table 2) was higher in the hillside plot grass, whether unwashed and washed. Washing removed about 75% of lead from the hillside and roadside grasses, suggesting that in both cases most lead was deposited loosely on the surface of the grass. In contrast, no lead was removed from the grass from the reseeded plot.

	Roadside	Hillside	Reseeded
Unwashed grass	2.72	3.42	0.28
Washed grass	0.73	1.04	0.31

Table 2. Lead concentrations in grasses (ppm).

There appears to be a noticeable difference in the form of lead recovered from the hillside and roadside plots (Table 3). Most of the lead washed from the hillside plot was Teepol-soluble, whereas most washed from the roadside plot was probably in the filtered particulate matter, i.e. was Teepol-insoluble. It can be surmised that most of the lead beside the road is deposited directly in the form of particles, whereas on the hillside most lead arrives in a different chemical form through aerial deposition of finer particles and droplets.

	Roadside	Hillside	Reseeded
Unwashed grass	51	266	274
Washed grass	53	95	113
Teepol soln.	20	110	12
Water soln.	9	37	40

Table 3. Total lead recovered from samples collected (µg).

	Roadside	Hillside	Reseeded
Unwashed grass	1.110	ND	1.128
Washed grass	1.112	ND	1.128
Filtered particulate matter	ND	1.129	1.128
Soil 0-2.5 cm	1.113	1.154	1.157
Soil 0-15 cm	1.148	1.163	1.145

Table 4. Lead isotope ratios ($^{206}Pb/^{207}Pb$) in grasses and soils.

Isotope ratio data (Table 4) gave additional information on the origin of the lead. The grasses and surface soil from the roadside plot have the same low lead isotope ratio, consistent both with petrol lead having a low 206/207 ratio and with the values found in rainwater samples (1.08 to 1.11) collected at various upland sites. The reseeded area gave uniform ratios for the grass and particulate matter which are higher than the corresponding roadside ratios but lower than those for geochemical lead. The topsoil has a higher ratio, however, indicating that the lead in the grass has a different origin to the lead in the topsoil. The fact that in both roadside and reseeded plots the washed and unwashed grasses have almost identical lead isotope ratios is further evidence for the grass lead to be the same as deposited lead.

With the exception of the roadside surface soil, the soil isotope ratios are different from the grass isotope ratios, indicating relatively little contamination by current inputs of petrol lead. The reseeded and hillside plots have similar surface soil isotope ratios (1.157 and 1.154), consistent with data previously presented for surface soils. There is increasing evidence that the enhanced surface concentration of lead might have had a common origin and that, whereas the roadside plot represents current inputs, the other plots represent historical inputs.
Contact name: **Jeff Bacon**

Use of farm and sewage wastes

Farm sewage and distillery wastes, which can be toxic to the environment, contain substances which are potentially valuable to plant growth. Novel systems are being devised to exploit the useful substances in these wastes while minimizing their toxicity.

The organic constituents of silage effluents are toxic to plant growth and even diluted 100 times with water these constituents still inhibited the germination of lettuce, clover and ryegrass. When the effluents were dialysed against water for 3 days, the dialysate comprised organic substances of low molecular weight (4000 - 500 daltons) which were proteinaceous and phytotoxic to the growth of tomato seedlings (Table 5). Treatment of this material with proteolytic enzymes (pronase, papain and chymotrypsin) lowered the molecular weight range to 950 - 500 daltons, but had no effect on its phytotoxicity.

Growth medium	D. wt (mg) of whole plant
Fresh bark	225 + 10.2
Composted bark	394 + 16.7
Fresh (bark + total effluent)	20 + 1.7
Fresh (bark + effluent dialysate)	32 + 2.8
Composted (bark + total effluent)	449 + 17.3
Composted (bark + dialysate)	455 + 17.2

Table 5. Stimulating effect of composting silage effluent (adsorbed on Sitka spruce bark) on the growth of tomato plants after 21 days.

Attempts were made to detoxify silage effluents by composting them on bark so that the beneficial effects of their nutrients towards plant growth were retained. Silage effluents, or their dialysate, were adsorbed on to Sitka spruce bark, and after the addition of urea and trisodium phosphate, the moisture content was adjusted to 60%. The mixture was composted in 26 litre composters for 14 days with constant aeration. The resulting compost produced a 15% stimulation in the growth of tomato seedlings compared with compost produced from the bark without the effluent (Table 5). This approach has considerable potential in the detoxification of silage effluents.

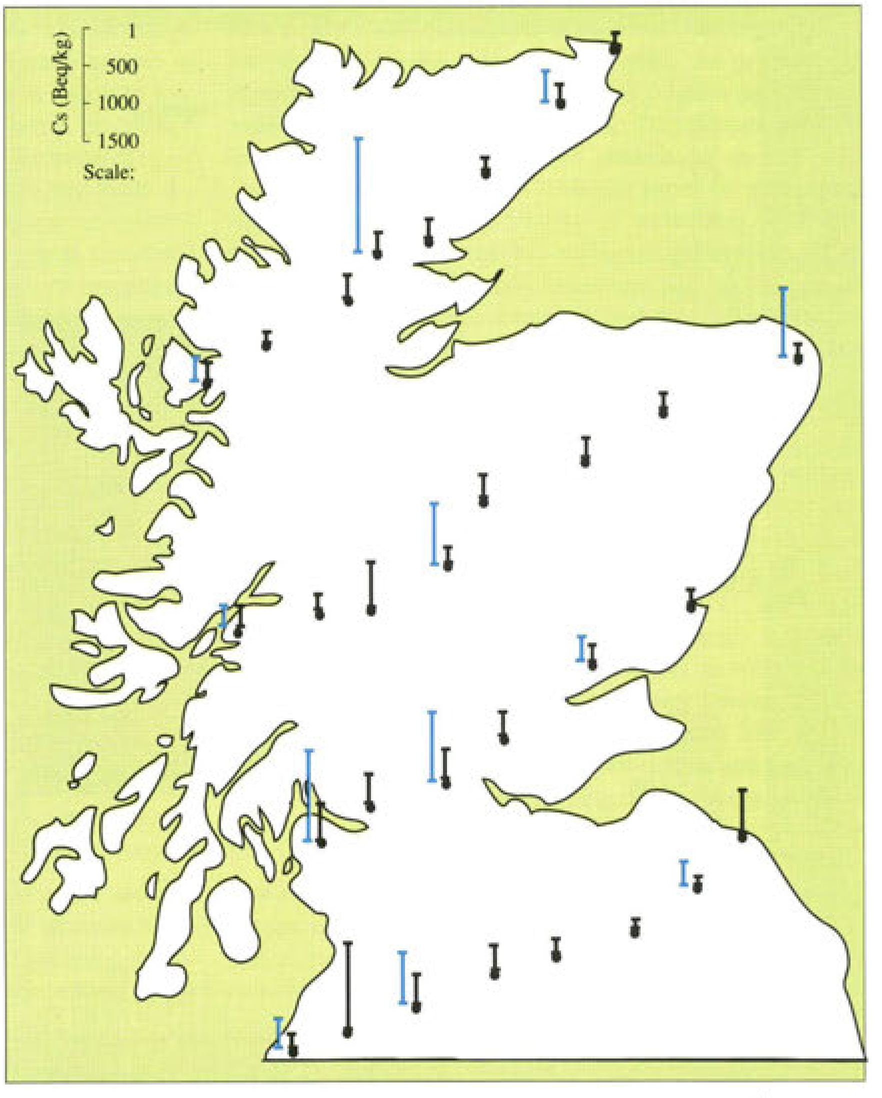


Figure 4. Radiocaesium concentrations in peaty soils (black) and in herbage (blue).

Longer term work has continued on heavy metal contents in soils and tree needle samples taken from experiments involving sewage sludge utilization in conventional forestry. The application of stored liquid undigested sludge to a mature 40-year old stand of Scots pine at Montreathmont near Brechin resulted in no significant uptake of metals into the needles, except for copper at the medium rate treatment in the autumn after the first growing season. In contrast, at Ardross near Tain, where stored liquid undigested sludge was applied to heather moorland before planting, Sitka spruce needles showed significant increases in copper and zinc. The concentrations in needle dry matter in the first year for the 0, 500 and 1000 m^3/ha sludge treatments respectively were for copper 2.3, 3.8 and 4.1 mg/kg and for zinc 21, 36 and 37 mg/kg. Young trees appear to take up heavy metals more readily than mature ones, possibly enhanced by space/furrow ploughing of the site which incorporated the sludge into the ridges where the trees were planted.
Contact name: **Derek Vaughan**

Radiocaesium pollution of soils

Samples of herbage and peat soils taken from sites along four east-west transects across Scotland show the persistence of available caesium in contaminated areas resulting from deposition of fallout from the Chernobyl accident in April 1986 (Figure 4).

The behaviour of caesium in organic soil contrasts with that in soils which are mainly mineral where caesium rapidly becomes fixed, and so experiments on highly organic soils have been conducted to try to understand the differences.

Two experimental plots were established on

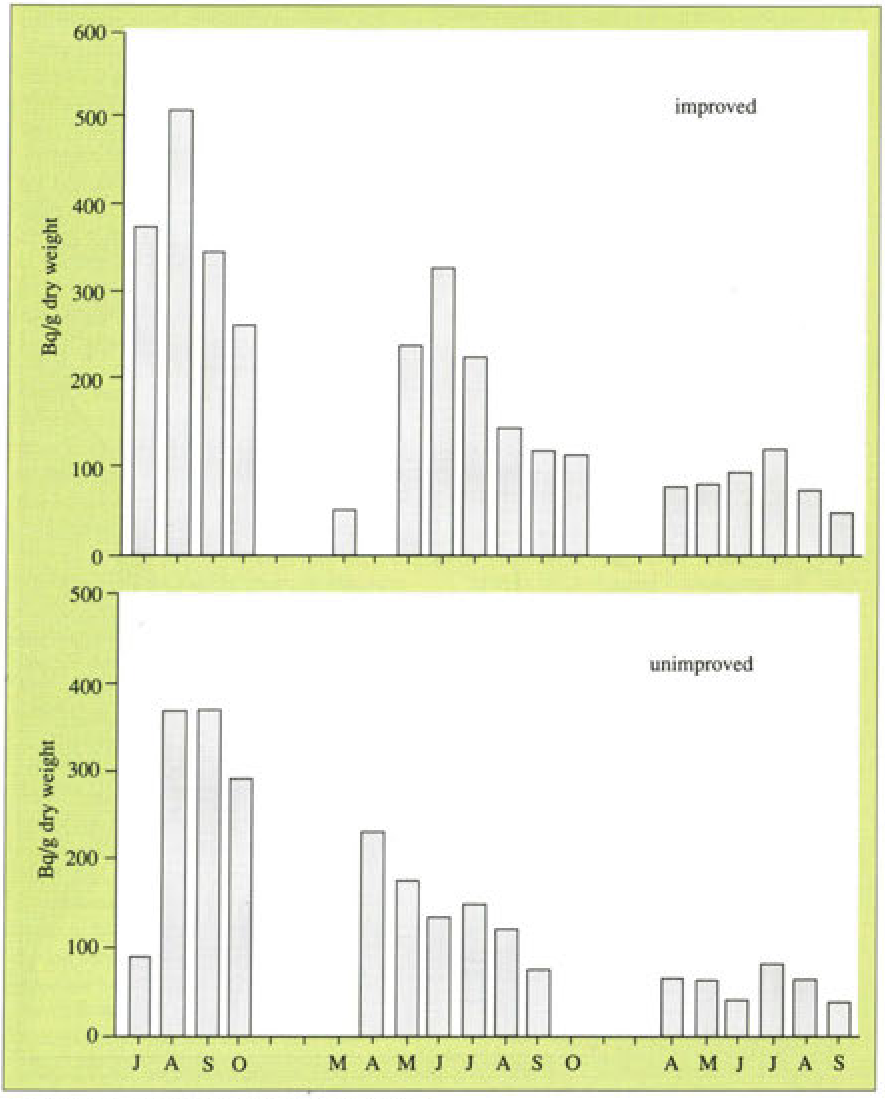


Figure 5. Caesium uptake by herbage over three seasons.

	>1.00	>0.50	>0.25	>0.15	>0.053	<0.053	Sum
			134Cs activity distribution %				
Cairn 0-3 cm	2.92	.88	1.63	3.10	9.45	80.58	98.56
Cairn 3-6 cm	.92	.77	1.59	1.32	9.46	82.98	97.04
Hatton peat	7.00	4.31	5.81	5.38	15.95	39.51	77.96
			Weight distribution %				
Cairn 0-3 cm	13.37	3.17	4.33	5.67	15.02	58.44	100.00
Cairn 0-6 cm	3.49	2.21	4.59	3.65	17.14	68.91	100.00
Hatton peat	9.38	5.69	7.37	6.44	21.28	49.84	100.00
			Relative activity per unit weight				
Cairn 0-3 cm	.22	.28	.38	.55	.63	1.38	
Cairn 3-6 cm	.26	.35	.35	.36	.55	1.20	
Hatton peat	.75	.76	.79	.84	.75	.79	

Table 6. Distribution of ^{134}Cs amongst soil and peat fractions.

a peaty podzol at the Glensaugh Research Station. One had been limed to pH 5, fertilized and reseeded with ryegrass and clover. The other was unimproved (pH 3.8), though old heather had been burned 6 - 8 years previously. The vegetation was grasses with regenerating heather. Both soils had ash contents of 14 - 16% in the organic surface horizons.

Experiments showed a progressive decrease in availability to plants of caesium, applied as CsCl, as measured by plant uptake, even though there was no overall movement of the caesium down the profile from the point of application at 3 cm depth (Figure 5).

Over three growing seasons total caesium removed in herbage amounted to 3.5 and 0.6% of that applied to the improved and unimproved soils respectively.

The extractability of the caesium from the improved soil also correspondingly decreased with time. Initially 30 and 56% of the cation was released by 1M ammonium acetate from the 0-3 and 3-6 cm horizons respectively. After 5 months the values had fallen to 12 and 7% and after 24 months to 1.6 and 3.3% respectively. In contrast caesium added to a peat with an ash content of less than 2% remained completely extractable after 2 months.

To investigate possible sites for the fixation of the caesium a fractionation of the peaty soil horizon which had been incubated with ^{134}Cs for several months has been made using wet sieving after ultrasonic treatment. The results obtained are shown in Table 6.

The greatest concentration of caesium was observed in the finest fraction, <0.053 mm. This fraction has the highest ash content suggesting that there is a concentration of soil mineral components there, and that these may be responsible for fixing the caesium. In contrast, with peat with a low ash content there were no differences in the relative caesium content per unit weight in the fractions.

Contact names: **Martin Cheshire, Charles Shand, Alan Hepburn**

Research in this programme unit identifies and quantifies the mechanisms and processes governing plant growth in areas characterized by low inputs of nutrients and with acid soils of poor inherent fertility and high levels of organic matter. Priority is given to the strategic understanding of these processes in indigenous pastures, including those dependent upon biological nitrogen fixation, and ecosystems which include trees such as agroforestry, farm woodland and conventional forestry. All these ecosystems are important components of rural land use in the UK, more widely in Europe and elsewhere.

Dr. P. Millard, Head of Plants Research

Studies of the processes and rates of nutrient cycling which affect the growth of plants in these ecosystems concentrate on the biological interfaces. Soil/plant and plant/animal nutrient transfers are considered in terms of soil nutrient turnover and plant uptake, and the consequences of grazing on plant nutrient partitioning and vegetation change. Studies of these two interfaces are linked together by investigating the factors influencing the internal cycling and nutrient partitioning within plants to support growth. The work involves a mixture of laboratory and field investigations.

There are only small inputs of nutrients to hill and upland soils, so plants rely upon the supply of nutrients from organic matter. Research on soil nutrient dynamics, therefore, concentrates on the release of both nitrogen and phosphorus from the soil organic matter and decomposition of leaf litter. Work on nitrogen investigates the processes of mineralization and immobilization in relation to both soil water status and microbial activity. Determination of the forms of organically-complexed phosphorus in soil solutions and the availability of different forms of phosphorus for plant uptake uses a variety of techniques, including NMR spectroscopy and ion-exchange resins. Effects of plant root exudates on soil microbial activity and rhizosphere enzymes and the consequent effects on soil nutrient dynamics are also considered.

At the interface between soil and plants, the dynamics and functioning of root systems are being studied in relation to both nutrient supply, and competition for nutrients and water between different plant species. A variety of techniques are used, including both destructive and non-destructive methods (such as mini-rhizotron video systems) to measure the turnover of roots. Nutrient uptake and partitioning between the roots and above-ground parts of herbaceous and perennial plants, particularly indigenous grasses and trees is considered. Internal nutrient cycling in trees is being studied in relation to root and shoot demography and the consequences for nutrient use efficiency. The impact of atmospheric deposition of pollutants on the processes of internal cycling is also being considered in relation to aspects of forest decline.

Reseeded blanket bog, Strath Halladale, Sutherland

Organic matter turnover in upland soils and its relationship with nitrogen and phosphorus transformations and availability to plants

Studies on the poor utilization of nitrogen by a grass sward on poorly drained reseeded blanket bog have concentrated on the competition for available nitrogen by microbial processes in the peat. The picture on preceding page 35 shows a typical grass sward used to study N turnover in peat soils. For an application of 112.5 kg N/ha ammonium nitrate denitrification rates of 6 kg N/ha/day were measured in cores taken from the surface 5 cm during April. Substituting ammonium nitrate with urea eliminated denitrification, because nitrification was absent. Consequently nitrogen in the first cut of herbage increased from 15 to 28 kg N/ha. This relatively small improvement in utilization showed that the greater proportion of ammonium in the peat was not remaining in an available form. This was confirmed by measurements of ammonium production in peat cores incubated *in situ*, showing net immobilization of nitrogen predominating between April and June with rates reaching 1.0 kg N ha day.

Incubation *in situ* results in samples being disturbed and plant uptake being removed, and measurements on newly fertilized plots are confounded by high and variable concentrations of mineral nitrogen. Therefore, current work has concentrated on measurements of the rate of dilution of ^{15}N labelled mineral N pools in the soil, providing a basis for calculating rates of both gross mineralization and immobilization of nitrogen in relatively undisturbed samples. Such data are not confined to rates of mineralization and immobilization alone; the location and fate of the immobilized nitrogen are also important factors. Therefore, the study of different organic nitrogen pools and their ^{15}N enrichment in nitrogen treated soils is also being developed. Nitrogen pools of interest at present include soluble organic nitrogen extractable in $CaCl_2$, microbial biomass nitrogen released after fumigation with chloroform and nitrogen readily mineralized under waterlogged conditions at 30°C. Injection of ^{15}N labelled ammonium nitrate (5 atom %) into peat cores *in situ* at spring temperatures (5 to 8°C) showed that after 20 hours an appreciable proportion of the labelled N was associated with the soluble extractable organic nitrogen (1.7-1.8 atom %). The rapidity of this incorporation suggests either exchange of nitrogen between different forms or else a very active microbial population. One month later, the ^{15}N enrichment of the soluble organic nitrogen pool had declined to 0.42 atom % and only the microbial (0.51 atom %) and ammonium (0.62 atom %) nitrogen pools showed ^{15}N enrichments. This short-term incorporation of mineral into organic nitrogen is being examined more closely under controlled laboratory conditions.

The influences of moisture and temperature conditions on the kinetics of nitrogen transformations in upland soils are also being investigated. In practice, the fate of ammonium and nitrate in soils is the net effect of several interacting processes that include plant uptake, mineralization, immobilization, nitrification and leaching. Moisture and temperature conditions vary widely in upland soils and defining their relationships with the rates of different nitrogen transformations will enable the development of mathematical models to simulate the dynamics of nitrogen and other nutrients in these soils.
Contact name: **Berwyn Williams**

Figure 1. Equipment for measuring organic P in soil solutions.

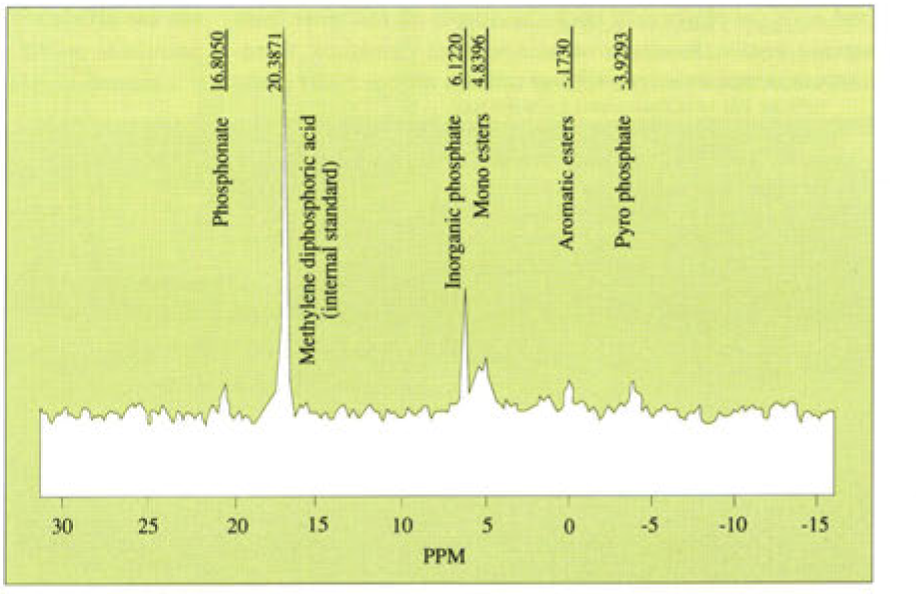


Figure 2. 121 MHz ^{31}P NMR spectrum of a NaOH extract of whole peat.

Dynamics of phosphorus depletion and repletion in soil solution in relation to plant growth

On wet, acid, upland soils, soil organic phosphorus may be the dominant reserve of P for plant growth.This resource is largely in the solid phase and a small proportion becomes available for uptake by plants after dissolution into organic or inorganic forms. The role of organic P *per se* in plant nutrition is not well understood. Work at MLURI has shown that on soils from several upland sites the amount of organically combined P in soil solutions (obtained by centrifugation of field moist soils) exceeds the amount of simple (ortho)phosphate by an order of magnitude. There is evidence in the literature that some forms of organically combined P are assimilated by plants both directly and indirectly. Because of the uncertainty of the role of organic P in plant nutrition and the apparent large capacity of the reserve there is a need to study this resource to maximize exploitation and minimize inputs. Methods for the selective determination of organic P in soil solution using UV-light catalyzed peroxide digestion have been developed (Figure 1) and used in conjunction with membrane filtration and size exclusion chromatography (500-300,000 daltons) to estimate molecular weight distribution of organic P complexes. The effect of plant growth, fertilizer inputs, pH and seasonality on the amounts and forms of P in soil solutions have been determined by field experiments on

Figure 3. Five-year-old trees at Glensaugh are protected by plastic guards.

several grass/clover swards. In order to assess the relative capacity of the organic P resource to sustain demand, the relative rates of repletion of organic P into soil solution has been measured in the laboratory and compared with inorganic P. To further the objective of improving understanding of the role that organic P plays in the nutrition of plant, studies on the cleavage of soil organic P esters by phosphatase enzymes and other hydrolytic agents are planned. The work reported here is supplemented by ^{31}P NMR studies of whole soils, soil extracts and intact plant roots. A special illuminated teflon cell to hold intact living plants with lines for recirculating nutrient solutions and oxygen has been constructed. A 121 MHz ^{31}P NMR spectrum of an alkaline extract of a whole peat (Figure 2) demonstrates the power of the technique.

Contact name: **Charles Shand**

Root competition between trees and grass for nutrients and water

In agroforestry systems the main effect of grasses on tree growth is through root competition for nutrients and water. The below-ground interactions between wild cherry (*Prunus avium* L.), growing at 4 m spacing, and grass in a permanent pasture were studied at the Glensaugh Research Station. The 5-year-old trees are protected from grazing animals by plastic guards (Figure 3). Four nitrogen (N) treatments were applied uniformly across the plots at a high (144 kg/ha) and low (72 kg/ha) levels of nitrogen at either of two frequencies of application (4 or 12 split dressings). Treatments were replicated twice and the grass was grazed to a constant sward height of 3 cm. Within each main plot, sub-plots of 9 trees received either no herbicide or the usual spot treatment of glyphosate (0.6 m radius) in late May, in order to study the effect of different levels of grass competition on trees against the background of different nitrogen supply rates.

In general high nitrogen supply rates (144 kg/ha) increased grass growth, but only one N treatment (144 kg/ha in 12 dressings) resulted in significantly less above-ground tree growth. Above-ground tree growth was significantly increased in all N treatments by using a herbicide to reduce competition with the grass. In the nitrogen treatment, 144/12, herbicide increased girth increment and shoot extension by 64 and 100% compared to 30-40 and 28-40 % respectively for the other treatments (Table 1).

Root growth was quantified using a mini-rhizotron. Increased frequency of N application increased grass growth particularly in the 144/12 treatment which of all the treatments gave the lowest shoot production and highest root production in the trees indicating a change in the root/shoot partitioning of carbon,

Treatment	Total shoot extension (cm)		White root counts	
Herbicide	Yes	No	Yes	No
Nitrogen at				
144 kg/ha in 4 dressings	512	393	1.74	1.46
144 kg/ha in 12 dressings	463	231	1.87	1.64
72 kg/ha in 4 dressings	471	343	1.37	1.34
72 kg/ha in 12 dressings	491	351	0.92	0.55
SED	73		0.49	

Table 1. Effect of nitrogen and herbicide treatment on shoot extension and mini-rhizotron counts (log + 1 transformed) of white roots in 5-year-old wild cherry trees at the time of maximum growth.

a sign of increased root competition. Grass growth limited tree growth, probably through root competition which was encouraged with an increased N supply. Such competition can be reduced by the use of herbicides or by using lower amounts of N fertilizer.

