MACAULAY LAND USE RESEARCH INSTITUTE

Annual Report 1987

Craigiebuckler Aberdeen and Bush Estate Penicuik

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

THE MACAULAY LAND USE RESEARCH INSTITUTE
Craigiebuckler, Aberdeen AB9 2QJ, Telephone (0224) 318611
Telex 733847. Fax (0224) 311556
Bush Estate, Penicuik EH26 0PY, Telephone (031) 445 3401
Fax (031) 445 4035

Scientific Editors, Dr D. Atkinson, Dr J. A. Milne, Dr P. Newbould
Technical Editors, Ms F.J. Cormack, Ms M. Alcock, Mrs A. Dickie
Designer, W. S. Shirreffs
Graphics and Photography, I. R. Pitkethly, D. Riley, W. S. Shirreffs
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INTRODUCTION

The Macaulay Land Use Research Institute (MLURI) came into being on 1st April 1987 by a merging of the former Macaulay Institute for Soil Research (MISR) with the Hill Farming Research Organisation (HFRO). The intention behind the merger, as stated in the Department of Agriculture and Fisheries for Scotland (DAFS) 1985 paper, 'Strategy for Agricultural Research and Development', was, "to create a new Institute with a remit that would span the existing programmes of HFRO and the marginal land and resource assessments of MISR. The work was to expand to include wider aspects of soil monitoring and agricultural/environmental interaction and would specifically deal with questions of land use and its implications. The new Institute would facilitate a closer integration of soil, plant and animal studies, which would create the opportunity for major new research initiatives".

The remit agreed for the new Institute by DAFS and by the Agricultural and Food Research Council (AFRC), and on which the new programme of research is based, states that **the Institute will primarily conduct research on the physical, chemical and biological components of agricultural and related land uses in the hills, uplands and marginal areas of Britain, with particular emphasis on interactions and systems development, so as to provide the basis for resource management decisions taking account of environmental, economic and social inter-relationships and additionally to characterise the soil resources of lowland Scotland.**

Since April 1987 the scientists in the Institute have developed a programme of research, the detail of which will be found on page 124 of this Annual Report. It has four major themes. The first theme concerns land use assessment, evaluation and monitoring; it involves the production of relational database information systems, production systems modelling and validation, land use modelling, and investigation of related socioeconomic issues. It is expected that within this theme some major new initiatives will be developed to provide an increasingly objective approach to land use and operational management decision making, and policy formulation.

The second theme is concerned with environmental issues; in particular the impact of external pollutants on agriculture and forestry, and of agricultural and forestry management practices on long term soil stewardship, vegetation and landscape, will be investigated. This is an important area of research and the Institute is well placed to carry out work which will provide information on which to base more environmentally sensitive management practices. Two research reports, one on Surface Water Acidification (page 14) and another on Radioactivity (page 21) expand on important environmental issues covered by this theme.

The third theme is concerned with developing systems of land management related to agriculture, forestry and farm forestry. These include systems which use sheep, cattle, deer, goats and camelids. This theme reflects the fact that while sheep and cattle are likely to remain important in hill and upland areas there is an increasing need to examine the potential of other animals for meat and fibre production. Opportunities for combining timber and livestock production also need to be researched and evaluated. Research reports on Forestry on Farms (page 5) and Alternative Animals (page 38) give a description of some of the work encompassed by this theme.

The fourth theme focusses on the need to improve the efficiency of the components of production systems and the need to obtain a greater understanding of biological processes through strategic research. This involves work on plant nutrient supply from soils; trace elements and heavy metals; plant nutrient uptake, growth and production; vegetation dynamics; energy expenditure of animals and the effects of shelter; nutrient partition; growth and carcass composition, and animal fibre production. All of this research underpins the work outlined in the other three themes: the research report on Soil Structure (page 29) provides an insight into the kind and level of strategic work that will be pursued by the Institute.

This first Annual Report of the new Institute provides a foretaste of the kind of research on which the Institute will be engaged in the future. At the same time it reports on concluding work from the former MISR and HFRO. However, the research summaries (pages 47-104) are presented in a way which reflects upon the new programme unit structure of the Institute and should leave the reader in no doubt that the primary aim of the Institute is to examine and research the options for land use in the widest sense. It is intended to provide information which will form the basis for determining the extent to which agriculture and forestry, together with recreation industries and processing and manufacturing

developments, can contribute to the economic viability of the hill, upland and marginal rural areas of Britain, and at the same time, be compatible with broader economic, social, environmental and conservation objectives. This is an exciting challenge to which the staff of the Institute have responded with enthusiasm, determination and innovative skill in developing a relevant and imaginative programme.

At present the Institute operates from its headquarters at Craigiebuckler in Aberdeen and from Bush in Edinburgh. In addition there are four Field Research Stations; Sourhope near Kelso in the Southern Uplands, Glensaugh near Edzell in the Eastern Grampians, House o' Muir in the Pentland Hills, and Hartwood, an upland unit, at the watershed of the Forth and Clyde Valleys. Further details will be found on page 105. MLURI also runs a joint programme of work with the Welsh Plant Breeding Station part of the Institute of Grassland and Animal Production (IGAP) at Bronwydd Mawr in Powys and has responsibility for the Highland and Islands Development Board's (HIDB) Rahoy Deer Farm.