Contact name: **Colin Campbell**

Seasonal nutrient storage in evergreen and deciduous trees in relation to nutrient supply, leaf and root demography

In order to study the processes of internal nitrogen (N) cycling in Sitka spruce trees, three year old clonal cuttings were grown in sand culture, with either 1.0 mol N m^{-3} (low N) or 6.0 mol N m^{-3} (high N) supplied as NH_4NO_3 with the irrigation for two years. During the first year all the N provided was enriched with ^{15}N to 5.0 atom % (labelled N), and throughout 1990 the N was supplied with ^{15}N at natural abundance (unlabelled N). The recovery of the unlabelled and labelled N in the new foliage was used to quantify the internal cycling of N in the two years, respectively. When grown with high N, trees produced two flushes of foliage growth each year, while rapid root growth did not start until the second flush of foliage growth, in August. Trees grown with low N showed a similar pattern of growth, except that they produced only one flush of foliage growth in the first year, and a greater proportion of their biomass was recovered in roots. By November 1990 the root/needle dry matter ratio was 1.95 for the low N trees, compared to 1.36 for those receiving high N (Figure 4).

Figure 4. The effect of N supply over two years on the growth of Sitka spruce.

Nitrogen was stored overwinter in both the needles that had grown that year, and roots. During the first six weeks growth in the spring of 1990, N was remobilized from these stores for the growth of new foliage. Subsequent growth depended upon root uptake of N. The remobilization of stored N was not affected by the current N supply because the same amount of unlabelled N was recovered in the foliage grown in 1989 by trees from both treatments. During 1990 the low N trees remobilized a greater proportion of their labelled N from the roots than the needles grown in 1989, compared to the high N plants. In the autumn of both years there was a rapid uptake of N into the roots and current year's needles, which contributed directly to the overwinter storage of N.

Contact name: **Peter Millard**

Figure 5. Residue treatments in Kielder. In the foreground either coarse or fine residues are retained on the plot, while in the background all residues have been removed from the plot.

Factors affecting nutrient source/sink relations in second rotation Sitka spruce crops

Fertilizer requirements of second-rotation tree crops are often lower than for the first rotation. The extent to which nutrient release from decomposing harvest residues is responsible for this reduction in fertilizer requirements is not clear. Residues do, however, impede the replanting of a site, particularly where the felled stand was Sitka spruce. A collaborative project between MLURI and the Forestry Commission aims to quantify the potential long-term impact of whole-tree harvesting on the sustainable growth of trees.

In order to reduce the length of the study an age-series of five stands has been selected in Kielder Forest, Northumberland. These stands range from pre-clearfell of the first rotation through towards canopy closure of the second. Within each stand a number of replicated experiments have been established and the extent to which the stands in the age series match one another will be judged by how well each moves towards the original state of its neighbour when the five-year study is complete. Trees from each stand were felled and detailed measurements were taken in winter 1989 and the stands will be sampled again in 1994.

+ Site	Treatment	Height (cm)	Diameter (mm)	*Volume (cm^3)
1	All residues removed	63.2	11.8	23.6
	Coarse residues retained	56.1	11.1	19.9
	Fine residues retained	59.7	15.6	39.2
	All residues retained	60.6	13.0	28.2
2	All residues removed	61.2	17.8	52.5
	Coarse residues retailed	62.9	16.6	46.9
	Fine residues retained	64.8	18.9	62.9
	All residues retained	72.2	18.8	68.5
	SE (n = 20)	1.8	0.65	4.54

+ Site 1 = Clearfelled 1983, planted 1984 and replanted 1989 when trees planted in 1984 were removed

+ Site 2 = Clearfelled 1988 and replanted 1989

* Volume calculated assuming trees were cones

Table 2. Effect of harvest residues on tree growth.

Within Kielder, a 'bench-felling' technique has been used for many years in which the trees are felled across one another in lines, leading to strips of dense residues adjacent to strips free from harvest residues. By studying differences in tree growth in these contrasting zones it is possible to quantify the effects residues have had on subsequent tree growth.

On two of the sites where the residues can still be identified a number of 'flip zones' have been created. In these the coarse material has been flipped across to the adjacent clear zone whilst the fine litter of foliage and twigs has remained in position (Figure 5), to separate out the effect of coarse residues, which may offer some physical protection, from that of the finer residues which are more likely to affect moisture and nutrient regimes.

In the site clearfelled in 1988 and replanted in spring 1989 growth of the trees (although small) has been greatest in areas originally under brash with the displacement of coarse material having, as yet, little effect (Table 2). On the site which was felled and replanted in 1984 a similar pattern has occurred. The second crop was removed in 1989 and again replanted and subsequent growth has been considerably less than that on the site clearfelled in 1988. The study will continue for another three years, focusing upon the processes by which removal or retention of harvest residues affect tree growth in the longer term.

Contact name: **Mike Proe**

The overall aim of the research is to develop an understanding of the interrelationships between the grazing herbivore, predominantly the domesticated ruminant, and sown and indigenous vegetation to meet agricultural, conservation and amenity objectives. In particular, the objectives of the research are to provide a quantitative understanding of (a) the response of individual plants and plant communities to grazing, (b) the foraging and grazing behaviour of herbivores as influenced by the distribution of different plant species and communities and (c) animal and plant factors which control diet selection and nutrient intake by herbivores.

Vegetation dynamics - responses of individual plants and plant communities to grazing

There is a clearly identified need to manage hill and upland resources to meet conservation and amenity as well as agricultural objectives. These objectives may include sustaining or increasing the area of particular vegetation communities, such as heather, controlling the spread of undesirable species, such as *Nardus* and *Juncus*, or increasing the diversity of plant species, for example in extensified sown swards. The outcomes can be directly related to meeting a specific botanical objective or to a wider wildlife objective such as the development of wildlife habitats consequent upon the presence of certain plant species and vegetation communities. Over much of the land area of the hills and uplands, domesticated ruminants are the principal means whereby these vegetation objectives can be achieved and an understanding of the impact of grazing by these species on vegetation dynamics is central to meeting these objectives.

Dr. J.A. Milne,
Head of Animals and Grazing Ecology Research

Current studies include the interaction between edaphic and disturbance factors on plant morphology, plant competition, community dynamics and floristic change with a combination of field, box and plot-scale experiments. Though treading and excretal return are considered, the central theme is the impact of defoliation by herbivores, which is an area that has been under-researched by plant ecologists and which has direct relevance to the research on foraging strategies.

The plant species and communities chosen for study are those which provide useful models for a wider range of circumstances or which have current or future importance in achieving management objectives for hill and upland swards. Examples of species and communities being studied are *Nardus*, *Molinia*, species-poor *Agrostis-Festuca* grassland, Atlantic heather moor and grass/clover swards undergoing extensification.

Results of research on the impact of grazing on *Nardus* grassland communities are described below, which show clearly how grazing by different ruminants can alter plant community dynamics and indicate what mechanisms may be included. The role of the composition of different hill plant communities in influencing the transfer of radiocaesium through the food chain is also described, illustrating the differential uptake of radiocaesium by different plant species and the significance of selectivity by sheep in influencing radiocaesium transfer.

Foraging strategies of large herbivores

Large domesticated herbivores are the principal management tool that can be used to meet objectives which aim to create vegetation communities of desired species and structure. To effectively use animals as management tools requires a knowledge of how they graze extremely heterogeneous plant communities. While cattle and sheep are the main domesticated ruminants that can be used, other species may have advantages in certain circumstances and, with the prospect of surpluses of conventional meat products in the EC, the development of alternative agricultural products is currently being given a high priority. The foraging strategy of these novel species has not yet been described. Moreover the foraging strategies of wild herbivores, such as red deer, rabbits and hares, also impinge upon the achievement of agriculture, conservation and amenity objectives and require to be better understood.

Research is being undertaken to understand why and to describe how large herbivores select their intake when grazing heterogeneous plant communities. For sheep and cattle there is information on what will be selected from within most of the major plant communities found in hill and upland areas. Such information is lacking for red deer, goats and camelids, the three most likely alternative animal species, and this is being obtained. However, our knowledge of the foraging strategies by ruminants given choices between plant communities is limited and this information is essential to the development of adequate computer simulation models of grazing. Foraging strategy theories based on the rate of nutrient intake have been developed and are being tested in experiments with sheep in simple combinations of plant communities in field and mini-sward experiments using sown swards, predominantly as models, and indigenous plant communities. Examples of the combinations currently being examined include *Nardus-Agrostis/Festuca*, *Juncus*-sown sward, heather-*Agrostis/Festuca* and grass-clover. The importance of the size and distribution of patches of different communities is a significant current element of the research. Computer simulation models of diet selection and impact on vegetation are currently being developed.

An essential prerequisite in research on foraging strategy is the ability to measure the diet selected. The n-alkane technique, developed at MLURI, has considerable potential in this area and some further uses for the technique in examining species selection and leaf/stem proportions are described below. A central feature of most foraging strategy models is the use of intake rates from individual communities to predict diet composition. The research described below illustrates some of the difficulties in this approach with evidence that intake rate may be determined not only by total biomass but by relatively subtle rates of change in biomass. The aim of much of the research is to provide information for the development of computer simulation models to predict the agricultural and environmental consequences of grazing. A model of heather moorland management being developed currently is described below.

Physiological and nutritional ecology - animal and plant factors which control diet selection and nutrient intake

In the hills and uplands a high proportion of the nutrients ingested are obtained from grazed herbage from indigenous, sown pastures and specially grown crops, such as forage brassicas. EC policy is likely to lead to greater extensification of ruminant production in the hill and upland sector and UK government policy is designed to achieve recreational, amenity and conservation as well as agricultural objectives. This will lead to a higher proportion of nutrients being derived from grazed herbage than at present and to a desire to identify genotypes of sheep and cattle with physiological characteristics which will make them more adapted to a range of environmental and nutritional circumstances. Associated with these changes, which are likely to lead to a reduced reliance on feed resources external to the farm, is the consumers' desire for more naturally produced animal products. This can be more readily achieved from nutrients derived from farm-grown herbage. To meet these objectives research is required on (i) animal and plant factors which control nutrient intake and diet selection by the grazing animal and how they can be modified and (ii) how attributes of the animal's physiology interact with nutrient intake and environmental constraints.

Research is being conducted on (i) the effect of physiological state, such as fatness, on diet selection and intake by sheep and some of the experimental results obtained are described below, (ii) the effect of the chemical composition of herbage on intake and digestive and metabolic adaptation in ruminants with particular reference to potentially toxic compounds and (iii) the impact of energetic constraints on foraging behaviour in a range of genotypes of sheep.

The programme relates to specific attributes of plants and animals which modify responses in diet selection, intake, digestion and metabolism of grazing ruminants.
The subjects that have been selected for study reflect where important issues have been identified and scientific progress can be rapid. An example of one area that has received attention is the potentially toxic role of sulphur-containing compounds in forage brassicas to sheep and this is described in the section on Training and Education.

Scottish Blackface sheep grazing mixed Nardus/Juncus *communities*

Dynamics of *Nardus* cover in acid grasslands as influenced by grazing by different ruminant species

The relationship between biomass of the preferred species and the effect of grazing different ruminant species on the cover of the less preferred species has been described for *Nardus* grassland communities. Sward responses differed depending on species of grazing animal. The present study investigates the nature and speed of sward responses following a change from cattle to sheep grazing. An area of *Nardus* grassland, on which 5 years of grazing by cattle had led to a reduced *Nardus* and an increased broad-leaved grass cover, an increased live-dead ratio of the herbage, and

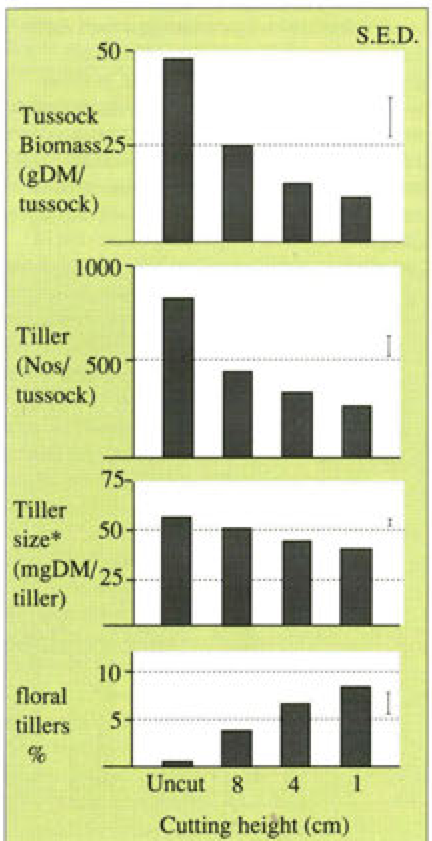


Figure 1. Effects of severity of defoliation on Nardus *growth. Tussocks had received four successive seasons of cutting, repeated in June and July and were then allowed a season of uninterrupted growth before harvest in August 1990. Data are means of six replicates.*
** vegetative tillers*

removal of the tussocky nature of the sward, was returned to sheep-only grazing in June 1989. Two treatments, between-tussock grasses maintained at 3.5 cm or 4.5 cm surface height by sheep, were imposed. The aim of the work was to investigate the extent and rate of reversion to *Nardus* once cattle were removed. After one year of sheep-grazing *Nardus* cover had increased substantially on both treatments, from an average cover of 22.7 to 35.1% which is equivalent to an increase of 35%. *Nardus* tussock height increased from 69 mm to 93 mm on the 3.5 cm sward and from 75 mm to 117 mm on the 4.5 cm sward between July 1989 and August 1990. The results suggest that changes in species composition and sward structure brought about by manipulation of grazing by one ruminant species can only be sustained for as long as the regime itself is sustained. Clearly the presence of cattle, or a species of grazer with similar grazing behaviour to cattle, in addition to sheep is necessary for at least part of the growing season if spread of *Nardus* and build up of dead material is to be kept in check.

The mechanisms involved in grazing-mediated floristic change were investigated in two further experiments. In the first experiment, the response of *Nardus* tussocks to different frequencies and severities of defoliation by cutting was studied. Treatments were applied for four successive seasons after which the tussocks were allowed a season's uninterrupted growth before harvest. Selected treatment results for tussock characteristics at harvest (Figure 1) show that, comparing tussocks which had been cut closely (in both June and July to leave 1 cm of lamina) with uncut controls, tussock biomass was reduced by 75%, tiller numbers by 65%, and tiller size by 30%; flowering vigour, however, was substantially increased.

The second experiment aimed to elucidate nutrient cycling aspects of the competitive relationship between the commoner grasses of *Nardus* grassland. Samples were collected from adjacent grazed and ungrazed sites in May 1990 to measure nutrient content of the tissues of several grass species. Results suggest that the adverse effects of defoliation on nutrient uptake, whether via effects on root size or function, are greater for the two fine-leaved grasses *Deschampsia flexuosa* and *Festuca ovina*, than for the two broad-leaved grasses *Agrostis canina* and *Anthoxanthum odoratum*.

Contact name: **Sheila Grant**

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

Many upland areas of Britain received a relatively high radiocaesium deposition after the nuclear accident at Chernobyl in April 1986. The subsequent monitoring of vegetation and sheep showed a high transfer of radiocaesium from soil via plants to animals on organic soils, due to their low content of Cs-binding clay minerals. Studies of the effects of pasture type and season on the transfer of radiocaesium to plants and sheep are, however, lacking.

A field experiment was set up on an area grazed by sheep consisting of 0.7 ha heather moorland and 0.3 ha unimproved grassland on a soil with an organic surface horizon (iron podzol). In 1989 small areas of pasture were artificially contaminated with ^{134}Cs by soil injection. Seasonal changes in the contamination of plant species were measured (Figure 2) and the ^{134}Cs intake by sheep was calculated from measurements of herbage intake, diet composition and ^{134}Cs concentrations in the contaminated vegetation, assuming that all of the grazed area had been contaminated. The effect of diet selection on ^{134}Cs intake was assessed through comparison of sward and diet composition.

Heather (*Calluna vulgaris*) accumulated more ^{134}Cs than any of the other plant species present. Concentrations of ^{134}Cs in current season's shoots of heather were about 4-5 times higher than in grasses. Within the other species concentrations decreased in the order: *Galium saxatile*, *Carex pilulifera*, *Agrostis* spp., fine-leaved grasses (*Deschampsia flexuosa*+*Festuca ovina*). Particularly low levels were found in *Vaccinium myrtillus*, *Erica cinerea*, *Juncus squarrosus*, *Nardus stricta* and dead plant material.

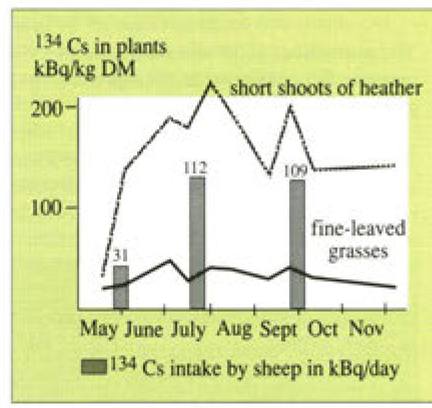


Figure 2. Seasonal changes in ^{134}Cs concentrations of plants and ^{134}Cs intake by sheep.

In the first year after contamination seasonal changes in ^{134}Cs concentrations showed similar trends in all herbaceous species, with relatively high levels in summer followed by a decline in autumn. A similar pattern was recorded for current season's shoots of heather, but levels did not decline until winter. Very little seasonal variation was found in woody fractions of heather in both years and concentrations were lower than in shoots. In the second year the level of contamination in herbaceous plants and heather shoots was about 60-70% less than in the first year, probably as a result of progressive fixation of ^{134}Cs in the soil. The lower overall sward contamination on the unimproved grassland compared to improved grassland (MLURI Annual Report 1989-90) was attributed to lower availability of the ^{134}Cs on the soil of the former site due to the higher mineral content of the soil.

The diet selected by the sheep changed over the grazing season. In May when sufficient herbaceous vegetation was available on the grassland, the diet was made up of 70% grasses. In July 50% heather and 20% grasses were ingested and in September the contribution of heather increased to 75%. Owing to the high contamination levels in heather, 80-90% of the ^{134}Cs intake by sheep in July and September was through heather, whereas in May 80% was contributed by grasses. The total ^{134}Cs intake increased three-fold from May to July as the proportion of heather in the diet increased

(Figure 2). The further increase of heather in the diet between July and September was compensated by decreasing contamination levels, so that the ^{134}Cs intake remained at the same level as in July. Compared to estimates of ^{134}Cs intake on improved pasture, the intake on unimproved pasture was lower in May, higher in September and similar in July. The main factors influencing radiocaesium intake on improved grassland are seasonal changes in sward contamination and sward composition, whereas on unimproved pasture the relative proportions of the vegetation types and the selectivity of the sheep were found to be more important.
Contact names: **Bob Mayes, Carol Salt** (now University of Stirling)

The potential of plant wax compounds as markers for estimating diet composition in grazing animals

The long-chain n-alkanes of plant cuticular wax have been used as markers to estimate the plant composition of the diet of grazing ruminants. In order that the method is effective, the patterns of

	Constant		Increasing+	Decreasing+
Target lamina height (cm)	3.5	6.0	3.5 to 6.0	6.0 to 3.5
Lamb live-weight change (g/day)	10	112	90	-44
Digestibility of OM of diet	0.816	0.802	0.806	0.795
Herbage intake (g OM/day)	500	586	542	448
Bite mass (mg OM/bite)	13.8	21.1	17.9	12.0

+ Daily rate of change in target lamina height = 0.09cm/day

Table 1. N-alkane contents (mg/kg DM) in leaf and stem of some grasses.

individual alkanes must differ between plant species. The composition of plant-wax hydrocarbons in a number of grass species taken from a rotationally-grazed lowland pasture in Co. Cork, Ireland in June, 1988, was examined. In order to investigate the homogeneity of the plant wax hydrocarbons within the plant, each species sample was separated into leaf and stem fractions prior to analysis.

The concentrations of n-alkanes, in the range C_{23}-C_{35}, were estimated, together with those of other components (probably iso-alkanes or n-alkenes) which elute on the chromatograph slightly earlier than each of the major odd-chain alkanes of the same carbon number.

The n-alkane concentrations in the leaf and stem fractions of the grasses are summarized in Table 1. Clearly, differences exist between the grass species sampled, and it should be possible to evaluate dietary composition of animals on swards having certain mixtures of grass species. However, the n-alkane concentrations of

Species		*X_{25}	X_{27}	X_{29}	X_{31}	X_{33}
Lolium perenne	Leaf	0	0	1	0	0
	Stem	1	4	26	8	1
Poa annua	Leaf	0	0	1	0	0
	Stem	18	42	74	9	0
Festuca rubra	Leaf	0	0	0	0	0
	Stem	2	10	29	8	1
Agrostis stolonofera	Leaf	0	0	0	0	0
	Stem	2	9	28	4	0

*The number represents the chainlength of the n-alkane which is eluted immediately after the component peak

Table 2. Iso-alkane or n-alkene concentrations (Xn, mg/g DM) in leaf and stem of some grasses.

Phleum pratense and *Dactylis glomerata* are probably too low for these species to be identified in the diet.

For most species relative differences between leaf and stem in n-alkane concentrations were largest for C_{23} n-alkane. These results suggest that for most grasses, n-alkanes can be used to evaluate the leaf:stem ratios in the diet of grazing animals.

Table 2 shows the concentrations of iso-alkanes or n-alkenes (designated 'X' + chainlength of the n-alkane immediately following the component) in a selection of the grass species. For all the species examined, except *D. glomerata* and *P. pratense* which had negligible amounts (not shown in Table 2), these components are found predominantly in the stem fractions, with that appearing prior to C_{29} n-alkane being present in the highest concentration. These components potentially offer a very sensitive means of estimating leaf:stem ratios in the diet of grazing ruminants. Further work is necessary to positively identify these compounds, since it is possible that iso-alkanes and alkenes may behave differently in the ruminant digestive tract, and to establish faecal recovery values. Further division of the stem component of the grasses into pseudostem, true stem and flower heads is also of interest in order to gain a greater understanding of the grazing behaviour of ruminants at pasture and the technique could also be used for this purpose.
Contact name: **Bob Mayes**

The effect of direction of change in sward height, and in sward structure, on the ingestive behaviour and performance of weaned lambs grazing ryegrass

Sward (i.e., lamina) height is a major factor influencing both net herbage production and also ingestive behaviour and herbage intake by grazing sheep (and consequently their performance). The density of short swards also influences ingestive behaviour and this effect may modify the performance of grazing lambs. The inter-relationships between both static and changing sward conditions and the performance, diet selection and ingestive behaviour of weaned lambs have been studied experimentally at Hartwood Research Station.

Crossbred lambs grazed a perennial ryegrass sward subjected to eight treatments from early July to late August. Two rates of herbage growth were created, by differential fertilizer application, and four plots at each rate of growth were maintained at constant lamina heights of 3.5 and 6.0 cm or increased or decreased between these levels by manipulation of stock density every two days at the required rate of change.

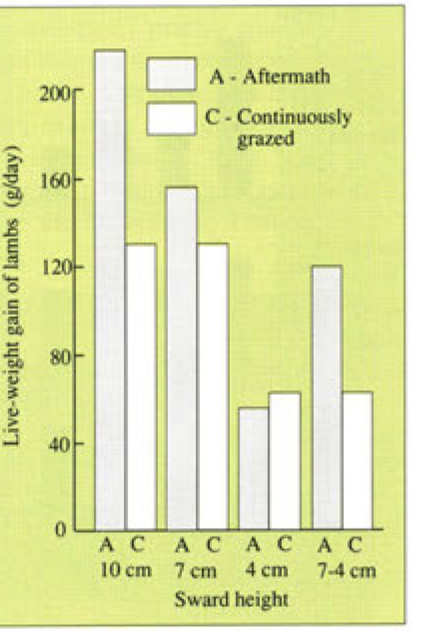


Figure 3. Sward height and lamb growth.

As expected, live-weight gains of lambs were greater on the constant 6 cm than on the 3 cm swards (Table 3). They were also positively associated with the direction of change in sward height; this effect appears to be a more potent influence than that of sward height *per se*. In general the rates of gain on low herbage growth rate treatments exceeded those on the high herbage growth rate treatments.

Diet digestibility was high with no difference between treatments. There were, however, wide between-treatment differences in the levels of herbage intake/day and also in bite mass (daily herbage intake /bites per day) which reflected the differences in live-weight change, particularly in the case of bite mass. The frequency of

	Constant		Increasing+	Decreasing+
Target lamina height (cm)	3.5	6.0	3.5 to 6.0	6.0 to 3.5
Lamb live-weight change (g/day)	10	112	90	-44
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+ Daily rate of change in target lamina height = 0.09cm/day

Table 3. Stocking density and mean lamina height in relation to herbage intake, bite mass, live-weight change and digestibility of the diet.

occurrence of young leaf in lamb diets was positively associated with the direction of change in sward height. This is limited evidence for the hypothesis that changes in sward height influence the proportion of young leaf in the grazed horizon.

Mean values for herbage mass, lamina height and depth of the lamina layer (difference between lamina height and pseudostem height) over the experiment were only poorly related to live-weight change although their values at the end of the experiment accounted for 75% ($P<0.01$), 55% ($P<0.05$) and 61% ($P<0.05$) of the total variation respectively. There was no relationship between live-weight change and the rate of new herbage growth but new herbage allowance (new herbage growth/stocking density) explained 74% of the total variation in live-weight change.

Associated studies with weaned lambs at Bronydd Mawr Research Centre at slightly higher sward heights ranging from 4 cm to 10 cm show similar responses in animal performance. They also showed (Figure 3) greater individual lamb performance on aftermath swards than was the case on previously continuously-grazed swards. This was contrary to previous observations at Hartwood Research Station and is likely to reflect the higher proportions of white clover in the aftermaths at the Bronydd Mawr site.

These results indicate that the direction of change in sward height has a greater influence on ingestive behaviour and lamb performance than was hitherto appreciated and also suggests that swards differing in white clover content may produce different responses in animal performance to change in sward height.
Contact name: **Richard Armstrong**

Modelling the agricultural and environmental consequences of sheep grazing heather moorland

Heavy grazing by ruminants on heather moorland can cause it to be converted to grassland. Such a change is generally associated with a decline in nature conservation value, in grouse populations and in the ability of the resource to support livestock over winter. In order to devise stocking regimes which will fulfill the objectives of both nature conservation and agriculture, the effects of different management regimes on hill vegetation have to be predicted. These effects depend not only on the density of grazers at different times of the year but also on the nature of the vegetational resource available to them. Computer modelling is a useful technique for integrating the diverse plant and animal information needed to predict the effects of grazers on vegetation. Such a model has been developed with the aim of providing a tool which will help land managers to make decisions about optimum stocking regimes in hill areas in the UK.
The model has been designed to use inputs which should be easily obtainable for most hill areas. These include the location, rainfall and soils of the site as well as the area of each vegetation type and the numbers and average live weight of large herbivores on the hill in each month of the year.

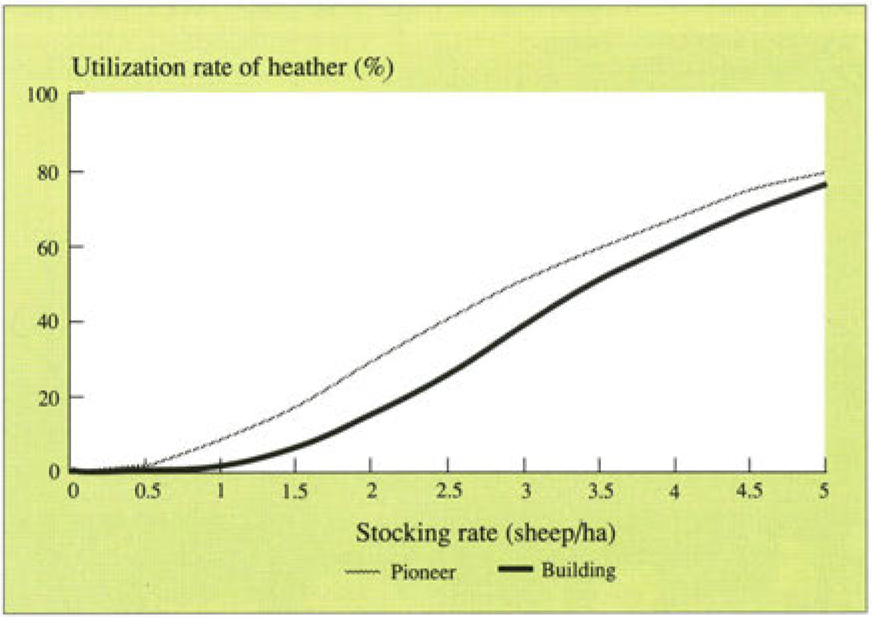

Figure 4. The effect of changing stocking rate on utilization of heather derived from a series of runs of the simulation model.

Six types of semi-natural and improved grassland and seven types of heather moorland can be included in the model.
Monthly production of each of the vegetation types is predicted using published information and by making adjustments for altitude, climatic zone, summer rainfall and soil type. This is then converted into daily production and the intake of an average sheep is calculated on a daily basis and divided between the different vegetation types according to the availability of digestible material from each vegetation type and the area of each. Each day, green and dead biomass of the grass vegetation types and the biomass of the current year's growth of the heather is calculated after growth and offtake. At the end of each month senescence and litterfall are estimated and new biomasses again calculated for each vegetation type. At the end of the year, annual production and offtake figures are used to calculate annual utilization rates on each vegetation type. Other information on plant growth, offtake and biomass and on grazing time, digestibility of the diet and intake from each vegetation type is also available from the model for the last day of each month.

Information available from the model will be invaluable to land managers who wish to predict the effects that different management systems will have on vegetation. For example, Figure 4 shows the effect of increasing year-round sheep numbers on the utilization of pioneer and building heather on a typical hill farm derived from a series of runs of the model. Stocking rates which give a utilization rate of less than 40% will ensure the continued vigour of the heather as well as slowing down the ageing process sufficiently to allow the maximum time between burns.
Contact name: **Helen Armstrong**

The effect of fatness and previous level of nutrition on herbage intake of ewes grazing autumn pastures

Both fatness and the level of nutrition available from pasture to ewes prior to mating have been shown to be important in determining reproductive rate. These factors are to some extent inter-dependent since fatness or body condition may affect herbage intake directly, and the body condition of the ewe in autumn will depend on the demands made on the ewe during lactation, and on the level of nutrition available after weaning.

An experiment was designed to separate the normally confounded effects of current body condition and level of previous nutrition on herbage intake by ewes grazing autumn pasture. For a period of 6 weeks after weaning, a group of 96 housed Greyface ewes in a wide range of body condition were fed a diet of dried grass pellets at either a low (55 g/kg$W^{0.75}$ day) or a high (105 g/kg$W^{0.75}$ day) feeding level. These treatments produced a difference in mean live weight of 5.2 kg between groups and a difference in mean body condition score of 0.25. The ewes were then transferred to a pasture and allocated on the basis of previous treatment to two different sward heights (5 cm and 10 cm) with two different predominantly perennial ryegrass swards as replicates. During weeks 3 and 6 of a six-week grazing period, intakes of herbage were measured by using the n-alkane technique and grazing times by using vibracorders.

	Sward height (cm)	Previous feed level	Herbage intake (gDM/kg $W^{0.75}$/day)
Replicate 1	5.2	L	70.3
		H	58.2
	9.2	L	72.6
		H	65.2
Replicate 2	6.0	L	57.3
		H	55.7
	11.1	L	69.8
		H	71.4
		S.E.D.	3.99

Table 4. Herbage intake at two sward heights showing effect of previous feed level.

Herbage intakes on replicate 1 were higher for the ewes that had previously been on the low feeding level (Table 4), at both sward heights and during both measurement periods, although the difference was greater at the low sward height. There was also a negative relationship between body condition score and intake at the low sward height during both periods. On the other replicate, there was no effect of previous level of nutrition although there was a negative relationship between body condition and intake at the low sward height in the second period. When the interaction between current body condition and previous level of nutrition is examined, the effects on intake can be explained in terms of current body condition, since there was no effect of previous level of nutrition within sheep of the same condition score.

Grazing times, like intakes, were negatively related to body condition score on each replicate and for each sward height, although the proportion of the variation in grazing times explained by body condition score was greater at the lower sward heights. The difference between the two replicates in the relationship between intake and body condition was probably due to a difference in sward structure. Sward density was lower on replicate 1 than on replicate 2 (186 kgDM/ha/cm compared to 263 kgDM/ha/cm) at the beginning of the experimental period with densities being relatively similar for the two replicates in period 2.

These results demonstrate that fat ewes graze for less time than thin ewes, particularly on short swards, and that body condition has a consequent effect on herbage intake. Previous level of nutrition may also effect intake, but in this experiment no effect was demonstrated beyond that achieved by the resulting differences in body condition.

Contact name: **Angela Sibbald**

Sheep grazing Autumn pastures at Glensaugh Research Station

The overall aim of the research is to provide a better understanding of (i) how hill and upland land resources can be efficiently utilized by current forms of livestock production to meet multi-objective land uses in the hills and uplands, and (ii) the role of novel alternative species, such as deer for meat production, goats for fine fibre and meat production and South American camelids and sheep for fine fibre production.

The role of grazing animals in land management systems for animal enterprises or as vegetation managers for other goals in hill and upland areas is constrained in part by the energetic efficiency with which productive processes and metabolism of adipose tissues interact with natural seasonal environmental fluctuations. Of particular relevance are (1) the seasonal biology of ruminants which has an impact on the optimum utilization of seasonally varying patterns of forage supply, daylength and climatic conditions, and (2) the study of combinations of ruminant species and genotypes with different physiological attributes. The objective of this research is to understand at a mechanistic and quantitative level interactions between these processes and the utilization of a range of land resources.

The objective of the research on novel alternative animal species are (1) to understand the biology of these species in respect of the products that they produce and (2) to examine the welfare consequences of farming these semi-domesticated species.

Research effort is described under the headings of Energetics and Seasonal Biology, Ruminants/Resource Use and Alternative Animals.

Energetics and seasonal biology

Changes in land use in the hill and upland sector are likely to lead to increases in the area under forestry either as farm/forestry or agroforestry and to diversification in terms of species of livestock and agricultural output. One of the implications for ruminant production as the amount of forestry increases is that the amount and degree of shelter will increase. A model has been developed, for example, which predicts the turbulent outflow in agroforests and which has described the reduction in air speed with reduced tree spacing. This work is described in the section on Training and Education. This could result in reductions in the energy expenditure of ewes in the winter, enhanced survival of lambs in the spring and resultant improvement in animal welfare. Quantification of the energetics of this potential change in land use is being studied. This requires the development of techniques to measure the energy expenditure of free-grazing animals which is also central to research on foraging strategies and physiological and nutritional ecology. An example of some of the research being conducted is given below, which shows the differential effect of shelter for sheep breeds with different physiological characteristics.

One of these physiological characteristics is in relation to the seasonal variation of metabolic rate. The most likely alternative forms of livestock in the hill and upland sector are deer for meat production and goats for fibre production. Both of these species also exhibit a high degree of seasonality in metabolic rate, reproduction, intake and coat growth. An ability to manipulate the intake cycle in juvenile deer and the shedding and growth cycle of the coat in the goat, in particular, could improve the efficiency of production systems in these novel species and such knowledge is being obtained. Research on the hormonal control of shedding is described in Section 6 on Training and Education and illustrates the type of approach that is being adopted in an important area of biology.

Ruminants/resource use

Domesticated herbivores are the principal means whereby many of the conservation and amenity objectives, which are likely to become more important in the future in hill and upland areas, can be achieved. Extensification of animal production systems may occur under some circumstances but animal production systems of a variety of types will be of central importance to the economy and social fabric of rural upland areas. Continued improvements in the efficiency of resource use in respect of animal production will allow this sector to remain in as competitive a position as possible and reduce reliance on EC and UK government subventions. Moreover, resource use will require to be considered against a background of lower inputs than exist in many current systems and a need to meet multiple land use objectives.

There is a requirement, therefore, to understand those aspects of ruminant resource use which will increase biological efficiency, particularly in the context of low-input or extensive systems, and also to achieve a range of conservation and amenity objectives. For example, it is likely that animal attributes of size, lactation performance and ability to store and mobilize adipose tissue will confer greater advantages in some circumstances than in others. Further, some combinations of animal species utilizing pastoral resources are also likely to be more effective in some circumstances than in others. Research to elucidate many of these interactions over a wider range of land management systems than has so far been considered will be undertaken.

Areas of research which are currently being studied are the complementary nature of grazing combinations of animal species on resource utilization, the effect of animal attributes such as body size, litter size and growth potential on the efficiency of resource use, including the achievement of resource management objectives other than those associated primarily with animal production, and the effects of social behaviour on animal responses to food availability. There is also strong emphasis on modelling ruminant/resource use interactions.

The research will deal with populations of animals and their interactions in relation to resource use and link the research conducted in Programme Units 14 and 15 on individual animal or species responses to that of the modelling of integrated upland livestock systems and of land use options at the farm level in Programme Unit 11.

Two examples are given below of how animal attributes, such as animal size, lactation potential and ability to store adipose tissue in cattle can influence resource use, and how resource availability in the early life of the breeding sheep can influence lifetime performance.

Alternative animals

Agricultural land use in the hills and uplands is predominantly by sheep and cattle. Self sufficiency in meat products from these species in the EEC is likely in the next decade. Apart from farm/forestry, alternative animal species are the most likely enterprises to replace sheep and cattle, provided that they can be shown to be suited to hill and upland environments and produce commodities in demand or for which there is potential for another market development. Deer and goats for meat production and goats, sheep and camelids for high quality animal fibre production are the likely alternative species. The aim is to understand the biology of these species within an agricultural context in the UK in order that systems of production can be developed which meet production and welfare criteria.

Research is conducted on a number of aspects of deer biology, the biology and quantitative genetics of fibre production from cashmere goats in collaboration with the Institute of Animal Physiology and Genetics Research, the biology of fibre production from the guanaco and the alpaca and fine-wool genotypes of sheep and on aspects of fibre identification and measurement. Particular interest is taken in those aspects of fibre biology which relate to fibre quality, yield and means of harvesting. The welfare aspect of current research involves the farming of red deer captured as adults from the wild. It is anticipated that the amount of effort on welfare aspects will increase.

Descriptions are given below of two facets of the deer research programme. One describes a long-term study of the large scale management of deer in a West Highland environment and highlights the high levels of performance that can be obtained from efficient systems of deer management. The second facet described in an initial study on the measurement of stress in farmed red deer whose success is central to the development of welfare research on farmed deer.

A llama guanaco cross at Glensaugh Research Station, part of the alternative animal fibre production programme

Effect of shelter on energy expenditure of two breeds of sheep in winter

Sheep grazing outdoors in winter divert some portion of their digestible energy intake to heat production, and depending on weather conditions this may be affected both by the provision of shelter and breed.Previous studies have shown that basal metabolic rate and food intake of sheep may vary seasonally, being depressed in winter compared to summer. This metabolic seasonality has been shown to vary between genotypes and in the field situation is likely to be modified by the provision of shelter. This study investigated the effect of artificial shelter on energy expenditure of Dorset (aseasonal) and Scottish Blackface (seasonal) ewes grazing sown swards.

A perennial ryegrass sward was divided into exposed and sheltered areas using 'Netlon' artificial windbreaks. During three periods of 5 days in October, December and March 1990/91, CO_2 production rate, as an index of energy expenditure, was measured in four sheep of each breed grazing on the exposed and sheltered plots. Carbon dioxide production rate was measured using continuous infusions of $NaH^{14}CO_3$ and automatic blood sampling. Animals were penned for one hour per day but otherwise grazed undisturbed. Sward conditions were kept similar in exposed and sheltered areas.

In each of the three periods CO_2 production rates were greater in animals grazing the exposed compared to sheltered plots. This difference between sites varied with breed, the Dorset breed having a 24% greater CO_2 production rate ($P<0.05$) in the exposed, while the increase in the Scottish Blackface breed was only 12% (non significant). There was a consistent breed effect, with the Scottish Blackface having a greater CO_2 production rate than the Dorset, by 27% in the sheltered ($P<0.05$) and 15% in the exposed. The lower CO_2 production rate in the Dorset ewes in both plots may be associated with different activity patterns or grazing behaviour, and data on these variables are currently being investigated.

This experiment used two breeds of sheep with different patterns of seasonal basal metabolic rate in order to compare results with a study on the seasonal variation of basal metabolic rate as measured by calorimetry. In comparison with the calorimetry study there was no overall seasonal pattern in either genotype after adjusting for the effect of shelter. This is probably due to masking of seasonal effects by variation in weather conditions, energy intake and behaviour in the field situation.

Contact names: **Peter Fenn, Glenn Iason**

Resource use efficiency by beef cows with different nutrient partitioning potential

Within any species of livestock there are a range of genotypes which vary in characteristics such as body size and nutrient partitioning potential. These characteristics interact with the resources used in systems of livestock production such that under different nutritional environments some genotypes may be more appropriate than others in terms of achieving specific objectives.

An experiment was conducted at Bronydd Mawr Research Centre in conjunction with IGER to examine the effect of nutrient partitioning ability (i.e., the way in which nutrients are partitioned into milk synthesis or body reserves) in beef cows on the utilization of vegetation resources. The nutrient supply from vegetation was varied by varying the sward height of sown pastures. Three genotypes of cow, Hereford x Friesian (HF), Angus x Friesian (AF) and Welsh Black (WB), were used. All were mated to Charolais bulls to calve in March/April. During summer they grazed sown swards maintained at sward surface heights of either 4-5 cm or 7-8 cm from turnout until weaning on 7 October. The experiment was conducted over 4 years.

Some of the data on animal performance are given in Table 1. As has been demonstrated previously in the Institute, sward height had a large effect on the live-weight gain of both cows and calves and on cow milk yield with the 4-5 cm sward resulting in reduced live-weight gains and milk yields.

	Sward height					
	4-5cm			7-8cm		
Genotype	HF	AF	WB	HF	AF	WB
Cow live-weight gain (kg/day)	0.06	-0.15	0.06	0.50	0.42	0.54
Milk yield (kg/day)	10.1	8.9	7.0	11.7	10.8	8.3
Calf live-weight gain (kg/day)	1.00	0.93	0.82	1.12	1.09	1.04

Table 1. Performance of Hereford x Friesian (HF), Angus x Friesian (AF) and Welsh Black (WB) cows and their calves when grazing at two sward heights.

Levels of live-weight gain were similar for HF and WB cows, but the WB cows produced less milk than the HF cows on both sward height treatments. The AF cows produced slightly less milk than the HF cows and their live-weight gains were the lowest of all three genotypes. Indeed on the 4-5 cm sward they lost live weight. In general calf live-weight gains reflected milk yields. Thus the calves of HF cows had the highest live-weight gains and those of WB cows the lowest

A full interpretation of the data must await results on herbage intake and on changes in body composition associated with the different live-weight gains. These latter data will be obtained from information following the slaughter of cows at different levels of fatness. Nevertheless it is clear that the WB cows partition lower proportions of their intake into milk synthesis while the AF genotype is inappropriate in environments which cannot sustain a high level of nutrient intake. Low levels of live-weight gain in summer have important implications for the amount of feed to be supplied in winter.

The study demonstrates the large effect that the characteristics of different genotypes have on the way in which they utilize resources and indicate the importance of matching animal attributes to the nutritional environment.

Contact name: **Iain Wright**

Welfare aspects of some management protocols in deer farming

There are a number of potentially stressful situations in the catching of wild deer for use in deer farming. These relate to the method of capture, transportation and integration into farming systems. In order to quantify the stresses imposed on deer and establish soundly based management, the aim of the first phase of the study has been to define a basic set of behavioural and physiological indices. Opportunity was also taken to investigate the action of a long-acting neuroleptic in terms of behaviour modification and the attenuation of post-stress disturbance.

Eighteen non-lactating female red deer were used in an experimental study. One group of six animals remained as a control, being only used for behavioural observations. The remaining two groups were subjected over a period of 6 weeks to various management stressors of increasing intensity. One group received a long-acting neuroleptic (LAN) by intramuscular injection. Blood samples were taken automatically over an 6-hour period which included the application of the stressors.

In order for physiological measurements to be made preliminary work developed a harnessing system capable of retaining automatic blood sampling equipment and heart rate monitoring equipment on the backs of free-ranging deer. Resultant plasma samples collected were assayed for cortisol, total protein, creatinine phosphokinase (CPK), aspartate aminotransferase (AST) and testosterone. Heart rate was recorded once per minute over the study days. Behavioural observations were made not only on the treatment days but also on non-treatment days each week. A standard ethogram was prepared based on 13 defined and exclusive behaviours.

Plasma cortisol levels fluctuated widely both within- and between-animals and treatments. For example results from the first sampling occasion showed mean values from individuals over the 11 sampling times to range from 12.5-71.5 nmol/l. The largest rise in plasma cortisol concentrates was seen, however, in the 30-minute period after the stressors were applied with concentrations tending to return to pre-stress levels within 90 minutes thereafter. The LAN treatment reduced the rise in plasma cortisol levels.

Although post-capture myopathy is well-recognized in deer, plasma CPK levels did not generally fluctuate widely within a sampling period for an individual animal but there were marked between-animal variations. Higher plasma CPK levels were associated with elevated cortisol concentrations.

AST levels showed considerable between-animal variation although over a single sampling session levels remained relatively stable. AST concentration in plasma is an indicator of liver damage, although it is released from tissue other than liver, including muscle. Total protein levels in plasma were generally consistent, both between animals and between treatments. These measures provided evidence as to the integrity of the sampling system and the lack of significant haemodynamic change over the sampling period. Testosterone levels were low in all animals, giving no indication of group dominance structure. The lack of sufficient behavioural interactions also made it impossible to predict a dominance hierarchy.

Heart rate showed a dramatic increase over the 'stress' periods.There was a significant correlation between heart rate and plasma cortisol concentrations though heart rate returned to baseline levels more rapidly following stress. On some occasions heart rate was greatest in the LAN-treated group. This may be due to more subtle alterations of behaviour in these animals. In addition, like the plasma cortisol results, there was a considerable between-animal difference .

Moving, resting and feeding behaviours showed large and contrasting differences between the three groups. During the pre-stress control period the LAN-treated animals appeared most nervous. This was unexpected but was possibly related to their recent move to the experimental area and the fact that their paddock was the most visible and subject to disturbance. The absence of any recognizable physiological change during this time suggests that there may be a hierarchical response to stress, with a behavioural response being the first to appear. Thus a significant 'location' effect was identified in the pre-stress control period.

As levels of stress increased there was a corresponding increase in psychomotor activity of the deer. Moving behaviour was the chief activity which differed between the LAN and untreated groups.

The work has shown that sensitive behavioural observations can be made in terms of recognizing animals' response to stressors. Remote acquisition of physiological data was also shown to be possible and to provide valuable information. This combined approach allows a good insight into the whole animal response to stress in which LANs would appear to have a potentially useful role.

Contact names: **Peter Goddard, Iain Gordon**

The development of a large-scale system of management for farmed red deer in the West Highlands

Farming of red deer for meat production is becoming a significant form of diversification, particularly in upland areas as a means of meeting policy objectives for improving the rural economy. The potential for the development of large-scale management systems in the Highland area, however, has not been examined in relation to the use of land resources and management protocols.

Resource	Winter Dec-March	Spring & Summer (April-July)	Spring & Summer (August)	Autumn (Sept-Nov)
	Seasonal stocking of the resources			
Grassland (20 ha)	-	1-6 yr old hinds and stags	1-6 yr old hinds	1.5-6.5 yr old hinds and stags
Improved hill grazings (32 ha)	Stags	6-15 yr old hinds and stags	1-6 yr old hinds and stags	7.5-14.5 yr old hinds and stags
Indigenous pastures (686 ha)	1.5-14.5 yr old hinds	6-15 yr old hinds	6-15 yr old hinds	7.5-14.5 yr old hinds and stags
Housing	Replacement calves	-	-	675 weaned calves

Table 2. Resource management.

The aim of a study, which has been conducted since 1985 by MLURI, is to describe the relationship between stocking rate and sustainable plant and animal productivity, to examine management protocols for the weaning of calves in relation to feasibility and welfare and to provide a source of animals to aid the development of deer farming in the Highland Enterprise Area

The study is being conducted at the Rahoy deer farm which lies on the north-west sector of the Morven peninsula in Argyll. The farm was purchased by the Highlands and Islands Development Board in 1977. From April 1985 the management and development of Rahoy was contracted to MLURI, and in November 1988, MLURI leased Rahoy to allow the work to be completed.

The land resources at Rahoy comprise 686 ha of rough grazings and 20 ha of grassland and some 32 ha of improved hill grazings. The land rises from sea level to a height of 462 m. The mild maritime climate of Rahoy is characterized by small variations in the mean air temperatures, high windspeeds at sea-level, and high rainfall evenly spread throughout the year. The mean annual rainfall is approximately 2000 mm.

The management system is based on grazing the reseeded areas during the summer and autumn with yearling female replacements and younger hinds and grazing the hill area in the summer and autumn with a proportion of the hinds and in the winter with all the hinds. In winter supplementary feeding is given to ensure that the pregnant hinds do not lose more than 5% of their live weight. Since 1986 the management system has remained essentially the same and the number of hinds has been increased from 523 to 725. The management scheme is outlined in more detail in Table 2. As can be seen from Table 3, the performance of hinds, as measured by mean live weight prior to the rut and the live weight of the calf at weaning, has increased over the period even though numbers have been substantially increased. Part of the reason for this is that yearling hinds entering the herd have increased in live weight thus ensuring high levels of

Performance	1983	1984	1985	1986	1987	1988	1989	1990
Total deer numbers	387	491	597	639	691	755	804	825
Mean live weight of adult hinds (kg)	77.6	81.9	83.6	86.0	86.8	87.3	90.8	90.6
Calving rate of adult hinds (%)	76	78	87.6	85.3	93.1	96.0	87.8	96.8
Mean live weight of yearling hinds (kg)	58	63.7	69.5	74.6	74.5	78.6	77.1	81.0
Calving rate of yearling hinds (%)	0	16	43.6	53.3	83.3	82.0	86.6	91.6
No. of calves weaned	191	269	342	401	500	559	570	649

Table 3. Performance of the deerstocks (1983-1990).

performance in younger hinds. On the other hand calving rate, which increased up to 1988, declined in 1989 and these data, taken with the lower performance of calves on one part of the hill area, suggest that the stocking rate at which sustainability can be maintained is being approached. Adjustments made in 1989 and 1990 to the management of the hill areas by rotating stock between areas of the hill in different years appears to have increased calving rate and weaning weight of calves in 1990 over the values obtained in 1989. The overall high levels of performance show the potential that exists for weaned calf production in such an environment.

The management of calves at weaning is designed to provide weaned calves with a period of 2 to 3 weeks to be accustomed to eating concentrate feed before sale. This involves staggering the date of weaning to allow for the extent of the housing accommodation. In 1990 weaning was staggered, starting on 4 September and finishing on 18 October. Over this period 649 calves were weaned and five deaths of calves were recorded, a mortality rate of less than 1%. Weather conditions over the weaning period were wet and windy. The data demonstrate that low levels of mortality can be achieved with such a management system which has proved to be practicable.

A total of 242 animals were disposed of to farmers entering HIDB's Deer Farming Start-up Package scheme. The project will be terminated in 1991 and a full economic analysis of deer farming in the West Highlands will be undertaken.

Contact name: **Bill Hamilton**

Effect of early-life nutrition on lifetime reproductive performance of sheep and the mode of action

Lifetime reproductive performance in ruminants is an important determinant of resource use efficiency. The effect of early-life nutrition on lifetime reproductive performance is considered to be potentially important but no information exists on when in early life nutrition could have these effects nor whether these effects manifest themselves when ruminants are maintained in a range of nutritional environments throughout their adult life.

A long-term experiment has been conducted to examine the timing of levels of nutrition in early life and different subsequent lifetime managements on lifetime reproductive performance in sheep.

In a Scottish Blackface hill flock, ewe lambs were reared on high levels of nutrition during the last 100 days *in utero* (Group P), or the first 100 days of life (Group L), or were reared on the hill throughout (Group C). Subsequent lifetime management was in either a hill or a nutritionally more adequate upland environment, where reproductive performance was described for four lamb crops.

The mean live weights of ewes from birth to 3.5 years are given in Table 4. Those lambs receiving higher levels of nutrition in pregnancy (Group P) had higher birth weights and this group, together with those lambs receiving higher levels of nutrition in lactation (Group L), had higher weaning weights than the control group of lambs. By 30 months of age (i.e., at their second mating) ewes of all groups had similar live weights. The proportion of barren ewes and those bearing single lambs in the first three lamb crops are given in Table 5. There was a significantly ($P<0.01$) higher proportion of ewes bearing single lambs in the control group than ewes from the other two groups.

		Time after birth (months)					
Treatment	**Births**	**1.5**	**4**	**6**	**18**	**30**	**42**
P	4.0	18.1	32.4	34.6	54.3	61.1	65.5
L	3.5	17.7	31.6	34.8	54.0	60.2	63.8
C	3.5	17.0	30.8	33.5	52.5	59.8	64.2

Table 4. Live weights (kg) of sheep from birth to 3.5 years of age.

Barrenness was significantly ($P<0.05$) lower in the L group than the other two groups. The consequences of these two sets of observations was that the mean lambing rate per ewe mated was 1.31, 1.40 and 1.50 for the C, P and L groups respectively.

These results have profound effects on the efficiency with which nutritional resources can be used. There is a considerable biological and economic efficiency from providing higher levels of nutrition to these ewe lambs which will subsequently enter the breeding flock. The mechanisms involved in the development of these effects are unknown and that investigation is likely to be a fruitful one of study not only to ruminant resource use but in other areas of biology.

Contact name: **John Milne**

Treatment	Rate of barrenness	Proportion of single-bearing ewes
P	0.093±0.0144	0.460±0.0277
L	0.047±0.0103	0.444±0.0260
C	0.088±0.0137	0.567±0.0269

Table 5. Rate of barrenness and proportion of single-bearing ewes after 3 lamb crops (±SE).

Red Deer at Rahoy

Photo: Highlands and Islands Enterprise

Photo: Words and Pictures, Aberdeen

MANAGING the IMPACT of HUMAN ACTIVITIES on the ENVIRONMENT:

practical possibility or unrealized ideal?

I. J. Graham-Bryce, Shell Internationale Petroleum

1. Introduction

The preoccupation with the environment by all sectors of society which is such a marked feature of contemporary life, would no doubt have brought a wry smile to the lips of the founder of this institute and the distinguished scientists who have established its reputation over the years. For they recognized early the importance of understanding the nature of the environment and the processes taking place within it. It is a great honour therefore to be asked to present this lecture named after Thomas Macaulay in the institute which continues to do so much to advance that understanding.

Understanding, at least to some extent, must be the key to management in any field, which brings me to my title. It is an ambitious title and it needs some delimiting. The question which it poses can be answered at various levels and from various perspectives. My own perspective now is that of industry, specifically a very large company active in several businesses: oil and gas, chemicals, metals, coal and forestry. It is a company which operates in over 100 countries with a turnover of approximately $100 billion per year. Because of its size, its geographical spread and the range of its interests, it is a company which is touched by virtually every environmental issue. We have a strong vested interest in protecting the environment and in the establishment of valid approaches to managing the impact of human activities.

2. Concepts of the environment

In seeking an answer to the question in my title, we first need a concept of what it is that we are trying to achieve through management. This concept must recognize firstly, the legitimate aspirations of a rapidly increasing world population for material benefits and an adequate standard of living and secondly, that there is virtually no environment, at least in the developed world, which has not been substantially affected by man. Idealized conceptions of a pristine nature unaffected by human activities sadly have no validity or value for practical purposes, although of course nature conservation must be an essential component of any management scheme.

The current unifying concept which best brings the different considerations together is that of sustainable development as elaborated by the World Commission on Environment and Development (1987) (The Brundtland Commission). Sustainable development is defined as:

'To meet the needs of the present generation without compromising the ability of future generations to meet their own needs'.

How to interpret and implement this concept is a matter of active discussion. In the present context, it can be taken to imply:

(i) *Maintaining environment functions,* for example biogeochemical cycles (including degradation of products from human activities)

(ii) *Maintaining habitats,* broadly defined, which will allow survival and flourishing of organisms including man, domestic animals, crops, wildlife. This together with item (i) above often translates into what the layman thinks of as clean air, clean water and clean soil.

(iii) *Stewardship over resources* including renewable resources and other biological resources including genetic material. Clearly certain material resources (including fossil fuels) are finite. Hence the objective must be to use them most efficiently and thereby prolong their useful life. Long-term sustainability, however, must also imply that the purpose for which they are needed will eventually be satisfied by substitute means. Industry can have a key role and responsibility in efficient resource use and in providing such long-term solutions.

(iv) *Amenity and aesthetic considerations* need no further elaboration.

	Scale of Impact	Control Measures	Management
Early Industry	Limited, specific local	Minimal	Minimal
Industrial Revolution	Local/Regional	Some "end of pipe" (EOP)	Piecemeal
Modern Society	Local/Regional/ Global	EOP → Integrated	Systematic
Future	Decreasing (?) Local/Regional/ Global	Clean Technology	Integrated

Table 1. Environmental impacts and environmental management: the industrial sector.

Clearly industry together with other sectors in society has a direct vested interest in most of these elements. It relies on a healthy environment and on the availability of resources to conduct its activities. Furthermore, although it is less directly concerned with amenity and aesthetic aspects as a sector, its members have a keen interest in these aspects as individuals.

3. Management requirements

Having considered the broad objectives, we need next to identify the requirements for managing to achieve these and to assess how we stand in relation to these requirements. The requirements fall under three interlinked headings:

- ☐ knowledge of the current situation;
- ☐ criteria for acceptability;
- ☐ means of control to meet these criteria.

To preface consideration of these requirements and to help see them in perspective, it should be recalled that the nature and scale of environmental impacts from human activities have evolved in step with economic development, population increase and improvement in standard of living. Table 1 summarizes this evolution for the industrial sector.

In the earliest stages of the industrial and agricultural revolution, activities were limited, so that impacts were modest and could be accommodated by the environment without significant impairment. As industrial activities developed, environmental effects became more substantial and apparent, although most were still relatively localized. We have now moved to a situation where mankind's technological activities are of such magnitude that, if not properly controlled, they can overload environmental processes and cause major environmental damage not only locally but also regionally and even globally. Fortunately, environmental management concepts and procedures have evolved in response to this trend, as will be discussed below.

3.1 Knowledge of the current situation

For proper intelligence about the current situation, we need information on inputs and levels of contaminants in the

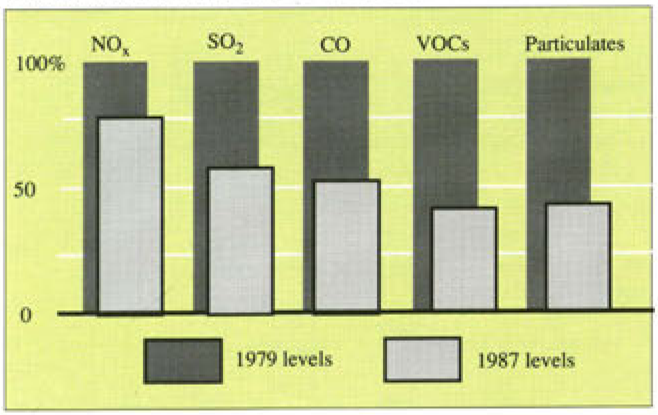

Figure 1. Reduction in emissions to air 1979-1987 in West Germany.

environment and on impacts. With respect to inputs, at least for industrial activities in developed countries, many sources are reasonably well characterized. The data show that discharges of many major pollutants have declined markedly since their peak: contrary to popular belief many environmental situations are getting better. For example, Figure 1 shows reductions in emissions to air in the Federal Republic of Germany over the last decade.

Making inventories of levels of contaminants in the environment can clearly be a formidable task, particularly for materials which are likely to be widely distributed. Pesticides provide the best known examples. Indeed realization of the widespread occurrence of organochlorine pesticides throughout ecosystems, often far from their point of application, did much to awaken environmental awareness and to increase understanding of environmental processes and vulnerabilities. This widespread redistribution among living and inanimate components of the environment results from the stability and lipophilicity of the compounds concerned - properties which when combined with their activity against pests made them very effective for their purpose and hence very widely used. As knowledge of their adverse effects has become clearer, so they have been replaced by alternatives with fewer disadvantages and their levels in the environment have accordingly declined (Table 2). Their brief case history provides a good example of the evolution of practices in the light of improved understanding. A more recent example in a different sector is the phasing out of CFCs according to the Montreal protocol.

Our knowledge of how man-made substances interact with the environment is steadily increasing, partly through research and partly through practical experiences such as those just discussed. This has helped greatly in making it possible to anticipate and prevent environmental damage. Nevertheless we should not be surprised or distressed by further cases where improved understanding suggests changes. Currently there is active interest in the occurrence of pesticide residues in groundwater which may lead to modified practices and different materials. We should not however be misled simply by detection of a substance in the environment, particularly in the light of the extreme sensitivity of modern analytical methods. It is a central

State	Year	No. of specimens	Mean residues (mg/kg)
Minnesota	1969-72	n.a.	0.90
	1976	7	0.56
	1978	5	0.15
Wisconsin	1976	12	0.45
	1977	8	0.37
	1978	10	0.55
	1979	11	0.12

Table 2. Residues of HEOD in Bald Eagle eggs in the USA, 1969-1979 (Wiemeyer et al., *1984)*

principle of ecotoxicology that hazard is a function of both toxicity and exposure, exposure in turn being related to the bioavailable concentration and the time period over which this is experienced. The bioavailable concentration may be substantially less than the bulk concentration as a result of sorption and partition processes. Presence is therefore by no means synonymous with hazard. In this connection the EEC Drinking Water Directive (No. 80/778/EEC) is of particular concern in that, without reference to toxicological significance, it stipulates a maximum allowable concentration of 0.1 mg/l for any one pesticide or related substances and 0.5 mg/l for the total of all such compounds. It therefore departs from previous approaches, including that adopted by the World Health Organization which appear to have served society well.

Recognition that hazard is a function of both toxicity and exposure implicitly underlies the general approach now universally adopted for assessing the potential environmental impact of prospective new products before they can be registered by authorities for use in practice. This approach combines measurements of toxicity to indicator species (either direct or through effects on functions) with investigation into the behaviour of the compound in the environment, for example mobility, stability and partition properties. The validity of this approach will be discussed further in the consideration of criteria below.

Evaluating impacts can introduce still further complications. While acute, severe damage from accidental spills or gross environmental mismanagement can be clearly visible and unambiguously associated with the cause, generalized chronic effects may be much more difficult to recognize and unravel. A familiar example is forest decline attributed to acid rain, but almost certainly the result of several factors interacting with air pollution.

	Ethylene dibromide		Disulfoton	
	Measured	Calculated	Measured	Calculated
Solubility, mg/1	4300	4700	25	32
Vapour pressure mm Hg	11.0	11.3	1.8×10^{-4}	3.4×10^{-4}
Soils adsorption coefficient	0.5	2.3	25.1	37.3

Table 3. Comparison of measured and calculated properties for representative soil-applied pesticides (Graham-Bryce, 1984).

Even more difficult to identify are the signals of global warming, where any fingerprint of an augmented greenhouse effect will be extremely hard to distinguish against a background of natural climate variation and regional differences, particularly given the problems of making reliable and accurate global measurements of characteristics such as temperature and sea-level.

To supplement traditional and modern observational methods (including increasingly, satellite remote sensing), computer modelling is becoming progressively more powerful and valuable. As knowledge of underlying physico-chemical processes and relationships advances as a result of basic research, it is increasingly possible to predict behaviour using models and quantitative structure/activity relationships (QSARs), especially when supplemented by comparison with 'benchmark' chemicals whose behaviour in the environment has already been established. As an example, Table 3 compares measured physicochemical properties with values calculated from basic relationships starting only with the molecular formula (Graham-Bryce, 1984).

	Aggregate stability*	Organic carbon (%)	Total nitrogen (%)
Old grassland	82.2	3.79	0.39
Old arable	0.3	1.08	0.10

*Expressed as percentage of oven-dry soil particles of diameter < 0.5 mm in water stable aggregates of diameter > 0.5mm

Table 4. Aggregate stability of silt soils in Lincolnshire (Low, 1972).

Notwithstanding these advances, there remains a need for a continuing strong programme of observations on the state of the environment, ranging from monitoring for possible adverse effects of pesticides on wildlife to complex internationally coordinated programmes of global observation in relation to phenomena such as the augmented greenhouse effect - a point firmly underlined at the recent Second World Climate Conference.

3.2 Criteria for acceptability

Leaving aside cases of severe, obvious environmental damage which are clearly unacceptable by any standards, the issue of what constitutes a significant and unacceptable effect can be difficult and controversial. In addressing this issue we should bear in mind two further fundamental ecotoxicological principles. The first is that ecosystems can accept some man-made impact without impairment. This is because of the resilience of natural populations and the operation of processes such as degradation, redistribution and recycling which are essential for dealing with naturally occurring substances and maintaining the health of ecosystems. The crucial requirement is, of course, not to overload these processes. The second principle is that different ecosystems differ in vulnerability as a result of differences in composition, sensitivity of organisms present and so on. The burden which can be tolerated without impairment therefore differs from ecosystem to ecosystem.

Against this background, I shall discuss criteria for acceptability using just two examples from the myriad of possibilities: first, acceptability of pesticides used in agriculture as an example of industrial products and second, soil decontamination as an example of a common problem close to the interests of this institute.

Environmental aspects of the use of pesticides in agriculture should be seen against the perspective of the impact of agricultural activities in general. It should be recalled that the establishment and practice of agriculture, even 'traditional' agriculture and organic methods can have profound environmental effects, generally more severe than any known impact of pesticides. The initial clearance and drainage to produce the traditional farming landscape, so admired by some conservationists, clearly destroyed the existing ecosystem. Changes in cropping policy, often the result of fiscal incentives self-evidently have substantial environmental consequences. These range from visual effects such as the proliferation of oil-seed rape in recent years to less obvious but equally significant effects such as those on soil structure. Table 4 shows effects resulting from a change from permanent grassland to arable crops identified in the classical work by Low (1972).

Even minor adjustments such as changing cereal varieties can disturb ecological relationships, for example changes in pathogen races or pest/predator ratios (Graham-Bryce, 1989).

The acceptability of pesticides must be seen against this dynamic background. As indicated above the cornerstones of approaches to appraising acceptability are measurements of toxicity and investigations into fate and behaviour in the environment. This appraisal has evolved in the light of improving understanding into a formidable battery of tests (Table 5) which accounts for a significant part of the $30-40 million now required to develop a new pesticide. Whereas in the 1950s the appraisal involved consideration of only acute toxicity to selected species, it now includes tests of direct toxicity to a wide range of organisms, tests of effects on key environmental functions and extensive studies on degradation and movement of the chemical in the environment.

We may note in passing that over the years, this approach has played an important part of the discovery and

1950s	1980s
Acute toxicity: birds Acute toxicity: fish Acute toxicity: bees	Acute toxicity to fish (3 spp). Fish, early life stage tests. Fish, bioaccumulation. Acute toxicity to aquatic invertebrates (4 spp). Acute toxixity to algae. *Dalphina*, reproduction study. Acute toxicity to bees. Acute toxicity to birds (2 spp). Dietary toxicity to birds. Effects of soil fauna. Residues in earthworms. Leaf litter decomposition. Effects on nitrification and CO_2 evolution from soil. Biodegradation rate, inhibition. Physiochemical properties, notably partition coefficient.

Table 5. Typical laboratory and small plot tests for environmental acceptability required by authorities (Graham-Bryce, 1989).

Insecticide	LD50 to Rats mg/kg (acute oral)	LD50 to *M. domestica* mg/kg (topical)	Ratio rats:insects
Parathion	3-6	0.9	5
DDT	118-250	10	18
Fenitrothion	800	1.4	572
Malathion	1400-1900	18	917
Bioresmethrin	8600	0.2	43000
Aspirin	1750	–	–
Caffeine	200	–	–

Table 6. Relative toxicity of insecticides to insects and mammals.

development of products having remarkable degrees of selectivity and behaviour in the environment closely matched to the requirements for specific pest control objectives. These include systemic fungicides and insecticides, insecticides selective between pests and predators and herbicides acting selectively between closely related plant species. Table 6 provides just one example: it shows levels of selectivity which can be achieved between insect pests and mammals expressed in terms of ratios of acute toxicity to rats and to target species. In these terms bioresmethrin represents one of the safest insecticides known with an astonishing degree of selectivity and an acute toxicity to mammals less than that of many materials in common household use such as aspirin or caffeine.

The evaluation scheme depicted in Table 5 is generally regarded as providing a reliable safeguard against direct effects in the environment. It is also likely to detect any potential major threat to ecological relationships. As these approaches to assessing direct effects have become established, so attention has turned increasingly to indirect effects and more subtle ecological effects. This introduces many more uncertainties and difficulties. It requires consideration of not only lethal but also sub-lethal effects at the population, community and ecosystem levels. Postulated effects of pesticides must be related to any other factors affecting population dynamics if erroneous conclusions are not to be drawn. The issues involved are clearly demonstrated in several impressive studies on the ecological aspects of pesticide use, for example the Cereals and Gamebirds Research Project of the Game Conservancy (Oliver-Bellasis and Sotherton, 1986) and the Boxworth Project (Hardy, 1986). These projects have provided much valuable information; they have also brought out the problems of determining what constitutes a significant effect and the difficulties of distinguishing the influence of pesticide usage from other effects of farming systems. Experimental design is problematical because ecological considerations dictate very large plots and this limits the scope for replication. Such investigations are also very demanding in terms of land, manpower and other resources.

Such investigations obviously should be continued in order to improve understanding and establish underlying principles. However, it is clear that they cannot be routinely adopted as part of the evaluation of pesticides or form a basis for establishing criteria for acceptability.

More pragmatic unambiguous indicators of adverse impact on ecological relationships are required. In appropriate cases such as with perennial crops, alteration of predator/prey relationships could provide such an indicator. This was demonstrated for apples by the long term studies of Cranham *et al.*, (1984) on control of the spider mite (*Panoychus ulmi*). These investigations led to a scheme for classifying pesticides according to their relative effects on *P. ulmi* and its most important predator *Typholodromus pyri* which is capable of regulating the pest to non-injurious levels.

In summary, the most appropriate basis for setting criteria for the environmental acceptability of pesticides remains the familiar tiered or stepwise approach which has developed and become more sophisticated over the years. The initial step is determination of basic physicochemical properties and fate in the environment, coupled with measurement of acute and chronic toxicity to standard species. This can then be supplemented by more detailed studies of key indicator species and key processes in the light of initial results. Observations of effects on predator/prey relationships and field monitoring as appropriate for the intended use pattern can then complete the assessment. It is, however, important to keep approaches under regular review so that they may be adapted in the light of new knowledge and so that surprises can be avoided.

My second example concerns criteria for contaminants in soil, a situation which may arise from accidents or from long term industrial activity.

Environmental Protection Agency, USA	20-166.5
New Jersey, USA	100
California, USA	1000
Alberta, Canada	800 (pH < 6.5)
British Columbia, Canada	500
Quebec, Canada	200
United Kingdom (residential)	500
United Kingdom (amenity)	2000
France	100-500
The Netherlands	150

Table 7. Required decontamination levels for lead in soils (ppm).

It has proved difficult to establish a basis for setting acceptable levels for substances in soil and to answer the question 'how clean is clean'. As a result, figures adopted can appear somewhat arbitrary as Table 7, which gives levels applied by different authorities, indicates.

The need for a more objective and scientific concept has been widely recognized. In the Health, Safety and Environment Division of Shell Internationale Petroleum Maatschappij B.V., C.L.M. Poels and W. Veerkamp have led the development of a scheme for hazard assessment of chemical contaminants in soil which has formed the basis of an approach now put forward by the European Chemical Industry Ecology and Toxicology Centre (ECETOC, 1990). The essence of the concept is to compare maximum tolerable exposure levels (MTELs) (as determined from toxicological investigations) with measured or estimated 'environmental exposure levels' (EELs). EELs are determined by characterizing the source of the exposure (the contaminated soil) and defining the exposure routes. The exposure can then be quantified, making allowance for any background exposure from other sources.

The hazard assessment is best approached in a stepwise manner (Figure 2). Following an initial evaluation to determine if a potential exposure exists, a preliminary exposure assessment is conducted making use of a computer model HESP (Human Exposure to Soil Pollutants) specifically developed for the purpose. HESP incorporates all known exposure routes and estimates the resulting exposures on the basis of known relationships for the exposure processes. These relationships are quantified by setting values for the appropriate site-specific variables and parameters determined by the prevailing circumstances and characteristics of the exposed population. Figure 3 on page 56 shows the exposure routes typically considered for a residential situation.

Experience shows that in most situations only a small number of exposure routes prove to be significant, simplifying the estimation.

If the exposure levels estimated by the model exceed the maximum tolerable exposure levels (which invariably include substantial safety factors) then a definitive exposure assessment, involving measurements for the specific local

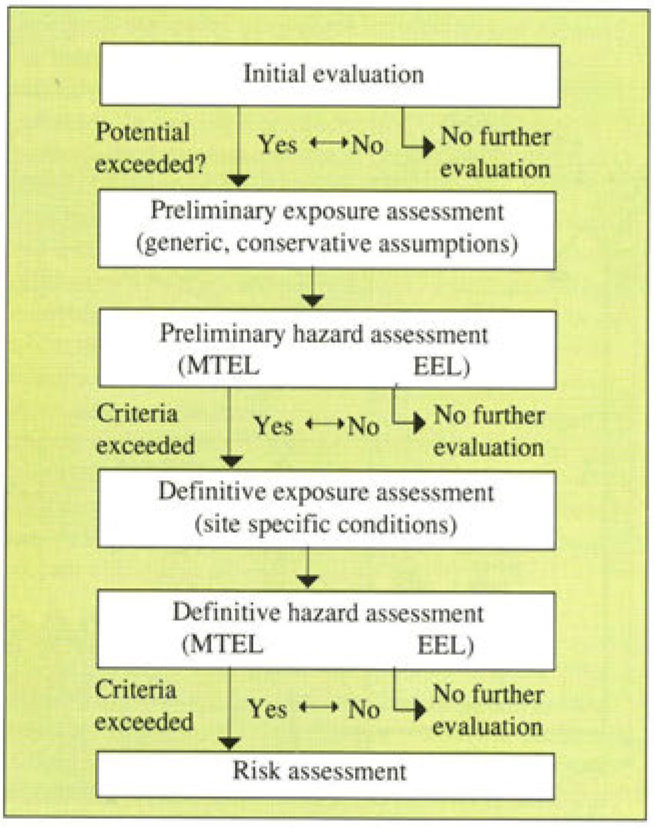

Figure 2. Hazard assessment of chemical contaminants in soil (stepwise approach).

conditions of the site, must be undertaken, from which a definitive hazard assessment can be made. If this also suggests, that the MTEL criteria could be exceeded, the final step is a risk assessment to determine the probability that the hazard is realized in practice. As each step in the process is conservative, an indication that the criteria are not exceeded can be regarded with confidence as indicating that no hazard exists.

Figure 4 illustrates the use of the model for the case of DDT. It can be seen that the Acceptable Daily Intake for adults will not be exceeded as a result of exposure from contaminated soil and that even for children this would only occur at high levels of contamination in comparison with those likely to occur in practice.

The approach can be extended to organisms in the environment other than man, although in most cases there is much less basic information on toxicity and exposure routes so that more assumptions are needed.

It may be noted that in both the cases discussed abqve, a stepwise procedure for assessing hazards is recommended as a valuable, pragmatic and cost-effective approach to establishing criteria for acceptability.

3.3 Means of control

Controlling human activities to satisfy the criteria for acceptability must comprise technological, regulatory and managerial components. The details lie outside the scope of this lecture and discussion here will be confined to a few general comments.

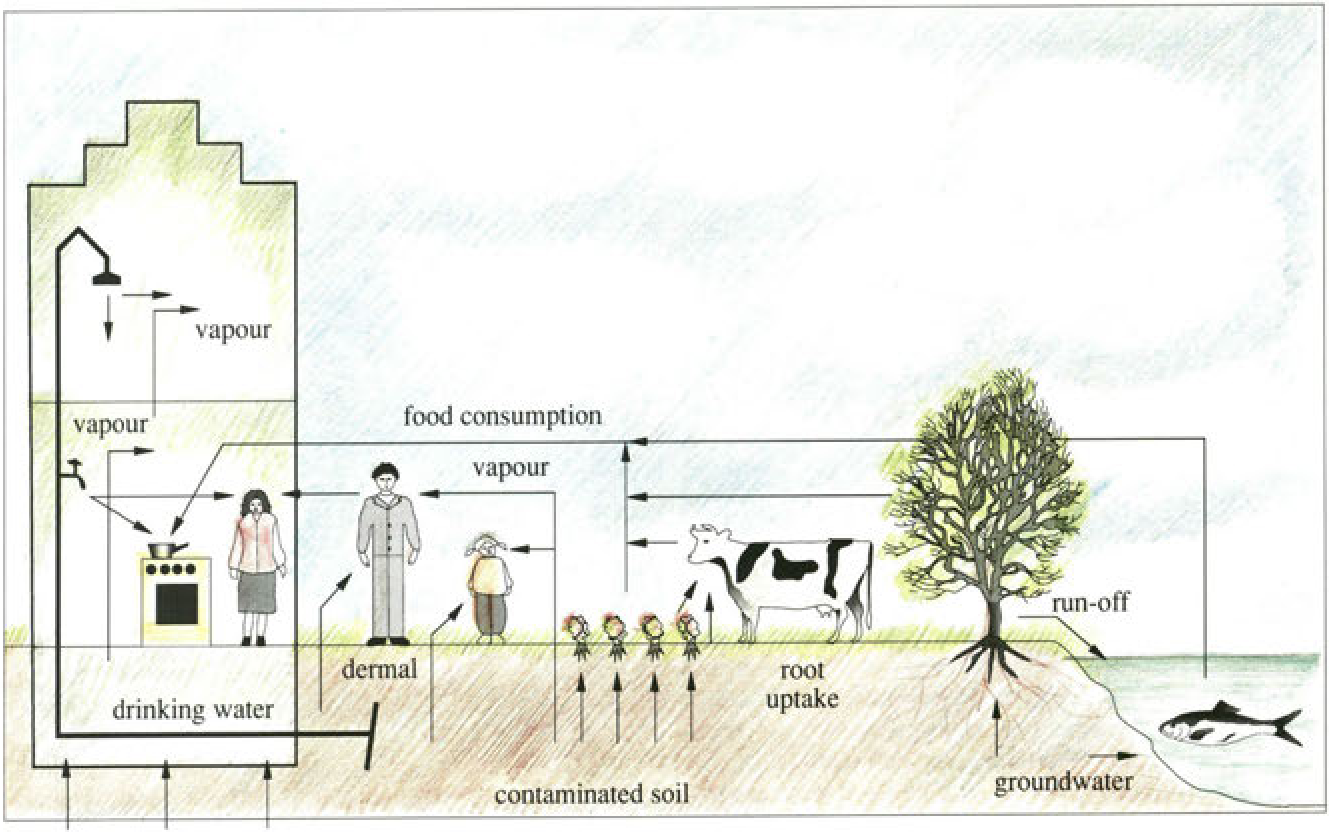

Figure 3. Routes of exposure to soil contaminants.

With respect to technology, attention is drawn again to the evolution depicted in Table 1. As environmental effects from industrial activities became progressively more apparent and understanding of their consequences developed, various control measures were introduced which were largely designed to filter out noxious discharges associated with the production process. It has been increasingly recognized that this approach can be wasteful and that it is both more effective and more efficient to integrate the environmental protection measures into the heart of the production process itself. The fullest expression of this is the concept of 'clean technology' where environmental considerations are a vital part of the specification from the earliest stages of design. Many older processes are now being displaced by this concept. In applying it, it is important that all environmental considerations are evaluated, including energy use so that benefits in one direction are not off-set by disadvantages in another. It is also important to recognize that establishing new processes can require substantial capital investment and that the opportunity to install clean technology may only occur when old plant is being decommissioned.

Concerning regulations, these are generally welcome by all sectors provided that they are soundly based and harmonized and provided it is recognized that they can never be exhaustive. They must be supplemented by the voluntary actions of industry and other sectors of society in the spirit of responsible care. There is also now growing interest in the use of economic instruments as an alternative to regulations.

This leads to managerial aspects, which have also evolved as shown in Table 1. For example, the systematic, integrated approach to environmental management developed within the Royal Dutch/Shell Group of companies is outlined in Table 8 (overleaf). The different

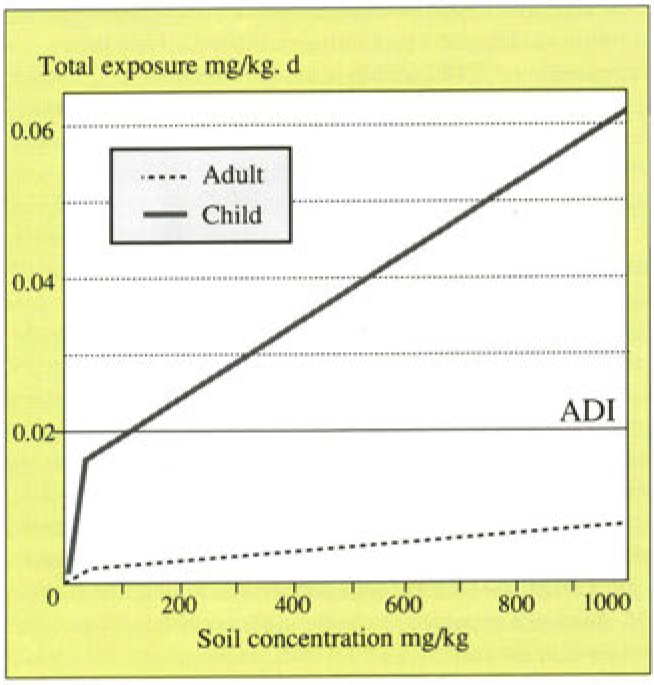

Figure 4. Human exposure to soil pollutants - DDT.

components are closely linked but for ease of presentation they may be divided into procedures applied before an operation, during the operation and after the operation has ended.

Planning phase ■ Determine environmental properties of candidate products ■ Environmental baseline studies ■ Environmental Impact Assessment (EIA) ■ Prevention: design clean technology ■ Emergency/contingency planning
Operational phase ■ Emission control and monitoring ■ Effluent control and monitoring ■ Waste management ■ Field investigations (once-off or monitoring) ■ Environmental audits ■ Incident recording/reporting
After cessation ■ Decommissioning/clean up/restoration ■ Landscaping

Table 8. Environmental management: techniques and procedures.

The key features are that the approach is comprehensive, applying to all stages of an operation or product from its initial conception to final termination and that it is inseparable from other aspects of management.

4. Conclusions

In the light of this brief review of considerations applying to environmental management, what conclusions can be reached concerning the question posed at the outset? Not surprisingly, I suggest that the answer must be positive, but with qualifications. Managing the impact of human activities is a practical possibility, indeed it must be, but it is still an imperfect art - a mixture of science and pragmatism. It is essential that we continue to strengthen the science, both observations and understanding of processes, through work of institutes such as this. It is a truism to state that we as yet have only a rudimentary understanding of how the environment works, at least for the purpose of precise management. It seems unlikely that such understanding will ever be complete, and hence the pragmatism.

I have indicated the nature of that responsible pragmatism by quoting examples from my own company. It is a pragmatism which must be developed by consultation and discussion between all parties: industry, authorities, scientists, environmentalists, politicians and representatives of the community. It is a pragmatism which must err on the side of caution. But at the same time it must recognize the reality of resource constraints and the need for balance and trade-offs between different societal objectives which may require difficult decisions about priorities. In seeking a common view on these issues, a particularly important element is consensus on attitudes to risk.

To ensure further progress against a rapidly developing but still incomplete scientific background, we have recently reinforced a further cardinal principle to guide operations in companies of the Royal Dutch/Shell Group. This is to seek a continuous improvement in operations by progressive reduction in effluents, emissions and discharges of waste known to cause negative impact on the environment, with the ultimate goal of elimination. We believe that implementation of this principle should help us to meet the challenge which faces all sectors of society namely to satisfy expectations for a steadily improving environment as part of the aspiration for a better quality of life.

5. Acknowledgements

The views expressed in this lecture have benefited from stimulating interactions with many colleagues over the years in various organizations, most recently in the Health, Safety and Environment Division of Shell Internationale Petroleum Maatschappij. It is a pleasure to acknowledge their help.

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Introduction

The Institute continues to develop collaborative projects with scientists throughout the world. This section describes two EEC funded projects nearing completion, summarizes recent links with Europe, indicates progress in building links with Central and East European countries (the SARI Initiative) and concludes with a brief description of some other international links.

UK delegates to the Japan/UK Joint Seminar on the Interaction of Agriculture with Climate Change, Tsukube Science City, 6-7 November, 1990. Left to right, Dr N.R. Sackville Hamilton, IGER, Aberystwyth; Dr P. Mellor, IAH, Pirbright, Dr R.A. Leigh, IACR, Rothamsted; Dr H.G. Jones, HRI, Wellesbourne; Dr T.A. Dyer, IPSR, Norwich; Dr R.V. Birnie, MLURI, Aberdeen; Dr P. Rowlinson, University of Newcastle-upon-Tyne; Dr M. Carpenter, AFRC, Swindon, Prof. J.R. Hillman, SCRI, Invergowrie.

EEC PROJECTS NEARING COMPLETION

Agroforestry

On 1 January 1988, the Institute (Dr P. Newbould) in collaboration with Aberdeen University (Professor D. Atkinson and Dr J. Hooker), Kinsealy Research Centre, Eire (Dr M. Bulfin) and University of Thessaloniki, Greece (Professor N. Papamichos and Professor M. Paponastasis) started to study the environmental impact of biogeochemical cycling in agroforestry. The objectives of the programme funded by the EEC as part of the 4th Environment programme were, to quantify the biogeochemical cycling of nutrients (N, P and S) during the establishment phase of a silvopastoral system; to determine the interactions between the tree, grass and animal components of the system; and to identify the major factors influencing nutrient cycling and so produce a management system with minimum environmental pollution.

Sycamore *(Acer pseudoplatanus)* trees were planted in pasture at Glensaugh Research Station at four spacings (2500, 1600, 400 and 100 stems/ha) with the underlying herbage being grazed, mown or sprayed out with herbicide. A grazed pasture without trees was used as an agricultural control. The experiment shares some treatments with the larger systems experiment at Glensaugh Research Station which is part of the United Kingdom national network agroforestry experiment.

Variations in soil water and nutrients close to trees and away from trees, together with the growth and nutrient content of trees and pasture, were measured, the objective being to quantify possible environmental effects of mixed tree and pasture systems during the establishment phase of the trees.

Trees grew better in the absence of underlying pasture but the likelihood of leaching of nitrate to water is greater. An early conclusion is that the understorey of grass should be maintained until the trees are established. Trees have grown better with the protection of shelters, though changes in the ratio of diameter to height suggest that their stability or survivability in high winds might be less than trees grown without shelter in traditional forestry systems.

This research will continue under the EEC STEP programme. Two new groups, the University of Bologna, Italy (Professor U. Bagnaresi) and the University of Hanover, Germany (Dr H. Bohne) have joined the programme together with the Scottish Agricultural College (SAC) Aberdeen all under the co-ordination of Professor D. Atkinson. New experimental sites will be established in Italy, Germany, Greece and at Craibstone near Aberdeen on a soil previously used for arable agriculture (i.e. set aside). Sycamore trees will be grown at all sites, although local trees will be used as well, and the new sites will include a grass/clover treatment. Measurements will continue at the existing sites at Glensaugh Research Station, Kinsealy and Thessaloniki.

Factors affecting radiocaesium transfer to ruminants

Since its inception the Radiation Protection Research and Training Programme has adapted itself to promote research to fulfill the changing needs of radiation protection policies. The aftermath of the Chernobyl accident highlighted deficiencies in the state of knowledge on the behaviour of radionuclides (in particular, radiocaesium) in the environment, such that it limited the accuracy of prediction of their transfer through the human food-chain. Collaborative work by the Institute of Terrestrial Ecology (ITE) and MLURI, and substantiated by other workers, showed that radiocaesium transfer to ruminants can be influenced profoundly by the dietary source of radiocaesium. Contemporary models, designed to predict transfer of dietary radiocaesium to animal products, paid little attention to variations in its availability to animals and this was the major stimulus for the instigation of the project. The project, of two years' duration and initiated in 1990, involves workers from 10 laboratories in seven countries of Western Europe and Scandinavia. The project is co-ordinated by ITE, Merlewood Research Station.

The studies involved in the project represent a co-ordinated programme to determine the relative importance of the factors which influence the dietary uptake and behaviour of radiocaesium in ruminants.

Experimental approach
The transfer of radiocaesium from the diet to animal products has commonly been quantified in terms of the transfer coefficient, which is defined as the ratio of the concentration of radiocaesium in the animal product at equilibrium to the daily radiocaesium intake. Equilibrium conditions, with respect to tissue concentrations of radiocaesium, are difficult (or sometimes impossible) to achieve. An alternative measure of radiocaesium availability, the true absorption coefficient, which is the fraction of the radiocaesium intake which is transferred to blood plasma, has been adopted for use in this programme of research. Equilibrium conditions are not necessary for its estimation; rapid and economical estimates of radiocaesium availability can thus be made. Although the concept of the true absorption coefficient is not new, having been used to assess mineral availability in animals, the method used here for radiocaesium, which involves the concurrent use of intravenous infusion of ^{134}Cs, is novel and was developed at MLURI.

Most studies use sheep as a 'model' ruminant but some experiments with dairy cattle are also being conducted.

Components of the project
The research can be divided into four main topic areas: the effects of the physiology of the animal, dietary factors, radiocaesium behaviour in gut and tissues, and the development of mathematical models from the data provided by the other topics. MLURI plays an important role in most of these aspects of the work. Under the effects of the physiology of the animal, age, breed and stage of lactation are being studied by different groups. Under dietary factors, the effects of diet quality, drying, ensiling and freezing are being investigated, together with some ingestion.

Under behaviour of radiocaesium in the gut and tissues of ruminants, the conditions within the digestive tract, which may affect the behaviour of radiocaesium in terms of the sites of absorption within the tract and its recycling via saliva and other secretions, are being studied. These conditions, such as rumen pH and type of fermentation, the sodium, potassium and water contents of digesta and rate of passage along the tract, can be influenced by the nature of the diet and this is under investigation at MLURI using sheep given contrasting diets of either ryegrass or a maize-based concentrate diet.

The reason for the modelling aspect of the programme is to improve existing models and develop new models, as a result of the data provided by other studies within the programme. The models should also assist in providing directions for future research. As a result of work undertaken at MLURI, a model has been developed which describes the behaviour of radiocaesium in sheep tissues; the importance of the extracellular fluid pool, and also the solid and liquid components of digesta, all hitherto ignored, have been recognized, and are obvious focal points for future studies.

European links
Many of these links are funded by the EEC and involve several countries so are described under the project title with the relevant EEC programme in brackets.

Mineral transformations in soils developed upon industrial wastes and affected by heavy metal pollution
Dr M.J. Wilson and Dr M.L. Berrow have set up an academic link interchange scheme funded by the British Council with the Faculty of Agriculture, University of Belgrade, Yugoslavia involving Dr N. Kostic and Dr M. Jakovljevic.

Mineral weathering in relation to nutrient inputs in three French catchments (EEC, STEP/ENCORE)
Dr M.J. Wilson with Dr J. Ranger, INRA, Centre de Recherches Forestières, Nancy, France.

Decay of building and monumental sandstones from Scotland and Spain
Dr M.J. Wilson and Mr E. Paterson with Dr J.L. Perez-Rodriguez, Instituto de Ciencias de Materiales, Seville, Spain under the Acciones Integradas Scheme of the British Council.

Electron microscopy of clay minerals
Dr M.J. Wilson and Dr W.J. McHardy with Dr Vladimir Sucha, Institute of Geology, Bratislava, Czechoslovakia.

Biology and control of a soil borne phytopathogen (sclerotinia)
Dr D. Jones is developing links with Dr J. Gondran, INRA, Lusignan, France.

Analysis of reference soils and plants
Dr M.L. Berrow on behalf of the Reference Bureau of the EC Brussels.

Internal cycling of nitrogen in deciduous and evergreen forest trees (EEC, STEP)
Dr P. Millard is the co-ordinator of this project which involves Professor J.S. Pereira, Instituto Superior de Agronomia, Lisbon, Portugal; Professor A. Escudero, Departmento de Ecologia, University of Salamanca, Spain; and Dr A. Heilmeier, Lehrstuhl Pflanzenoecologie, University of Bayreuth, Germany.

Development of a routine internationally acceptable method to determine soil phosphorus status
Dr A.C. Edwards has a link, funded by IMPHOS, to study the use of ion exchange resins to measure soil P status with Professor Hanotiaux, University of Gembloux, Belgium.

Model uptake and internal cycling of nitrogen within deciduous trees
Dr P. Millard has a travel grant from the British Council to establish a collaborative link with Dr R. Habib, INRA, Avignon, France.

Management of farm forestry
Dr D. Vaughan has a travel grant from the EEC (Competitiveness in Agriculture) to establish links with Dr M. Bulfin, Teagasc, Dublin, Eire, to investigate management inputs for contrasting tree species.

Organic soil nutrient transfers
Dr B. Williams has a travel grant from the British Council to study the fate of fertilizer N in Portuguese soils with Pedro Alpendre, University of Evora, Portugal.

Development of mixed grazing systems of animal production for the management of semi-natural vegetation to protect the rural environment in sparsely populated areas (EEC, CAMAR)
Dr I.A. Wright co-ordinates this programme which involves work from INRA, Theix, France, École Nationale Superieure d' Agricole, Montpellier, France; Teagasc, Athenry, Eire; and Centro de Experimentacion de Agraria, Asturias, Spain.

Diversification by deer farming through improving efficiency of production, welfare and the development of new marketing strategies (EEC, CAMAR)
Mr W.J. Hamilton leads the MLURI contribution which involves also the National Institute of Animal Science, Denmark; ADAS Rosemaund Experimental Husbandry Farm, UK; and Teagasc, Piltown, County Kilkenny, Eire.

Evaluation and improvement of the animal production systems using natural resources by grazing ruminants in Mediterranean areas (EEC, CAMAR)
Dr J.A. Milne is the consultant to this group led by Dr M.E. Diaz, SIA Estramadura, Spain which encompasses workers from France, Spain, Portugal, Italy and Greece.

The evolution of incisor dentition in response to food limitation in arctic ruminants
Dr I.J. Gordon co-ordinates this project which is funded by the Department of Arctic Biology, University of Tromso, Norway.

Food limitation in ruminant grazing systems
Dr G.R. Iason has a linked research grant funded by Acciones Integradas, British Council, with Dr A.R. Mantecon, CSIC, Leon, Spain.

SARI East European Initiative

Early in 1990 the Institute joined its sister Scottish Agricultural Research Institutes (SARI) and the Scottish Agricultural Statistics Service (SASS) in a project to forge links with scientists in Central and Eastern Europe taking advantage of the considerable change in politics in those countries. A brochure describing the interests and expertise of the Scottish Institutes was prepared with financial help from the Scottish Development Agency (SDA) and circulated widely throughout Central and Eastern Europe. Fact-finding missions were made to Poland, Czechoslovakia and Yugoslavia, funded mainly by the British Council but with some help from the Royal Society. In addition, a small number of written contacts have been made with scientists in USSR, Rumania, Bulgaria and Hungary. A data bank of contacts has been initiated and several bilateral scientific exchange visits and co-operative research projects have been agreed.

In 1991 the steering group of the SARI Initiative decided to concentrate its efforts in three areas where expertise was available throughout the SARIs and which tackled major problems in Europe as a whole as identified from the fact-finding missions.

The SARI Initiative and the proposed Czech/Scottish Institute were discussed by Dr P. Newbould, Assistant Director of MLURI (front left) and Dr I. Bremner, Deputy Director of RRI (rear left) and Mr R Bartak, Deputy Minister of Agriculture, Czech Republic (centre), Ing M. Trnka, Director of Education and Research, Department of the Czech Ministry of Agriculture (rear right), and Dr I. Rais, Director of Grassland Research Station, Zavisin, Marianski Lazne, Czechoslovakia (front right).

The first project is to help design and construct a research institute and associated field research stations in the Czech Republic. The Institute is to be called 'The Czech/Scottish Institute for Ecology and Use of Hill Regions'. Since the late 1970s there has been a working association between sheep and pasture specialists in Czechoslovakia and in the Hill Farming Research Organisation fostered by the British Council and by the Great Britain East Europe Centre. The earlier contacts coupled with those of the Initiative led to the present proposal which has been strengthened by the 'state of the art' knowledge the Institute has in laboratory design consequent upon the design and construction of its new headquarters at Craigiebuckler. The new Czech/Scottish

Institute is required to deal with the socio-economic, land use and pollution problems of the Sudetenland and of the hill regions of Bohemia and Moravia. Following the visit of a Czech Republic delegation led by Mr R. Bartak, Deputy Minister of Agriculture, to Aberdeen in March, a formal Memorandum of Agreement was signed. Subsequently, the Czechs provided a basis for the design and Dr P. Newbould and the professional design team for the new MLURI building at Craigiebuckler have produced an outline brief with an indicative cost. This was discussed in Prague in August 1991. Subsequently, discussions on the scientific programme of the new Czech/Scottish Institute will take place and because there is an interest in extension work it is likely that staff from the Scottish Agricultural College will become involved in the project too.

The Director (left) in discussion with Mr Ramaholi, Chief Extension Officer for Thabana Marena Project, Lesotho

The second project, also co-ordinated by Dr P. Newbould, concerns the soil-plant-animal-food relationships of heavy metals and involves input from the SARIs (Moredun Research Institute (MRI), MLURI, Rowett Research Institute (RRI) and the Scottish Crop Research Institute (SCRI)) SASS and SAC. This project is aimed initially at Czechoslovakia but could be extended to other countries badly affected by industrial pollution such as Poland, Hungary and Yugoslavia. Attempts to arrange a joint Czechoslovakian/Scottish workshop to initiate detailed proposals are in train.

The third area co-ordinated by Dr B. Marshall from SCRI intends to develop models of soil-plant-crop processes including the socio-economics and development of systems at farm, district and regional level and involves the SARIs (MRI, MLURI, RRI and SCRI), SASS and SAC, and includes Edinburgh University. Again the proposals are aimed initially at Czechoslovakia but could readily be extended to Poland, Hungary and Yugoslavia where problems requiring farm systems expertise abound.

Recently it has been decided to expand the activities of the steering group to encompass Europe and the developing world. A further brochure will be prepared emphasizing the combined skills available in Scotland to deal with selected items covering the whole range of agricultural, environmental and human nutrition problems. The Scottish Agricultural College will become a full member of the new grouping likely to be called SARIC International.

International links

Australia

There are long-standing links with Dr H. Dove, CSIRO Division of Plant Industry, Canberra, on alkane analysis in intake and diet composition measurements and on the development of intraruminal-controlled release devices.

Canada

Dr P. Millard has set up collaborative experiments with Dr G.H. Neilson, Summerland Research Station, British Columbia to study the effect of timing of N supply on N partitioning in fruit trees.

Chile

Dr A.J.F. Russel in collaboration with the Rowett Research Institute (RRI) has evolved a British Council link with the Catholic University in Santiago, Chile, to promote research in camelid production.

China

Dr M.J. Wilson has developed a joint proposal to characterize, manage and utilize the Red Soil resources in Southern China with Professor Renchao Wang, Zhejiang Agricultural University, Hanhgzhou. He has also developed a proposal with the Department of Earth Sciences, Zhejiang University, Hangzhou, to study the mineralogy of the ball clays of North and North-Eastern China, under the sponsorship of Watts Blake Bearne & Co Ltd.

Dr J.A. Milne and Dr A.J.F. Russel are participating with the Ministry of Agriculture, Fisheries and Food (MAFF) in joint programmes related to cashmere and wool production under the UK/China Memorandum of Understanding.

Iceland

Links have been established with Dr D. Gudmundsson, Agricultural Research Institute, Reykjavik on the use of alkanes in determining intake and digestibility estimates in fish.

Japan

Dr R.V. Birnie was a member of the UK delegation which visited Japan in December 1990 and it is likely that joint work will develop on aspects of climate change.

Links have been formed with Professor T. Watanabe on the structure of interstratified clay minerals. Profesor Watanabe will contribute to a book on 'Determinative Methods in Clay Minerals' that is currently being compiled by Dr M.J. Wilson.

Lesotho
Professor T.J. Maxwell visited Lesotho during February 1991 to undertake a consultancy contract funded by the Overseas Development Agency of the UK at the request of the Hon. Minister of Agriculture of Lesotho to review land use policies, strategies, and Ministry of Agriculture structure in Lesotho.

New Zealand
A British Council link has been formed with Massey University to exchange staff for periods of 6 months and Mr G.T. Barthram will be the first beneficiary over the winter of 1991.

USA
Dr Helen Armstrong is to spend one month with Dr J. Folse at Texas A&M University, USA and then Dr Folse will visit MLURI to develop a prototype model of foraging strategy in heterogenous pastures.

Dr R.C. Ferrier has established links with Dr J. Cosby, University of West Virginia, to develop further applications of the MAGIC model in the field of land use.

Dr Jeff Wilson, Head of Soils and Environmental Research at MLURI (centre) with a group including Professor Li Guang Yow, Bureau of Mineral Resources, Hangzhou and Dr Ye Ying, Zhejiang University Department of Earth Sciences during discussions on proposed collaborative research with Zhejiang University on the clay resources of China

TRAINING AND EDUCATIONAL OPPORTUNITIES AT MLURI

MLURI provides a range of training and education opportunities for undergraduate and postgraduate students as well as offering facilities for post-doctoral training, and to Visiting Workers. Short courses are also organized for specialist groups to learn about specific techniques or areas of expertise.

There are opportunities for undergraduates to spend up to 6 months as part of a sandwich course working alongside a scientist, assisting in the conduct of experiments and the analysis of data. Because of the seasonal nature of much of the field research programme, there are opportunities for students to gain experience of working in a research environment during the summer vacation. Students in their Honours year are also provided with facilities for undertaking projects which relate to the research programme of the Institute. There can be as many as 20 undergraduates gaining research experience at the Institute at any one time with a recent feature being the number of students from EC countries gaining valuable experience.

POSTGRADUATE TRAINING

Postgraduate training is an important objective for the Institute. Facilities are provided for M.Sc. students from a number of courses, ranging from Soil Science to Animal Behaviour, at the Universities of Aberdeen and Edinburgh to undertake projects as part of their course. These projects are supervised by Institute staff who take a full part in these courses often contributing to the teaching of the M.Sc. course. The Institute also encourages the training of postgraduate students leading to the award of a Ph.D. There are currently 25 postgraduate students from the UK, Spain, Portugal, Italy, Nigeria, India and Sri Lanka studying subjects which include grazing ecology, animal physiology, population ecology, mineral weathering, clay mineralogy, peatland afforestation and tree root systems. They are registered predominantly at the University of Aberdeen but students are also registered at the University of Edinburgh, University of Nottingham, University of Cambridge, University of London, University of Strathclyde and University of Stirling.

Examples of studies completed this year include research on shelter effects in agroforestry by Steve Green, on the physiological effects of sulphur-containing compounds found in forage brassicas on sheep by Alan Duncan and the factors regulating the shedding of fibre by cashmere goats by Pamela Lynch. These show the range of subjects investigated and the brief descriptions given below indicate the depth and innovative nature of the research and its value in training future scientists.

Shelter effects in agroforestry

One advantage of agroforestry is the provision of shelter which will benefit the animals and plants. An understanding of the various aspects of the canopy microclimate, such as air flow, is needed to design the optimum agroforestry system. A series of field experiments, wind tunnel experiments and numerical experiments was undertaken to examine and predict the properties of turbulent air flow through a forest of widely spaced trees.

The field experiments were carried out in three stands of 8 m tall Sitka spruce trees (*Picea sitchensis* (Bong.) Carr) at spacings of 4 m, 6 m and 8 m between tree centres. Turbulent statistics associated with the air flow were measured using a vertical array of 3-component propellor anemometers, at heights of between $0.25h$ to $12.5h$, with h being the mean tree height. Mean wind speed in the forest trunk space increased with increasing tree spacing, and was 46% (8 m), 29% (6 m) and 16% (4 m) of mean wind speed in an adjacent, open area. Thermal stability acted to reduce speed turbulence at night by between 10% and 25%. Turbulence events within the widely spaced forest canopies were less extreme than reported elsewhere for closed forest stands.

A wind tunnel experiment was carried out in an open jet wind tunnel at the Civil Engineering Department, Edinburgh University, using 1:75 scale model forest (picture on page 3) made from 20 cm tall bottle-brush elements at spacings of $1/3h$, $1/2h$ and $2/3h$, extending a distance of $10h$ and $20h$ in the downwind dimension. The area densities matched approximately those of the forest study. Turbulence statistics were mapped from extensive measurements obtained using a 3-hot-wire probe. The wind tunnel study was successful in simulating many of the features of canopy flow identified in the field experiment. In addition, the experimental study resulted in a comprehensive set of measurements suitable for testing the predictions from the numerical experiment.

A numerical experiment was carried out in two-dimensions to predict turbulent flow in and above a small forest stand placed in an otherwise undisturbed rural boundary layer flow. The computations were performed using a well-tested fluid dynamics program called PHOENICS. Equations governing the transport of momentum turbulence energy and the turbulence dissipation rate were solved using a standard two-equation turbulence model. The canopy/airflow interactions were modelled using the spatially-averaged conservation equations for mean flow and turbulence kinetic energy. An additional (unconventional) term was included in the model to account for the energy transformation of shear-turbulence to wake-turbulence.

Several computations were carried out to simulate the wind tunnel experiments. Very satisfactory agreement was reached between the predictions and observations of transport of momentum and turbulence energy for a four-fold change in canopy density and a doubling of forest size. Although no full-scale comparisons are made, it is concluded that the model developed from this research is potentially suitable for predicting turbulent air flow in a forest of widely spaced trees.

The physiological effects of sulphur-containing compounds found in forage brassicas on sheep

The growth of sheep fed forage brassica crops is lower than would be predicted from the chemical composition of the crops, which are generally highly digestible and contain moderate concentrations of carbohydrate and protein. The problem has been attributed to low voluntary food intake (VFI) and among potential reasons for this presence, in the herbage, of secondary plant metabolites. The fate and physiological effects of two groups of compounds, the glucosinolates and S-methyl cysteine sulphoxide (SMCO) were studied in a series of *in vivo* and *in vitro* experiments.

The digestive fate of sinigrin, a commonly occurring glucosinolate, was examined by dosing sheep with either sinigrin or its breakdown products, allyl isothiocyanate (AITC) or allyl cyanide (ACN) and analyzing for urinary metabolites of AITC in the urine. Preliminary results indicated that the proportion of sinigrin broken down to AITC *in vivo* was 0.53.

The glucosinolate breakdown products ACN and AITC were continuously infused for 21 days into the rumen of sheep fed either fresh forage rape or dried grass pellets. The VFI of forage rape by ACN-infused sheep (2.4 mmol/d) was reduced, although not significantly, while AITC (2.4 mmol/d) caused no VFI reduction. Neither compound affected VFI when infused (4.8 mmol/d) into sheep fed the dried grass pellet diet. Thyroid hormone concentrations were unaffected by treatment on the dried grass diet but plasma T3 concentrations were reduced by AITC on the forage rape diet.

In a further experiment, three levels of ACN (0, 4.8 and 9.6 mmol/d) were infused intra-ruminally into dried-grass-fed sheep for 63 days. Voluntary food intake was again reduced by treatment and liver damage was indicated by elevated plasma gamma glutamyl transpeptidase (GGTP) concentrations. Clinical indicators of kidney function (plasma creatinine, plasma urea) indicated no renal effects. Hepatic cytochrome oxidase activity was significantly depressed at the highest rate of ACN infusion at the end of the treatment period indicating chronic cyanide toxicity.

Rumen degradation of glucosinolate breakdown products was examined by measuring the stability of ACN and AITC in rumen fluid *in vitro*. ACN was degraded by rumen fluid from cabbage-adapted sheep but not when the donor sheep had been offered dried grass pellets. In a further experiment, rumen fluid samples taken at intervals from sheep consuming cabbage for 30 days had variable ACN- degrading activity with little evidence for a cumulative increase in activity over time.

In a final experiment potential interactions between AITC, ACN (0 or 10 mmol/d) and the rumen product of SMCO, dimethyl disulphide (DMDS) (0 or 25 mmol/d), were studied by dosing sheep with combinations of the compounds for 35 days. Both the glucosinolate breakdown products, AITC and ACN, depressed VFI while DMDS did not affect VFI. Combined administration did not increase the effects of individual compounds.

The dual presence of DMDS and ACN reduced overall effects and this was attributed to changes in metabolic fate of the compounds emphasizing the importance of the composition of the whole diet in determining the ultimate effects of individual constituents.

It was concluded that glucosinolates may depress the VFI of sheep consuming forage brassicas through the release of nitrile and isothiocyanate breakdown products in the rumen. The mechanism of action of nitriles appeared to be via chronic cyanide toxicity while the action of isothiocyanates was not clear though goitrogenic effects did not seem to be important. Rumen detoxification may reduce the toxic potential of glucosinolates. Finally, interactions between the effects of glucosinolates and the haemolytic effects of DMDS did not increase overall physiological effects.

Factors regulating the shedding of fibre by cashmere goats

The seasonal growth of cashmere, with shedding occurring in late winter, constrains opportunities for harvesting the fibre. An understanding of the hormonal factors affecting fibre growth cycles of juvenile and adult goats is a pre-requisite to altering harvesting dates. The seasonal cycle of fibre growth and shedding is entrusted to an annual cycle of changes in photoperiod and these may be associated with changes in circulating concentrations of melatonin and prolactin. A series of experiments was conducted to examine the importance of these hormones in influencing the timing of shedding.

In the first experiment the administration of exogenous melatonin using an implant in December advanced the normal seasonal rise in plasma prolactin concentrations by 6 weeks. This was associated with an earlier onset of shedding of cashmere fibre. This was the first-known report of exogenous melatonin overriding the short-day suppression of prolactin and causing a long-day response, and the advance of the moult suggested that prolactin may be implicated in regulating the timing of the moult in cashmere goats.

This hypothesis was tested in a second experiment in which cashmere goats received one of the following four treatments from December:(1) untreated controls, (2) daily prolactin injections to increase plasma prolactin concentrations, (3) weekly long-acting bromocriptine injections to suppress plasma prolactin concentrations or (4) a combination of treatments (2) and (3). Prolactin treatment advanced the moult and bromocriptine treatment delayed the moult. The combined treatment caused an elevation in plasma prolactin concentrations and an advance in the date of moulting. It was also observed that the cessation of the bromocriptine treatment resulted in a condensed moult compared to the long duration of moulting in control animals.

To investigate this latter phenomenon a further experiment was conducted in which at the cessation of the bromocriptine treatment in mid-March, prolactin injections were given to one group of animals to cause rapid elevation in plasma prolactin concentrations. As in the previous experiment, the bromocriptine treatment resulted in a delay in the onset which was then more rapid in the prolactin-treated animals than in those not given injections of prolactin.

The results show that prolactin appears to have a control role in the moulting of cashmere fibres and has led to research on whether prolactin and epidermal growth factor receptors are present on the fibre follicles and the duration of their activity.

Workshops and seminars

As well as providing training opportunities for students in a number of ways, the Institute is also aware of the need to transfer their expertise and experience to those who may need to use it. The formal methods, such as publishing scientific papers and receiving visitors are augmented by the holding of workshops and seminars. Examples of subjects treated in this way in the current year are the role of Geographical Information Systems in regional and district planning, the management of heather moorland and the application of ultrasonic scanning in animal production. Such courses are often organized by the Institute and sponsored by other bodies.

The many uses of land and diverse changes to which it is subject are becoming increasingly susceptible to public interest and policies, technological advances and economic conditions. Effective responses to these influences require sound scientific understanding for sustainable productive use complementary with protection of the environment and conservation of wildlife.

The Resource Consultancy Unit (RCU) established in April 1991 aims to provide to a wide range of clients, such as Government Departments and Agencies, other Research Establishments, commercial bodies and private individuals, efficient, high quality consultancy research and services relating to the study and management of land resources and the environment. The Unit's consultancy involves both its own staff and co-ordination within MLURI. The suite of sophisticated techniques available to potential customers ranges from the interpretation of aerial photographs to the use of computer software for Geographical Information Systems (GIS), land use modelling and analytical techniques to characterize soil properties and environmental pollutants.

Dr. J.H. Gauld, Head of Resource Consultancy Unit

The scenic quality, environmental diversity, agriculture, forestry and field sports for which Scotland is rightly famed rest on the potential and opportunities offered by the land and its attributes. Of the factors that determine the qualities of the land resource much is now known. Intensively researched at Craigiebuckler for more than half a century, the soils have been mapped and databases of their properties created. Geology, relief, climate and vegetational history, elucidated and recorded by a number of publicly supported and other bodies, greatly influence the distribution and properties of soils and play major roles in determining the capability of the land and character of the environment.

An holistic approach to an integrated understanding of these factors is brought by the staff of the Unit to focus their accumulated experience on the practical needs of land users, environmentalists, planners and policy makers. Responsibility for a number of projects already within the MLURI programme is now being undertaken by the Unit. Some based directly on soil survey, characterization, evaluation and land use monitoring utilize existing skills of staff. Others represent initial stages in the anticipated progressive broadening of interests and extension of data applications.

Soil surveys, often supported by systematic sampling and laboratory analyses, provide a comprehensive appraisal of the areal extent and distribution of particular soil types, their properties and behaviour. The data obtained can be applied to a multitude of purposes ranging from land use management, land appraisal and land use planning. Amongst the many projects previously undertaken and anticipated to continue are preplanting surveys of land to be afforested. Information on physical conditions including depths of peat or mineral soil, permeability to moisture and drainage, and presence of compaction and indurated layers serves to guide ploughing and other ground preparation operations. Soil types and site characteristics relate closely to species choice, growth rate and production. Soils data combined with measures of exposure (topex) allow future projections of tree crop windthrow susceptibility and stability which affect greatly forest management, productivity and financial returns. Analyses of the data by geostatistical techniques give enhanced estimates of hazards and probability of occurrence of potentially damaging events.

Surveys are carried out of proposed mineral extraction and quarry sites, such as for the winning of coal by opencast operations (Figure 1), fireclay extraction and removal of gravel. Land capability assessments and environmental impact analyses give important support to planning applications. Information on topsoils, subsoils and the likely presence in the overburden of materials suitable for topsoils augmentation is used in guiding operations to strip, store and replace soils and in subsequent site and land restoration. Dependent in large measure on soil properties, ground conditions make a major contribution to the planning and execution of operations to install cross-country pipelines and the subsequent measures to be taken for land restoration.

Soils are surveyed also in support of the MLURI core programme of research to establish soil and site characteristics to assist the design and location of plots and to aid interpretation of results. Geostatistical techniques combined with systematic grid surveys give significantly enhanced results on appropriate sites.

Staff of the Resource Consultancy Unit have long experience of land assessments for a variety of purposes. They contributed to the creation and elaboration of the Land Capability for Agriculture system, now adopted for official use by the Scottish Office, and the Land Capability for Forestry guidelines. The combining of data on soils with information about landforms and climate allows assessments to be made of the basic biophysical capability or suitability of land for a range of broad or more specifically defined purposes. Rating land according to its flexibility for use and degree of suitability for arable cropping, improved grassland or stock supported by indigenous vegetation, Land Capability for Agriculture assessments are in continuing demand by a variety of central and local government agencies in relation to building developments, road-making or realignment or other changes of use. Private individuals, land agents, solicitors and others make use of assessments for a wide variety of purposes including planning applications, land sales or purchase, or legal matters. Staff of the Unit provide evidence on land quality to courts of enquiry.

The Unit is also able to provide assessments of environmental risks from soil erosion, grassland poaching, slurry or sewage spreading, heavy metal contamination and acidification by airborne pollutants.

Recreation encompasses many and varied pursuits ranging from the amusement amenities of crowded caravan sites to the solitary appreciation of lonely hill and moorland landscapes. The

Figure 1. A box scraper stripping the topsoil at an opencast coal site. (Photo: SOAFD)

soils and terrain are major contributory elements to the suitability of land to sustain the demands made by such uses. Examples can be cited such as areas suitable for golf-courses, for playing fields or hill walking.

The soils information accumulated through field survey as maps, written records or computer-stored databanks provide a means for rapid economic searches to locate land having defined properties suited to specific uses such as for forest nurseries or carrot growing.

Records of many years of observations, maps and analyses of Scotland's peat deposits made by MLURI are an invaluable resource. Services and advice on the properties of deposits and their suitability for horticultural use, fuel or other purposes can be provided. Information can be given further on the formation and scientific aspects of peat and questions relating to its associated plant commu- nities, wildlife and its value for conservation.

Experience gained by staff during careers in the systematic survey of Scotland's soils is now being applied more diversely. Aerial photographs have long been used, both in the field and in the office, under mirror stereoscopes to aid soil mapping through the recognition of vegetation and landforms and placing of boundaries. Both this familiarity with the use of photo- graphs and knowledge of land conditions regionally throughout Scotland are now being applied to carry out a major commission by the Scottish Office Environment Department. The aim of the project is to compile, through the interpretation of air photos, a comprehensive database of the land cover throughout Scotland to form a baseline against which future or past changes can be measured (Figure 2).

Skills in air photo interpretation, map digitizing and computer analyses are being further applied to the measurement and analysis of land cover change in some selected areas of high public interest. Historical databases provide critical information on the dynamics of rural land use change having application for agencies addressing scientific and political aspects of countryside management. The Unit has recently completed a project in which land cover changes in the Cairngorms have been measured and analyzed by comparing interpretations of air photographs taken in 1945-50 and 1964 with the recent mapping referred to above. It is anticipated that air photographs will be increasingly used to gather information on uses of land and quality of the environment.

Figure 3. Breadalbane ESA, Strath Tay near Aberfeldy. Unimproved grassland in the foregound and a patchwork of broadleaved woodland and improved grassland in the middle distance.

Environmental monitoring (Figure 3) forms a further major part of the duties and activities of the Unit. Biological monitoring of the Environmentally Sensitive Areas (ESAs) is being carried out to ascertain the effectiveness of management prescriptions introduced under the Scheme on aspects of the conservation of wildlife, principally broadleaved woodland regeneration, maintenance of heather moorland and preservation of botanical quality and diversity in general. The monitoring programme has been devised to detect change in features of interest. The methodology chosen has simil- arities with that devised for ESA monitoring by MAFF in England and Wales and the data collection is comprehensive. Transects, randomly sited on features of interest (for example heather moor, grasslands, woodlands) are sampled at 20 m intervals with relocatable sites and quadrats. Quadrat observations encompass detailed recording of sapling and seedling survival and growth, grazing and changes in cover of heather and the monitoring of species diversity of unimproved grasslands, along with soil, site and management data.

The Resource Consultancy Unit is presently deploying staff both in core areas of soil survey, characterization and evaluation and in wider applications to air photograph interpretation, land use change and environmental monitoring. Further extensions in the range of capabilities are being developed and every effort will be directed to making the broad range of scientific techniques, instrumentation and knowledge and understanding in MLURI available to serve the needs of a wider clientele and the general public.

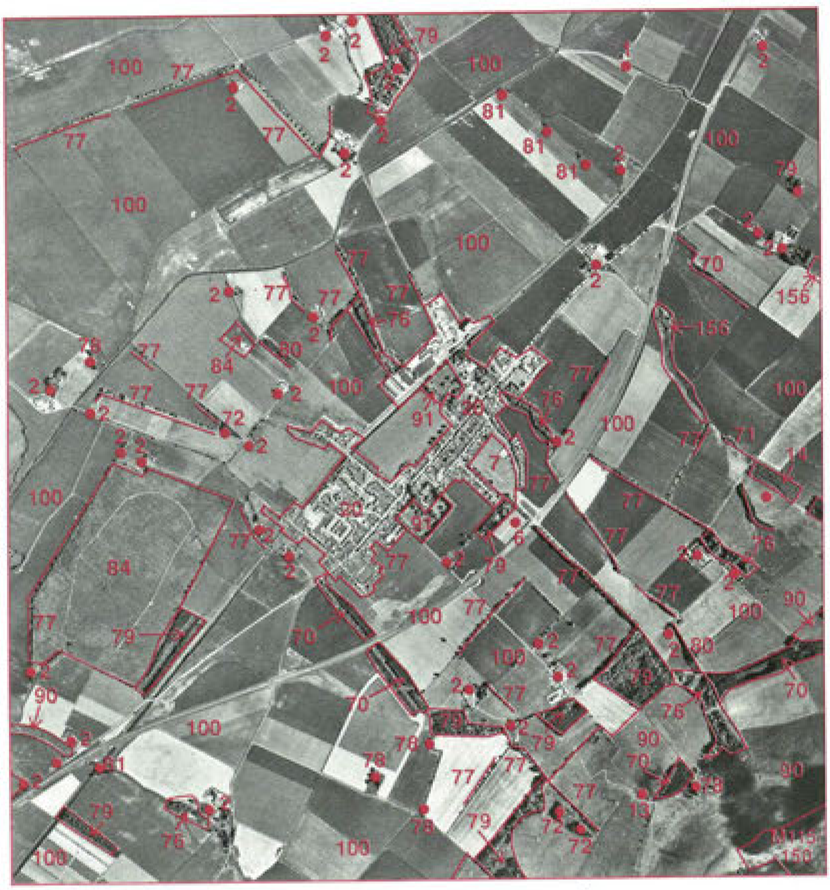

Figure 2. Air photo interpretation of land cover categories around Laurencekirk, Kincardineshire. The main units are: arable land (100), built-up area (20), lines of broadleaved trees (77), blocks of mixed woodland (79) and recently felled woodland (84). Photo: Crown copyright

Highly specialized facilities which are used on a routine basis are provided as a service within the Analytical Division and are operated by staff dedicated to analytical chemistry. Such a system ensures that highly expensive, sophisticated equipment is utilized to its full potential and research staff are available to further the scientific programme of the Institute. In addition, quality control and quality assurance can be monitored closely resulting in a high degree of confidence in the accuracy of the analytical results and in the precision of the various methods in use.

Dr A. Smith, Head of Analytical Division

The techniques available within the Division include mass spectrometry, inductively coupled plasma emission spectroscopy, electron microscopy, atomic absorption spectroscopy, gas chromatography and a range of automatic flow colourimetric systems.

The types of sample which are submitted for analyses have a wide diversity, ranging from a variety of soil types to materials derived from plants, waters, animals, physiological fluids and other biological tissues. The Division carries out the analyses of approximately 100,000 samples annually.

The use of stable isotopes such as ^{13}C and ^{15}N as metabolic tracers in biological studies is dependent on the availability of techniques for estimating small enrichments of these isotopes. Thus gas isotope ratio mass spectrometry is used extensively within the Division in association with combustion systems to convert biological material to a gaseous form. Thermal ionization mass spectrometry is used in support of programmes of research, such as those concerned with heavy metal deposition from the atmosphere, in which highly accurate isotope ratios of metals are required (Figure 1).

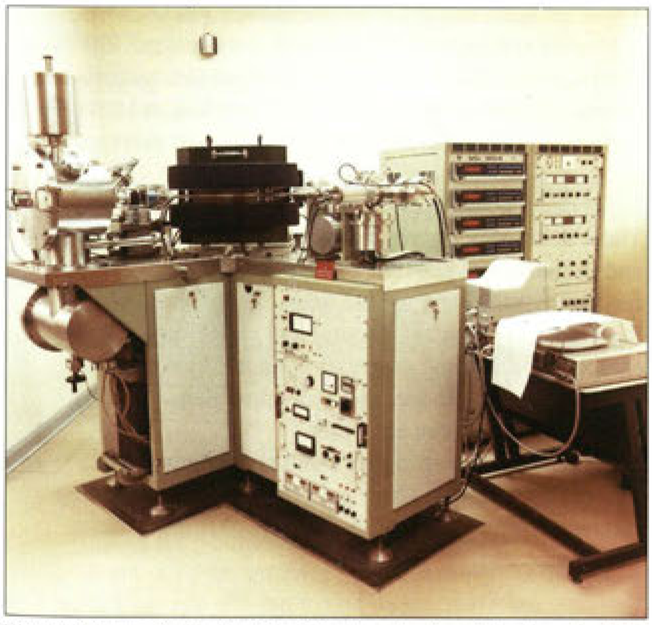

Figure 1. Thermal Ionization Mass Spectrometry is used for the estimation of isotope ratios of inorganic elements present in soils and plants.

Inductively coupled plasma emission spectro- scopy is fully utilized for the analysis of both major and minor inorganic elements (Figure 2). Flame and graphite furnace atomic absorption spectroscopy is also used for elemental analyses.

Figure 2. The concentration of a wide range of inorganic elements is estimated using Inductively Coupled Plasma Emission Spectrometry.

Scanning and transmission electron microscopy is available for detailed structural analyses of soils and other material. In addition to the other techni- ques used for estimating cations, anions and intact organic compounds, the mechanical analyses and physical characterization of soils is also undertaken.

An integral element in the provision of an effective central analytical facility is the require- ment to have a versatile approach to analyses and to organize the work in a cost effective manner. To this end, extensive use is made of a laboratory information management system which enables the traceability of samples at different stages of analysis and enables rigorous quality control and quality assurance procedures to be applied to every analytical test resulting in a high integrity of data.

The analytical facilities allow work to be under- taken for commercial and other sources and this is an area which is actively pursued and expanding.

The Analytical Division incorporates the Technical Services Section which is concerned with the construction and maintenance of scientific equipment as well as with the maintenance of the fabric of the buildings of the Institute.

Glensaugh Research Station

Glensaugh Research Station (above) is situated at the eastern end of the Grampians and adjoins the Fettercairn - Cairn o' Mount road. The altitude ranges from 122 to 456 m and the annual rainfall averages 1040 mm.

Soils

The Highland Boundary Fault divides the research station into two distinct geological areas.

North of the fault the soils are of the Strichen Association developed on drifts derived from schistose rock. The brown forest soils and podzols of the lower slopes give way to peaty podzols and, on the highest ground, to peat.

To the south of the fault the soils are developed on drifts derived from Old Red Sandstone. On Finella Hill, humus-iron podzols dominate the lower slopes and peaty podzols occur at higher elevations.

Land resources

The research station comprises 865 ha rough grazing, 78.3 ha enclosed grassland and 70.5 ha of land reseeded from rough grazings over the last 25 years. On the alluvial soils of the valley bottom the rough grazings are dominated by species-rich *Agrostis-Festuca* grassland. This gives way to species-poor *Agrostis-Festuca* on the lower slopes, with bracken (*Pteridium aquilinum*) also present.

The higher ground comprises dry heather (*Calluna vulgaris*) moor with blaeberry (*Vaccinium myrtillus*), wavy hair grass (*Deschampsia flexuosa*) and bell heather (*Erica cinerea*) locally important, and on the deeper peats of the highest land, crossleaved heather (*Erica tetralix*) and cotton sedge (*Eriophorum vaginatum*) become co-dominant.

Livestock

There are 450 Scottish Blackface ewes, 500 Greyface ewes, 300 crossbred ewes of a range of genotypes and 100 Blue Grey spring-calving suckler cows mated to Charolais and Limousin bulls. There are also 300 breeding red deer hinds and stags with associated 250 Yearlings and calves.

Experimental facilities

There is housing in group pens for 350 sheep/goats/deer and in individual pens for 164 sheep/goats plus ancillary feed preparation and service areas. There are three laboratories (chemical, general and radioisotope) for sample handling and preparation. In addition there are group pens for 150 deer and individual pens for 48 deer/South American camelids.

There is also housing for cows and calves, 500 ewes and 150 red deer calves. There are office facilities, meeting rooms, a mess room and shower for staff and visiting scientists.

Research

Research is conducted on agroforestry, the grazing ecology of semi-natural vegetation and sown swards undergoing extensification, welfare of farmed deer, fibre biology of South American camelids and cashmere goats, and aspects of the pollution and acidification research programmes. There is also an environmental monitoring site.

Hartwood Research Station

Hartwood Research Station (above) which extends to around 360 ha, is located near Shotts in Lanarkshire. It is situated in exposed countryside in an area of upland livestock-rearing farms at an altitude of 150 to 300 m above sea level. The rainfall is 1100 mm.

Soils

The soils are heavy textured, poorly drained gleys of the Rowanhill Series, and are fairly typical of the heavy soils that occur from Stirlingshire to Ayrshire. They contribute significantly to the marginal nature of the farming.

Land resources

The research station has 270 ha of sown grassland, 28 ha permanent pasture, 20 ha of woodland strips, 28 ha of indigenous hill vegetation and 15 ha of forage crops, mainly rape.

Livestock

There are 900 Greyface ewes, 150 Blackface ewes and 210 suckler cows (160 Hereford cross Friesian and 50 Blue Grey), calving in autumn, winter and spring in three herds.

Experimental facilities

There is housing for 60 cows and calves in individual pens for 120 cows and calves in group pens. Sheds accommodate 900 ewes and 180 cows and their calves. There are also facilities for housing up to 50 sheep and 23 cows in individual metabolism pens. Laboratory facilities, including a deep freeze, oven room and sample grinding room, to accommodate and service 10 scientific staff, are in the main building. There is self-catering accommodation for five temporary staff members or students.

Research

Research is conducted on grazing ecology of sown swards, extensification of sown swards grazed by sheep, sheep grazing systems on upland sown swards, short-term tree rotation evaluation, effects of shelter on sheep foraging behaviour, aspects of the ruminant/resource use research programme including complementarity of sheep, cattle and goats grazing, and some externally funded work for feed companies. There is also an environmental monitoring site.

House O'Muir Research Station

House O'Muir Research Station is located on Turnhouse Hill in the Pentlands about 2 miles from Pentlandfield. The land rises from 210 to 456 m and the annual rainfall is about 840 mm.

Soils

The soils on the upper slopes are freely draining brown forest soils of the Sourhope Series developed on drifts derived from rhyolite, trachyte and andesite lavas of Old Red Sandstone age. On the lower slopes, there are imperfectly drained soils of the Biel Series developed on parent materials derived from Carboniferous shales and Old Red Sandstone sediments.

Land resources

The rough grazings on the hill (185 ha) are mainly acid grassland but with some *Nardus*, *Molinia* and heather. In enclosures, there are 32 ha of indigenous *Agrostis-Festuca* grassland, 8 ha of reseeded grassland and 30 ha of permanent grassland.

Livestock

The research station carries 580 Scottish Blackface ewes and about 50 suckler cows.

Research

The facilities are used in relation to the ruminant/resource use, foraging strategies and alternative animals research programmes.

Buildings

Buildings comprise loose housing for 60 cows and 60 goats. There is a 22 stall cattle metabolism unit and a small laboratory and office.

Sourhope Research Station

Sourhope Research Station (above) which extends to 1100 ha, lies 15 miles south of Kelso, near the head of the Bowmont Valley, on the western slopes of Cheviot. The altitude rises from 210 to 608 m and the annual rainfall is around 940 mm.

Soils

The soils are developed on drift locally derived from andesitic lavas of Old Red Sandstone age. Acid brown forest soils characterize the lower slopes, while more acid peaty podzols and peaty gleys occur at higher elevations, with small areas of deep peat on hill summits. Stony skeletal soils are found on steep slopes.

Land resources

Some 20-30% of the 1033 ha of rough grazing vegetation occurs on mainly brown forest soils where *Agrostis* and *Festuca* species predominate with bracken of varying intensity. The remaining rough grazings are grass heaths dominated by *Molinia* (flying bent) or *Nardus* (white bent).

There are 40 ha of rough grazing which have been reseeded with a further 45 ha of enclosed grassland, of which 20 ha is capable of being conserved for hay or silage.

Livestock

Livestock comprises 1200 Scottish Blackface ewes, 1000 North and South Country Cheviot ewes, 50 spring-calving suckler cows and 340 goats for cashmere fibre production.

Buildings

There is inwintering accommodation for 50 cows, 660 ewes and 150 hoggs. Office/laboratory accommodation caters for the scientific staff and visiting scientists. There is self-catering accommodation for nine staff or students.

Research

Research is conducted on the foraging strategy of sheep grazing hill vegetation, fibre biology and genetics of cashmere goats, cattle and goats, extensification of sown swards grazed by sheep, and complementarity of sheep and cattle grazing *Nardus*-dominated swards. There is also an environmental monitoring site.

Rahoy deer farm

Rahoy deer farm (picture on page 71) is 738 ha in extent and lies at the head of Loch Teacuis on the Morvern peninsula in Argyll and ranges in altitude from sea level to 462m. The mean annual rainfall is 2000 mm.

Soils

The soils are chiefly peaty gleys and peaty podzols developed on drifts derived from Moinian schists and gneisses and Mesozoic sediments, with small areas of brown forest soils and humus-iron podzols.

Photo: Highlands and Islands Enterprise

Red deer at Rahoy Research Station, Argyll

Land and livestock resources

The farm at Rahoy comprises 686 ha of rough grazings, 32 ha of improved hill grazings, and 20 ha of arable grassland. The hill vegetation is predominantly *Calluna- Trichophorum* and *Molinia* in the wetter areas, and *Calluna* and *Nardus* communities in the drier areas. On the better soils, *Agrostis, Festuca,* bracken and *Juncus* predominate. All deer stocks originate from Scottish wild red deer. The farm currently carries 783 hinds and calves and 42 stags.

Buildings

The buildings at Rahoy can accomodate 480 weaned calves for the 3-week period from weaning until the store calf sales.

Research

Research is carried out on the performance and management of red deer in a West Highland environment.

Bronydd Mawr Research Centre

Bronydd Mawr Research Centre, which is jointly managed by MLURI and the Institute of Grassland and Environmental Research, is situated between Brecon and Llandovery in Powys, Wales. The area is predominately livestock rearing. The land rises from 250 to 400 m in altitude and the average annual rainfall is 1500 mm.

Soils

The soils are mainly well-drained brown earths overlying Old Red Sandstone.

Land resources

There are 230 ha, most of which have been reseeded over the last 15 years, and which provide a range of permanent pastures with different perennial ryegrass and white clover contents. There is also rough grazing for 542 ewes on an adjoining common and military range.

Livestock

There are 1000 Brecon Cheviot, 750 Beulah Speckleface and 150 Welsh Mule ewes. There is also a spring-calving herd of 60 suckler ewes of Welsh Black and Hereford x Friesian genotypes. Goats from MLURI are also used in rush-control studies.

Buildings

Cattle and sheep sheds for housing 60 cows and 600 ewes respectively in winter are available. There are offices and laboratories for the permanent scientific staff and visiting scientists.

Research

Current research is conducted by MLURI on control of rushes by goats, and detailed studies of the effect of grazing by cattle and sheep on clover development and sequential lamb performance. Sheep production evaluation of new grass and clover varieties and the effect of lower fertilizer inputs and stocking rates is conducted by IGER together with studies of N cycling in grass/clover swards, agroforestry and farm forestry. Research on low input sheep systems based on white clover is conducted jointly by both institutes.

INSTITUTE STAFF

Staff list at 6 August 1991

DIRECTOR'S GROUP

Director	Professor T. Jeff Maxwell, B.Sc., Ph.D.
Assistant Director	Peter Newbould, B.Sc., B.Agr., D.Phil.
Director's Scientific Administrator	Donald W. Futty, B.Sc.
Public Relations Officer	Susan P. Bird, B.Sc., Ph.D.
Director's Group secretaries	Catherine M. Smollet
	Fiona J. Cormack

LAND USE DIVISION

Head — Richard V. Birnie, B.Sc., Ph.D., PGCE
Divisional secretary — Christian T. Garden

1. *Land evaluation and management systems*

Project leader — Alan R. Sibbald (P)

Research objective leaders — Gordon Hudson, B.Sc.
Cathy S. Butcher, B.Sc., M.Sc., M.Phil. (P)
Nick J. Hutchings, B.Sc., Ph.D. (P)
Allan Lilly, B.Sc., M.Sc.
William Towers, B.Sc.

Other staff — Robert D.M. Agnew, L.I. Biol. (P)
Andrew J.I. Dalziel, B.Sc. (P)
Elizabeth V. Deans (P)

Visiting workers — Dong Hong Lin, B.Sc., M.Sc., Ningxia Academy of Agroforestry Sciences, Peoples Republic of China
Dr C. Thampi, University of Calcutta, India

Postgraduate student
Ph.D. — Allan Lilly, B.Sc., M.Sc.

2. *Remote sensing and Geographic Information Systems*

Project leader — Richard V. Birnie, B.Sc., Ph.D., PGCE

Research objective leaders
Richard J. Aspinall, B.Sc., Ph.D.
Gary G. Wright, B.Sc., A.I.Agr.E., M.R.S.Soc., M.I.C.D.Dipl.
Neil A. Brooker, BA, M.Sc.
Alistair N.R. Law, MA, M.Sc., Ph.D.
Keith B. Matthews, MA, M.Sc.
David R. Miller, B.Sc.

Other staff — Jane G. Morrice, MA
Paula L. Whitworth

Visiting worker — Mr P.S.A. Reddy, NBSSLUP Regional Centre, Hebbal, Bangalore, India

Postgraduate student
Ph.D. — David R. Miller, B.Sc.

3. *Socio-Economics*

Project leader — J. Robert Crabtree, B.Sc., Ph.D., M.Phil. (Joint MLURI/SAC)

Research objective leader
Douglas C. Macmillan, B.Sc., MS (USA)

Helen R. Edmond, B.Sc., M.Sc.
Neil Chalmers, B.Sc. (consultant)
Helen McHenry, B.Agr.Sc.

Postgraduate students
Ph.D. — Douglas C. Macmillan, B.Sc., MS (USA)
Helen McHenry, B.Agr. Sc.

4. *Information services/computing*

Project leader — Christopher H. Osman, B.Sc., M.Sc., Ph.D.

Geoffrey A. Reaves, B.Sc., M.B.C.S. (computer manager)
Lindsay Robertson, B.Sc. (database manager)
Alexander D. Moir (cartographic manager)
Linda R. Charnley, M.Sc.
Ian G. Finlayson (P)
Matthew Wells, B.Sc., M.Sc.
Helen Beattie
Susan MacLeay, B.Sc.
Ann Malcolm, B.Sc.
Ruth A. Morrison
Daniel W. Rogers

5. *Resource Consultancy Unit*

Unit Head — James H. Gauld, B.Sc., Ph.D.

John S. Bell, B.Sc.
Alex W. Blyth, B.Sc., BA, M.I. Biol.
Frank T. Dry, B.Sc. (P)
Margaret J. Still, B.Sc., Ph.D

Staff who have left Land Use Division since the last Annual Report

John S. Bibby, B.Sc.
Cyril J. Bown, B.Sc.
Lesley A. Crosher
Sheila A.I. MacDonald, B.Sc.
David Boyd
Steve R. Green, B.Sc., M.Sc.
J. Andrew Hipkin, B.Sc. (P)
Diane Hope, B.Sc., M.Sc.
Steven T. Johnstone, MA
Richard A. Pennington, B.Sc.
Peter Shand, B.Sc., Ph.D.
Beverley Tones, MA
Sally A. Ward, B.Sc., M.Sc.
David J. Henderson, B.Sc.
(transferred to Animals and Grazing Ecology Division)
Andrew J. Nolan, B.Sc.
(transferred to Animals and Grazing Ecology Division)

SOILS AND SOIL MICROBIOLOGY DIVISION

Head — M. Jeffrey Wilson, B.Sc., Ph.D.,D.Sc., FRSE
Divisional secretary — Aileen Stewart

1. *Acidification*

Project leader — M. Jeffrey Wilson, B.Sc., Ph.D., D.Sc., FRSE

Research objective leaders

Hamish A. Anderson, B.Sc., Ph.D.
Derek C. Bain, B.Sc., Ph.D.
Claire Bedrock, B.Sc., Ph.D.
Martin V. Cheshire, B.Sc., Ph.D.
Stephen J. Chapman, B.Sc., Ph.D.
Simon J. Langan, B.Sc., Ph.D.
John D. Miller, LRSC
Robert C. Ferrier, B.Sc., Ph.D.

Other staff

Anthony R. Fraser, LRSC
Donald M.L. Duthie, B.Sc.
Alan Hepburn, C.Chem., MRSC
Moira Stewart
Annette Kelly, HNC
Angela Norrie
Caroline M. Thomson, HNC
Kimberly Wood
Frank Milne

Visiting workers

Vidojko Jovic, University of Belgrade, Yugoslavia
Takashi Watanabe, Joetsu University, Japan

Postgraduate students

M.Sc. — Paola Adamo, University of Aberdeen
Ph.D. — Saman Hetteriatchichi, University of Aberdeen
Ph.D. — Simon Peacock, B.Sc., M.Sc., University of Aberdeen
Ph.D. — Fabio Tateo, Universita di Bologna, Italy

2. *Pollution*

Project leader

Michael L. Berrow, B.Sc., Ph.D., C.Chem., FRSC

Research objective leaders

Martin V. Cheshire, B.Sc., Ph.D.
Edward Paterson, B.Sc.
Jeffrey R. Bacon, B.Sc., Ph.D.
Robert W. Mayes, B.Sc., M.Sc., Ph.D. (P)

Other staff

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Alan Hepburn, C.Chem., MRSC
Irene J. Hewitt, HNC
Raymond Swaffield, LRSC
Carole A. Martin
Angela Norrie
Shona Ritchie
Caroline M. Thomson, HNC
Kimberly Wood

Visiting workers

Cui Zheng Dong, Chinese Academy of Sciences, Beijing
Thomas Forge, University of Minnesota
Sergio Gonzalez, Instituto de Investigaciones Agropecurias, Santiago, Chile

Postgraduate students

Ph.D. — Manas Rajan Banerjee, B.Sc., University of Aberdeen
M.Sc. — Wendy Ko, B.Sc., University of Aberdeen
M.Sc. — Ewan Macpherson, B.Sc., University of Aberdeen

3. *Climate change project*

Project leader — Edward Paterson, B.Sc.

Research objective leader

Stephen J. Chapman, B.Sc., Ph.D.

Other staff

Raymond Swaffield, LRSC
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Angela Norrie
Madeline Thurlow, B.Sc.
Alexander M. MacDonald, B.Sc.

Staff who have left Soils and Soil Microbiology Division since last Annual Report

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John C. Burridge, MA, B.Sc.
John F. Darbyshire, B.Sc., M.Sc., Ph.D.
James D. Russell, B.Sc., C. Chem., FRIC, D.Sc.
Wendy Davidson (transferred to Plants Division)

INSTITUTE STAFF

PLANTS DIVISION

Head — Peter Millard, B.Sc., Ph.D.(acting head)
Divisional secretary — Iona M. Shand

1. *Nutrient assimilation and cycling*

Research objective leaders
David Jones, B.Sc., M.Sc., Ph.D., MI.Biol., FRMS
Alan E.S. Macklon, B.Sc., Ph.D.
Peter Millard, B.Sc., Ph.D.
Derek Vaughan, B.Sc., Ph.D.
Carol A. Marriott, B.Sc. (P)
Lorna A. Dawson, B.Sc., Ph.D.
Mike Proe, B.Sc., Ph.D.
Barry Thornton, B.Sc., Ph.D.

Other staff
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Geoff R. Bolton, B.Sc.,(H)
Jess H. Griffiths, B.Sc., M.Phil. (P)
Brian G. Ord, HNC
Allan Sim, LRSC
Renate Wendler, Dipl. Biol., Ph.D.
Shona M. Pratt, HNC
Eileen J. Reid, HNC
Morag A. Smith B.Sc. (P)
Heather Brunton (P)
Deirdre Craddock, B.Sc., M.Sc.
Sandra Galloway, HNC
Sheila Gibbs
Doris Jones (P)
Mary R. Tyler
John A. M. Anderson

2. *Nutrient availability*

Research objective leaders
Alan E.S. Macklon, B.Sc., Ph.D.
Derek Vaughan, B.Sc., Ph.D.
Charles A. Shand, B.Sc., Ph.D.
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Colin Campbell, B.Sc., Ph.D.
Tony Edwards, B.Sc., Ph.D.
Mike Proe, B.Sc., Ph.D.

Other staff
Jess H. Griffiths, B.Sc., M.Phil. (P)
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Allan Sim, LRSC
Grace Coutts, HNC
Denise R. Donald, LRSC
Shona Smith, HNC
Yvonne E. Cumming, HNC
Wendy Davidson
Julie Sutherland
Miriam E. Young, HNC
David W. Nelson

Postgraduate students
Ph.D.
Peter Anderson, SERC
Anura Dissanayke, Rubber Research Institute, Sri Lanka
James Green, NERC
Elizabeth Lavender, AFRC
Lola Ron Vaz, Spanish Government
Loku Somasiri, Coconut Research Institute, Sri Lanka

M.Phil. — Denise R. Donald, MLURI/Aberdeen University

Staff who have left Plants Division since last Annual Report

Jane Chalmers, B.Sc.
Michael J. Goss, B.Sc., Ph.D.
Albert Patterson

ANIMALS AND GRAZING ECOLOGY DIVISION

Head — John A. Milne, BA, B.Sc., Ph.D. (P)
Divisional secretary — Janet M. Mabon (P)

1. *Vegetation dynamics*

Project leader — Sheila A. Grant, B.Sc., M.Sc. (P)

Research objective leaders
Peter D. Hulme, B.Sc., Ph.D., M.I.Biol.
David J. Henderson, B.Sc.
Carol A. Marriott, B.Sc. (P)
Andrew J. Nolan, B.Sc.

Other staff
G. Titus Barthram, B.Sc. (H)
David E. Suckling, HNC, C.Biol., M.Biol.(P)
Lynne Torvell, B.Sc. (P)
Julia M. Fisher
Evelyn M. Sim (P)
James L. Small (P)

Visiting worker
Maria Sitzia, Centro di Studio Sul Miglioramento Della Produttivita dei Pascoli, Sardinia, Italy

2. *Foraging strategies*

Project leader — Iain J. Gordon, B.Sc., Ph.D. (P)

Research objective leaders
Richard H. Armstrong, B.Sc. (Agric.) (P)
Helen Armstrong, B.Sc., Ph.D. (P)
Alison J. Hester, B.Sc., M.Sc., Ph.D. (P)

Other staff
Murray M. Beattie, HNC, C.Biol., M.Biol. (P)
T. Gordon Common, HNC (S)
E. Robertson, B.Sc. (H)
Gordon J. Baillie, HNC (P)
Iain L. Thomson

Visiting worker — John D. Milne, B.Sc., M.Sc., University of Edinburgh

Postgraduate students
Ph.D. Mariecia D. Fraser, University of Edinburgh
Iain Stevenson, University of Cambridge

3. *Physiology and nutritional ecology*

Project leader Glenn R. Iason, B.Sc., Ph.D. (P)

Research objective leaders
Alan J. Duncan, B.Sc., M.Sc., Ph.D. (P)
Angela M. Sibbald, BA (P)
David A. Sim, HNC (P)
Inge Bristow, B.Sc. (G)
Elaine Foreman (P)

Postgraduate students
Ph.D.
Iain Hulbert, B.Sc., University of Aberdeen
Anna Murray, B.Sc., University of Aberdeen

4. *Energetics and seasonal biology*

Project leader John A. Milne, BA, B.Sc., Ph.D. (P)

Research objective leaders
Stewart M. Rhind, B.Sc., Ph.D. (P)
Robert W. Mayes, B.Sc., M.Sc., Ph.D. (P)
Donald B. McPhail, B.Sc.
Peter D. Fenn, B.Sc., Ph.D. (P)
Pamela Lynch, B.Sc. (P)

Other staff
Patricia Colgrove, HND (P)
C. Stuart Lamb, B.Sc. (Agric.) (P)
Stuart R. McMillen, HNC (P)
Hazel Eayres, B.Sc. (P)

Postgraduate students
Ph.D. Luis Andrade, B.Sc., M.Sc., University of Edinburgh
Matthew Hayden, B.Sc., University of London
Katherine Pritchard, B.Sc., University of Nottingham

5. *Ruminant resource use*

Project leader Iain A. Wright, B.Sc., Ph.D. (P)

Research objective leader Claire Howard, B.Sc., Ph.D. (P)

Other staff Thomas K. Whyte, HNC, SDA (H)
Alison Smith, HNC (P)

Visiting worker Gete de Rosa, D. Vet. Med., Universidade Federal de Mato Grosso do Sul, Campo Grande, Brasil

Postgraduate student
Ph.D. Manuel del Pozo Ramos, University of Edinburgh

6. *Alternative animals*

Project leader Angus J.F. Russel, B.Sc., M.Sc., Ph.D. (P)

Research objective leaders
Peter J. Goddard, B.Vet. Med., Ph.D., MRCVS (P)
William J. Hamilton, BA, NDA, NDD, C.Biol., M.Biol. (G)
Margaret Merchant, B.Sc., Ph.D. (P)

Other staff
A. Robson Fawcett, AIMLS (P)
Alastair J. MacDonald, SDA, NDA (P)
Carol A. Soames, NDD (G)
Hilary Redden, B.Sc. (P)
David J. Riach (P)
Gavin A.M. Bryce (P)
John Leary (P)
Margaret Milne (P)
Jessie W. Brockie (P)

Visiting workers Carmen Olivan, University of Edinburgh

Postgraduate student
M.Sc.
Silvana Divero, University of Edinburgh
Shejana Alexieva, Institute of Animal Sciences Rostinbrod, Bulgaria
Jane C. Wheeler, BA, Ph.D., University of Colorado, USA

Staff who have left Animals and Grazing Ecology Division Division since the last Annual Report

Colin C. Evans
Wesley G. Kerr
Alastair D.M. Smith
Fraser J.G. Mitchell
Carol A. Salt
Elisabeth A. Thrower

ANALYTICAL DIVISION

Head Alistair Smith, B.Sc., Ph.D., C.Chem., FRSC
Divisional secretary Lynda M. Keddie

1. *Inorganic element analysis*
Albert C. Birnie, M.Sc., C.Chem., MRSC
John Mackenzie, HNC (P)
Eileen Smith, HNC (P)
Alison Stewart
Janette R. Strachan, HNC
Thelma Robertson

2. *Mass spectrometry* Jeff R. Bacon, B.Sc., Ph.D.
Jennifer J. Harthill, HNC
Arlene M. Taylor

3. *Soil analyses* Basil F.L. Smith, B.Sc., M.Sc., C.Chem., MRSC
Shirley S. Stout, LRSC
Martin Davidson
June McAdam

4. *Electron microscopy* Bill J. McHardy, B.Sc., Ph.D.
Sheila Young

5. *Radiochemistry* Harry Shepherd, LRSC

6. *Colourimetric analyses and chromatography* Ed Skedd (P)
Pat E. Moberly, B.Sc. (P)
Susan M. McIntyre, HNC

Tricia M. Reid, HNC
Lynn M. Clark, HNC
Kathleen Davidson
Michelle G. Hutchison (P)
Carrie Batty (P)

7. Technical services
Bert W. Stuart, HNC
Graham J. Gaskin, HNC
James S. Anderson
Gordon J. Ewen, HNC
Tony H. Phillips, B.Sc. (P)
Allan I.A. Wilson, HNC
David Clark, HNC
Jim Steinson

Staff who have left Analytical Division Division since the last Annual Report
Barry Sharp, B.Sc., Ph.D., DIC, C.Chem., FRSC
Gillian N. Galbraith, HNC (P)
Laura C. Goodwin, HNC
Margaret C. Mitchell
Barbara G. Rennie

RESEARCH STATIONS DIVISION

Head — Professor T. Jeff Maxwell, B.Sc., Ph.D.

Glensaugh

Head — John A. Milne, BA, B.Sc., Ph.D.

1. Farm resources
Officer-in-charge — David L. Nelson, B.Sc. (Agric.)
Jessie P. Black (cleaner)
John W. Black (Snr.) (grieve)
John W. Black (Jnr.) (tractorman)
John Ferguson (general farm worker)
Pamela Tapson (shepherd)
Norman McEwan (head shepherd)

2. Red deer
Officer-in-charge
William J. Hamilton, BA, NDA, NDD, C.Biol., M.Biol.
David J. Kyle (stockman)
Callum Thomson (stockman)
Lynne Thomson (recording officer)

3. Animal house
Officer-in-charge — A. Robson Fawcett, AIMLS

Hartwood

Officer-in-charge — George K.D. Corsar, B.Sc., M.S.
Administrative assistant — Sandra Denham

Staff
Ian Boustead (grieve)
James Farley (tractorman)
Robert Graham (head stockman-cattle)
Harry Habblett (head shepherd)
Robbie A. Hetherington, B.Sc. (Agr.) (cattle manager)
Paul Leonard (stockworker-cattle)
N. Neil Macaulay (tractor foreman)
Jim MacDonald, B.Sc. (stockworker-sheep)
Robert Shaw (general worker)
Lucy Wilson (stockworker-general)
Betty Farley (cleaner)
Debra MacDonald (cleaner)

House O' Muir

Officer-in-charge — A. Robson Fawcett, AIMLS

Staff
Robert Smith (managing shepherd)
James Smith (stockman/tractorman)
Hunter Smith (casual shepherd)
Isabella D. Smith (cleaner)

Sourhope

Officer-in-charge — Harry M.Sangster, B.Sc., Dip. FBOM

Staff
Geoffrey D. Gittus (deputy officer-in-charge)
John Wallace (head shepherd)
Charles M. Grant (shepherd)
T. Gavin Rogerson, Dip.FBOM (goats)
John A. McGlen (shepherd)
James Pringle
Patricia Gentry (recording officer)
Dorothy H. Wallace (cleaner)

Staff who have left Research Stations Division since the last Annual Report
James Davidson (G)
A. John Senior (G)
David Fleming (H)
Lilian Thomson (H)
David A. Henderson (H)
Colin Blackie (S)
June Gilfillan (S)
Robert Gilfillan (S)
Charles Grant (S)
Alexander S. Mathers (S)
John Rowe (S)

ADMINISTRATION DIVISION

Institute Secretary — Robert B. Devine, D.P.A., M.B.I.M.
Institute Deputy Secretary — Marie Milne
Secretary — Eileen J. Cockburn

Site Secretary (Pentlandfield) — Irene C.R. Anthony (P)

Financial and general administration
Christina M.R. Burness
Murray G.C. Mainland

Catherine Adams
Elaine Boyle
Elizabeth Kyle (P)
Janice M. Laing
Jacqueline S. Wales
Nicola G. Paterson

Secretaries/typists

Christian T. Garden
Janet P. Mabon (P)
Iona M. Shand
Ann R. Kenmure (P)
Caroline Rafferty (P)
Audrey Sinclair (P)
Carol A. Smith
Aileen Stewart

Telephonists

Roberta M. Simpson
Ann Calder (P)
Dorothy C. Millar (P)

Stores

Irene Hunter (P)
Lynne Thomson

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Anne L. Meekums
Lesley Taylor, BA
Marian Smith

Publications and Graphics

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Patricia R. Carnegie
Caroline C. Milne
David Riley
Colin Haggarty (P)

Ancillary staff

Cleaners

Sheila Angus
Hilary Cassidy (P)
Anne Conway (P)
Dorothy Gall
Elsie M. Gardiner
Margaret Kindness
Joyce McAllan
Jean McBeth (P)
Doris M. McCombie
Vilma Main
Hazel A. Mutch
Agnes M. Rennie
Linda Robertson (P)
Elizabeth M. Strachan
Margaret A. Walker
Margaret H.H. Young (P)

Outdoor staff

Brian N. Kemp (head groundsman)
Graham A.S. Davie (groundsman)
John S. West (groundsman)
David Burnie (part time gardener) (P)

Security staff

William Arnott (P)
Fred Brand
James Cherrie (P)
John R. Ewen
Walter J. Milligan (P)
William L.W. Ross
Alexander Stewart
Wilfred F. Wallace

Others

James Robertson
Harold Thompson (P)
David Allison (P)
Robert Johnston (P)

Staff who have leftAdministration Division
since last Annual Report

Anne Christie (P)
Aileen Glennie
Yvonne Irving
Desmond Miller
E. Ann Piggott
Ian R. Pitkethly (P)
Charles S. Robertson
Helen Tulloch (P)
Elinor I. Wallace
Frank Ward (P)

SASS STAFF SERVING MLURI

Head

Michael F. Franklin, B.Sc., M.Sc., PhD.

Staff

Stephen T. Buckland, B.Sc., M.Sc., Ph.D.
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HONORARY RESEARCH ASSOCIATE

Professor H.G. Miller, B.Sc., Ph.D., D.Sc., FI (For.)

PROGRAMME UNIT 11

Land use options and impacts on natural and human resources

011148 Develop and test land use suitability models (G.Hudson)

011150 Assessment procedures in wide area conservation evaluation (R.J.Aspinall)

011013 Field testing of low input upland sheep systems (A.R.Sibbald)

011803 Field testing of upland beef cow systems (I.A.Wright)

011151 Modelling and field testing of silvopastoral systems (A.R.Sibbald)

011152 Modelling upland sheep systems (N.J.Hutchings)

011153 Decision-support models for assessing land use options at the farm level (C.S.Butcher)

011155 Economic effects of land conversion to forestry from agriculture with special reference to environmental effects and development of multi-objective forestry policies at regional and national levels (D.C.Macmillan)

011146 The extent and significance of pluriactivity in Scottish agriculture (H.Edmond) [JAEP]

011156 Economic models in land use planning and policy development (J.R.Crabtree)

011157 Use of GIS techniques with process-based environmental assessment procedures for water quality modelling (D.R.Miller)

011158 Identify economic effects of acid deposition on water catchments in Scotland with special reference to land use change to forestry (D.C.Macmillan)

011159 Land suitability/risk assessment in relation to the disposal of wastes rich in heavy metals (W.Towers)

011847 Development of a GIS-based screening procedure for assessing the potential effects of climate change on Scottish agriculture (K.B.Matthews) [SOAFD Flexible Funding]

011160 To model effects of rainfall variability on soil water regimes (A.Lilly)

011161 Relationships between changes in agricultural intensity and land use on the nitrate and phosphate loadings of Scottish river systems (G.G.Wright)

011162 Application of remote sensing to land use change and agricultural statistics: towards a strategic European Advanced Agricultural Information System (G.G.Wright)

011163 Development of the Macaulay Land Use Information and Modelling System [MLUIMS] (C.Osman)

011164 Use of knowledge-based systems and geostatistical techniques in land use modelling procedures (A.N.R.Law)

011236 Integration of land cover and ecological information from MLURI and ITE surveys to provide an enhanced and co-ordinated land cover database for Scotland (N.A.Brooker) [SOAFD Flexible Funding]

PROGRAMME UNIT 12

Soil and the environment

012165 Determine environmental changes at a series of long-term monitoring sites (J.D.Miller)

012166 Quantify the principal hydrological and hydrochemical consequences of forestry, in relation to soil type, atmospheric inputs and management practices (J.D.Miller)

012167 Quantify sources and sinks of acidity under selected hill land uses, and their effects on water quality and quantity (H.A.Anderson)

012168 Retention and release of sulphur in upland soils by biological and other mechanisms (S.J.Chapman)

012169 Factors controlling the dynamics of organic matter decomposition in soil releasing organic acids and plant nutrients (M.V.Cheshire)

012170 Aluminium dynamics in acid-sensitive catchments

012171 Mineral weathering in relation to the vulnerability of catchments to acidification in Southern Scotland (D.C.Bain)

012172 Assess the critical loads of acid deposition on soils and determine the distribution of acid-sensitive waters in Scotland (M.J.Wilson)

012173 Water resource modelling; the effect of land use change and atmospheric deposition (R.C.Ferrier)

012174 Assess the retention of heavy metals and major nutrients following sewage sludge application to acid soils (M.L.Berrow)

012175 Characterize amounts, sources and fate of heavy metals deposited from the atmosphere on Scottish soils and taken up in the food chain (J.R.Bacon)

012176 Determine the effects of heavy metal pollution on microbial activity, including mycorrhizas, in forest soils

012177 Investigate interactions between heavy metals and the fine-grained constituents of mineral soils (E.Paterson)

012178 Effect of organic matter of soil on the cycling of radiocaesium and its availability to various upland plant species (M.V.Cheshire)

012179 Effect of diet quality, age and genotype on radiocaesium transfers in grazing sheep (R.W.Mayes)

012180 Investigate the nature and ion-exchange properties of hill and upland soils (E.Paterson)

012139 Climate change (increasing temperature and altered precipitation) and CO_2/CH_4 release from the organic matter of soils and peats (S.J.Chapman) [SOAFD Flexible Funding]

012181 Soil response to climate change (E.Paterson) [SOAFD Flexible Funding]

012258 Upgrading of long-term monitoring sites (M.J. Wilson) [SOAFD Flexible Funding]

PROGRAMME UNIT 13

Plant-soil relations

013182 Mineral nutrition and assimilate partitioning in trees, including consequences of coppicing. (M.F.Proe) [Central Scotland Countryside Trust/SOAFD]

013183 Effects of water and nutrient stress on root demography, architecture and turnover in deciduous trees (L.A.Dawson)

013184 Influence of management practices on the quality and quantity of root exudates produced by Sitka spruce, larch and sycamore (D.Vaughan)

013185 Effect of root exudate components on the ecology of specific soil microbial populations. (D.Jones)

013186 Analysis of the effects of climate change on tree crops in Scotland using indicator species (S.Allison) [SOAFD Flexible Funding]

013187 Consequences of atmospheric nitrogen fixation on internal nutrient cycling and growth partitioning of woody legumes (B.Thornton)

013188 The effects of grazing animals on partitioning and internal cycling of nutrients and the consequences for vegetation dynamics (C.A.Marriott)

013189 Seasonal internal cycling of nitrogen in evergreen and deciduous trees and the consequences for nutrient use efficiency (P.Millard)

013190 Leaf surface exchange of atmospheric inputs acting as pollutants or potential nutrients and their interactions with internal cycling and growth potential of trees (A.E.S.Macklon)

013191 Seasonal nutrient storage in evergreen and deciduous trees in relation to nutrient supply, leaf and root demography (P.Millard)

013192 Soil physical conditions and effects on activities of microbial populations. (B.L.Williams)

013194 Organic matter turnover in upland soils and its relationship with N and P transformations and availability to plants. (B.L.Williams)

013195 Influence of tree species on the release of cations to roots and on the activity of soil enzymes indicative of changes in the microbial biomass. (D.Vaughan)

013196 Dynamics of phosphorus depletion and repletion, and forms in soil solution in relation to plant growth (C.A.Shand)

013846 Dynamics of phosphorus forms in organic soils and utilization by clover (C.Bedrock) [IFS]

013197 Availability of nutrients, particularly phosphorus, in acid soils with a high organic matter content (A.C.Edwards)

013198 Influence of soil phosphorus dynamics and interactions with iron, manganese and aluminium on uptake, exchange and assimilation of phosphorus by *Agrostis tenuis* and *Lolium perenne* (A.E.S.Macklon)

013199 Factors affecting nutrient source/sink relations on second-rotation forest sites (M.F.Proe) [Forestry Commission/SOAFD]

013200 Root competition between trees and grasses for nutrients and water (C.D.Campbell)

013256 A study of leaf senescence using Nuclear Magnetic Resonance Spectroscopy (P.Millard) [SOAFD Flexible Funding]

PROGRAMME UNIT 14

Plant-animal relations

014201 The effect of grazing by species of ruminant on diet composition and proportion of *Nardus* in acid grassland (S.A.Grant)

014202 The effect of cattle grazing on the floristic composition and nutritive value of *Molinia* grassland (S.A.Grant)

014203 The effect of grazing by sheep on floristics, plant growth and diet composition from species-poor *Agrostis-Festuca* grassland (P.D.Hulme)

014204 Approaches to aiding the rehabilitation of degraded heather stands (P.D.Hulme)

014205 Interactions between burning and grazing by sheep on floristic change in different variants of Atlantic heather moor (A.J.Nolan)

014206 Phenology and morphology of ryegrass and white clover over a sub-optimal soil type under grazing by sheep (S.A.Grant)

014207 The development of spatial heterogeneity and the persistence of white clover in swards grazed by sheep (C.A.Marriott)

014208 Changes in floristic composition, diet selection and soil nutrients of grazed sown swards under nutritional stress (C.A.Marriott)

014209 Develop and test foraging strategy theories for ruminants grazing mixed indigenous hill vegetation (I.J.Gordon)

014142 The influence of vegetation pattern on the foraging strategy, plant dynamics and population ecology of sheep and deer (I.J.Gordon) [SOAFD Flexible Funding/ JAEP]

014210 Assessment of diet composition and behaviour of ruminants grazing indigenous hill vegetation (R.W.Mayes)

014211 Effect of sward composition and structure on sward growth rate and ingestive behaviour of herbivores in the autumn (R.H.Armstrong)

014212 Grazing strategies with goats to reduce the vigour of weed species in sown swards (M.Merchant)

014213 Intake, grazing behaviour and performance of goats grazing sown swards (M.Merchant)

014214 Diet selection by lambs in ryegrass/white clover swards differing in the distribution of clover in the sward (R.H.Armstrong)

014215 Grazing preferences by lambs for forage brassicas in the winter (R.H.Armstrong)

014120 Modelling the agricultural and environmental consequences of sheep and red deer grazing heather moorland (H.Armstrong) [IFS]

014216 Diet selection and intake by camelids and goats grazing indigenous hill plant communities (I.J.Gordon)

014143 Factors influencing the selection of individual plants within species by herbivores (G.R.Iason) [SOAFD Flexible Funding/JAEP]

014217 Prediction of herbage intake by grazing sheep from a study of physiological factors (A.M.Sibbald)

014218 Mode of action of S-containing compounds in brassicas in influencing intake, digestion and metabolism by ruminants (D.B.McPhail)

014219 Physiological factors influencing diet selection by sheep (I.J. Gordon)

014220 The nature and extent of herbivore adaptation to ingestion of plant secondary compounds (G.R.Iason)

014221 Energetic constraints on grazing sheep : their impact on foraging behaviour and shelter-seeking (G.R.Iason)

014257 Artificial intelligence modelling of foraging strategy (I.J. Gordon) [SOAFD Flexible Funding]

PROGRAMME UNIT 15

Ecology of grazing ruminants and resource utilization

015222 Effect of shelter on grazing behaviour, nutrient intake, energy expenditure and welfare of sheep in farm forestry systems (P.D.Fenn)

015223 Measurement of energy expenditure in grazing sheep (R.W.Mayes)

015224 Seasonal cycles of deer in relation to nutrient supply (S.M.Rhind)

015225 Hormone manipulation of seasonal coat growth in cashmere goats (S.M. Rhind)

015141 The role of the follicle in the control of the growth and shedding of animal fibres (P.Lynch) [SOAFD Flexible Funding]

015226 Fibre growth and energy expenditure of cashmere goats following harvesting of fibre (M.Merchant)

015227 The complementarity of sheep and cattle grazing indigenous hill vegetation (I.A.Wright) [EEC]

015228 The complementarity of sheep, cattle and goats through the sequential grazing of sown swards (I.A.Wright)

015229 Effects of grazing management strategies on cattle performance and floristic composition in *Nardus*-dominated swards (I.A.Wright)

015230 Effects of genetically derived increased prolificacy on production efficiency and welfare in different nutritional environments (A.J.F.Russel)

015231 Effects of size of dam and litter size of sheep on their efficiency of resource use and their welfare (I.A.Wright)

015100 Effect of nutrient partitioning on the efficiency of resource use by beef cows of different genotypes (I.A.Wright)

015098 Effect of body composition, nutrient intake on post-partum ovarian follicle activity and endocrine control in beef cows (S.M.Rhind)

015232 Cashmere production from goats and its improvement by crossbreeding and selection (A.J.F.Russel)

015233 Growth and carcass composition of dual-purpose goats used for cashmere and meat production (M.Merchant)

015234 Fibre production and characteristics of fibre from camelids in upland environments (A.J.F.Russel)

015235 The characterization of animal fibres according to their cellular structure (A.J.F.Russel)

015138 Welfare aspects of the catching of wild deer for use in deer farming (P.J.Goddard)

015101 Performance of red deer in extensive and large scale management systems (W.J.Hamilton)

015102 Assessment of the lifetime performance of red deer hinds (W.J.Hamilton)

015103 Development of hybrids between exotic deer and red deer and assessment of their potential for deer production (J.A.Milne)

015259 Behavioural stress and immuno-competence in farmed deer (J.A. Milne) [SOAFD Flexible Funding]

PROGRAMME UNIT 09, EXTERNAL CONTRACTS

Land Use Division / Resource Consultancy Unit

090838 Soil properties and land use in relation to peat and mineral extraction (J.H.Gauld) [SOAFD-Lands, British Coal]

090111 Interpretation of air photographs and development of a database expressing land cover types in Scotland (R.V.Birnie) [SOEnD/SOAFD]

090145 The measurement and analysis of land cover changes in the Cairngorms and Central Scotland with respect to interactions between agriculture, forestry, conservation and the impact of development policy (J.H. Gauld) [SOEnD/SOAFD Contract, Flexible Fund, RCU]

090254 Evaluation of land capability for agriculture, forestry or other uses (J.H.Gauld)

090255 To characterize the soils, vegetation and physical attributes of the Scottish Environmentally Sensitive Areas and monitor their response to management schemes (J.H.Gauld) [SOAFD RCU]

090261 The extent and significance of pluriactivity in Scottish agriculture (H.Edmond) [JAEP]

090264 Greenbelt Company (C. Osman)

090266 Soil Surveys of ITE sample 1km grid squares (J.H. Gauld)

090260 Peat as Fuel (R.V.Birnie) [ETSU EEC]

090269 Commercial contracts - [Miscellaneous]

Soils and Soil Microbiology Division

090250 Critical loads of acid deposition on soils and assessment of the distribution of acid-sensitive waters in Scotland (M.J.Wilson) [SOEnD]

090252 Commercial contracts - [Misc] Clay mineral analysis of soils and rocks (D.M.L.Duthie)

090253 Monitoring acidified catchments in Galloway (R.C.Ferrier) [SOEnD]

090147 Biological cycling of pollutant sulphur in organic soils (H.A.Anderson) [EEC/ENCORE/STEP]

090249 Mineral weathering in relation to the acid neutralizing capacity of acid-sensitive catchments (M.J.Wilson) [EEC/ENCORE/STEP]

090251 Certified Reference Materials: Trace and Heavy Metal Analysis - BCR Organization (M.L.Berrow) [CEC]

090262 British Council, Spain (M.J. Wilson)

090265 Natural History Museum (T. Forge)

090274 British Council, Yugoslavia (M.J.Wilson)

Plants Division

090129 Factors affecting nutrient source/sink relations during the establishment of second-rotation tree plantations (M.F.Proe) [Forestry Commission]

090247 Internal cycling of nitrogen in deciduous and evergreen forest trees (P.Millard) [EEC]

090248 Biogeochemical cycling in agroforestry systems (P.Newbould) [EEC]

090263 Soil physical measurements, Portugal (M.Goss) [NATO]

090267 The leaf demography and internal cycling of nitrogen in forest trees (P. Millard) [British Council, Spain]

090268 Modelling the growth and internal cycling of N within deciduous trees (P. Millard) [British Council, France]

090840 Assess the effects of agroforestry on soil condition and nutrient losses (P.Newbould) [EEC Funded]

090270 Commercial contracts [Miscellaneous]

Animals and Grazing Ecology Division

090119 The effect of controlled grazing on vegetation and tree regeneration in broad-leaved woodland (continuation) (A.J.Hester) [NCC]

090130 The application of reproductive technology to the Deer Farming Industry (P.J.Goddard) [MAFF/Institute of Zoology]

090132 Factors influencing the selection of individual plants within species by herbivores (G.R.Iason) [JAEP cognate with RO 042143]

090133 Advisory and development support for HIDB deer farming (W.J.Hamilton) [HIDB]

090134 The influence of vegetation pattern on the distribution and foraging strategies of hill sheep and red deer and consequential effects on vegetation community dynamics (I.J.Gordon) [JAEP cognate with RO 042142]

090135 Effect of body size and vegetation structure on functional responses and foraging choices in mammalian herbivores (I.J.Gordon) [NERC/University of Edinburgh]

090136 Fat cover in live animals - instrumentation (A.J.F.Russel) [SDA]

090137 The feeding behaviour of wild vertebrates in relation to the glucosinolate and SMCO content of oilseed rape (A.M.Sibbald) [MAFF/SCRI/Game Conservancy]

090237 Fibre testing and analysis (A.J.F.Russel) [Misc]

090238 Ultra scanning training (A.J.F.Russel) [Misc]

090239 Deer farming consultancy (W.J.Hamilton) [SAC]

090241 The substitution rates of sugar beet pulp and barley-based supplements fed with silage to pregnant ewes (J.A.Milne) [Trident Feeds]

EXTERNAL CONTRACTS

090242 Development of a method to rapidly predict the availability of radiocaesium in ruminants (R.W.Mayes) [ITE]

090243 N-alkane determinations (J.A.Milne) [SAC]

090244 Hill land use and lagomorph ecology (G.R.Iason) [Forestry Commission]

090245 Studies of the transfer of $^{S}35$ to milk (R.W.Mayes) [ITE/Nuclear Electric]

090240 Factors affecting radiocaesium transfer to ruminants (R.W.Mayes) [EEC]

090246 Development of mixed grazing systems of animal production for the management of semi-natural vegetation to protect the rural environment in sparsely populated areas (I.A.Wright) [EEC]

090273 Diversification by deer farming through improving efficiency of production, welfare and the development of new marketing strategies (J.A. Milne) [EEC]

090271 Commercial contracts [Miscellaneous]

Analytical Division

090272 Commercial contracts [Miscellaneous]

Photo: The Scottish Picture Library, Strathpeffer, Hugh Webster

Native Pine Forest, Ryvoan Nature Reserve

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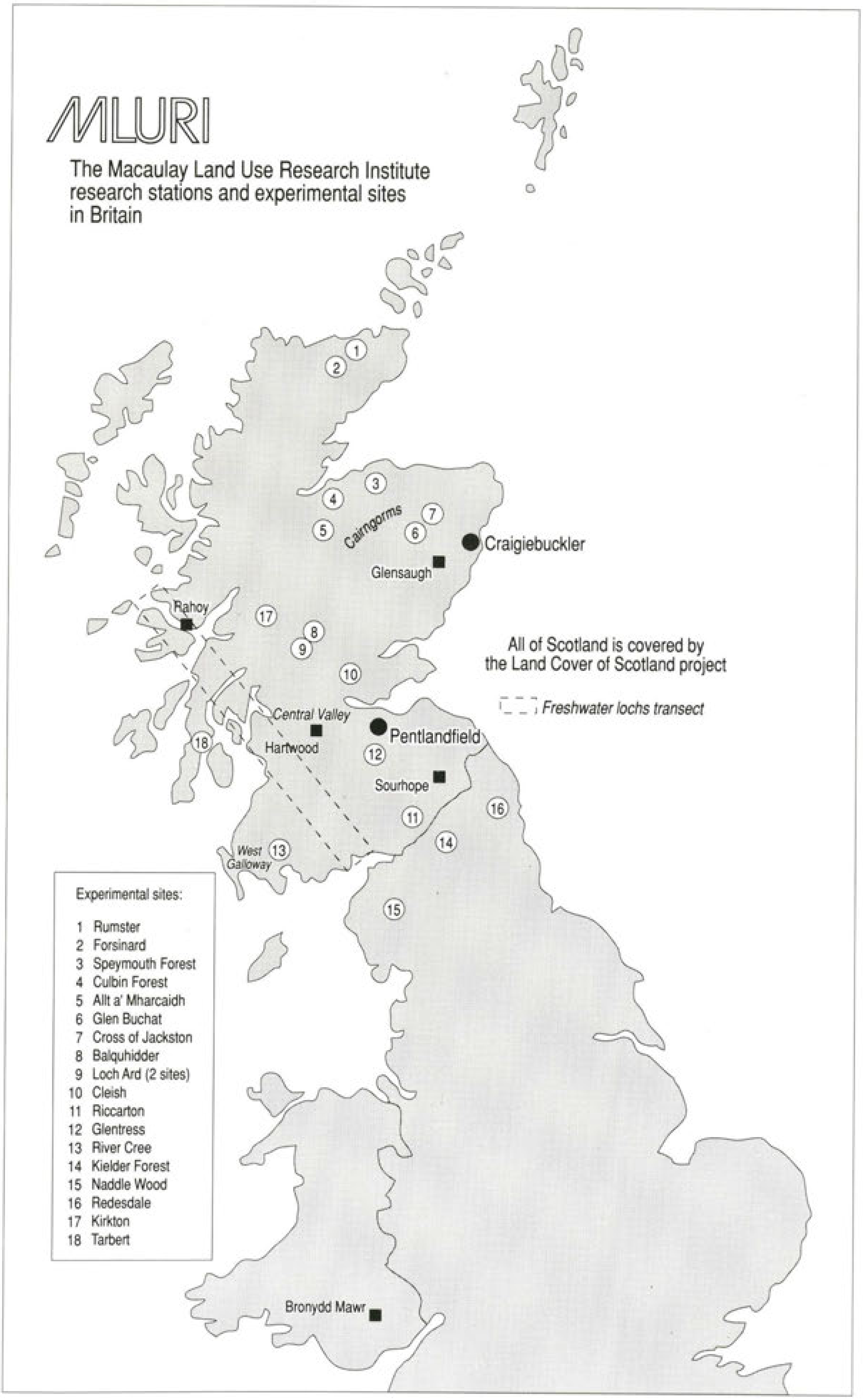
A Scottish cashmere goat developed and bred at Sourhope Research Station


MLURI
The Macaulay Land Use Research Institute research stations and experimental sites in Britain
Craigiebuckler
Glensaugh
Cairngorms
Rahoy
Central Valley
Hartwood
Pentlandfield
Sourhope
West Galloway
Bronydd Mawr
All of Scotland is covered by the Land Cover of Scotland project
Freshwater lochs transect
Experimental sites:
1 Rumster
2 Forsinard
3 Speymouth Forest
4 Culbin Forest
5 Allt a' Mharcaidh
6 Glen Buchat
7 Cross of Jackston
8 Balquhidder
9 Loch Ard (2 sites)
10 Cleish
11 Riccarton
12 Glentress
13 River Cree
14 Kielder Forest
15 Naddle Wood
16 Redesdale
17 Kirkton
18 Tarbert