The Institute has a total scientific staff complement of 260 to carry out its programme of work. They are organised into Divisions of Land Use, Soils and Soil Microbiology, Plants, Animals and Grazing Ecology, and the Analytical, Administration and Research Station Divisions (see page 118). The Institute is primarily funded by the DAFS; at present about eight percent of research funds are obtained from other sources.

During the next four years it is intended that the Craigiebuckler site will be developed so that by 1991/92 the majority of staff of the Institute will be based in Aberdeen with some relocation of others to the Research Stations. Until this takes place the full integration of the work of the Institute and the benefits of the dynamic interaction of staff will not be fully realised. Nevertheless, despite the present logistical impediments, staff from both sites have made a gallant effort to ensure that the programme has been developed in a way which utilises the wide range of disciplinary skills in the Institute to the fullest extent. Interdisciplinary activity extends beyond the Institute; collaborative work with the Scottish Agricultural Colleges, all the other Scottish Agricultural Research Institutes, the AFRC Institutes of Grassland and Animal Production, and Animal Physiology and Genetics Research, the Forestry Commission, the Institute of Terrestrial Ecology and the Nature Conservancy Council is in progress and discussions with the Scottish Development Department, the Scottish Development Agency, the Countryside Commission for Scotland and the Highlands and Islands Development Board have influenced the direction and content of our programme. The Institute is a member of the Aberdeen Centre for Land Use and has close relationships with the relevant Departments of Aberdeen and Edinburgh Universities.

At a time when the agricultural industry is passing through a period of dramatic change and uncertainty, it is entirely appropriate and indeed necessary that the Institute is commissioned by the DAFS to research issues which are likely to have a profound and lasting effect on the rural life and countryside of upland Britain. Many of us regard it as a privilege to be given the opportunity to contribute to a more fundamental understanding of how the seemingly conflicting objectives of land use in upland Britain may be accommodated, rural populations developed, the landscape and amenity of the countryside, and diversity of wildlife enhanced, and the heritage of the land sustained. I hope, that like the staff, readers of this Annual Report will be encouraged by some of the possibilities that lie before us.

T.J. MAXWELL, Director

Forestry on farms

D. Atkinson, J. S. Bibby, M. Proe and A. R. Sibbald

Introduction

Surpluses of the major arable crops, such as cereals, and of dairy products, together with the need to sustain farm incomes and to respond to the concern expressed by a predominantly urban population about the environment, have resulted in pressure for an increase in diversity on the farm, and for the production of a range of crops not currently in surplus and in systems which are environmentally acceptable. While there is scope for the development of industries based on recreation and tourism (for example bed and breakfast, camping and caravan sites, pony trekking etc.), these options may be limited to regions with particular scenic or historical attractions and which are easily accessible from urban population centres.

The most applicable form of diversification of land use in the more remote areas is the direct use of the land resource to produce crops but the number of crops that can be produced is limited. This has resulted in an increased interest in the growing of trees. The Forest Industry Committee of Great Britain has reported recently that Britain currently consumes approximately £6000 million of forest products, 90% of which has to be imported. (F.I.C. GB 1987). They

also state that the net trade deficit in forest products exceeds 6% of Britain's total import bill. This situation will improve as the results of the afforestation programme implemented since 1945 increase annual conifer production from the present 4.5 million cubic metres to an anticipated 8.8 million cubic metres during the early years of the next century. Even with this increase in production our dependence upon imports will remain high as the demand for timber products is forecast to increase.

Forestry has expanded in the hills and uplands of the UK over the last few decades, although the trend has been for large scale afforestation which has developed on the basis of relatively low land prices, favourable financial support and fiscal incentives from Government and the existence of a body of "large" investors (pension funds, etc.) willing to take on long-term investments. In recent years this type of large-scale afforestation has become more controversial because of changed public perception and sensitivity to its effects on landscape and wildlife. This has resulted in radical changes in the financing of forestry in the U.K. (F.C. 1988), the consequences of which have yet to be seen, although the Government remains committed to a continued programme of afforestation.

A contentious issue in respect of traditional forestry is its impact upon rural communities and rural employment. A stated objective of present Government forestry policy is "to stimulate and support the local economy in areas of depopulation by the development of forests, including new plantations, and of wood using industry", but the discontinuity of the labour requirements in forestry and the need to transport personnel considerable distances to their place of work have resulted in criticisms. Continuity of labour may take time to develop but personnel seem likely to have to serve large geographical areas in order to maintain their full employment. Given that there is a need to retain populations in rural areas and that viable populations are based upon sources of adequate and regular income, it follows that forestry on a small scale, within the boundaries of existing farms, and involving the farmer directly could be beneficial.

A range of different production systems is likely to be employed on farms depending upon the objects of management, availability of labour and types of land being planted. Some of the possible options, with an emphasis on those relevant to hill and upland farms, (although the considerations are also generally relevant to more intensively managed land), are discussed here, beginning with a definition of terms.

Tree Production System

Conventional forestry is the management of single or mixed tree species in large blocks where the primary objective is the production of timber.

Agroforestry is a collective name for land-use systems in which trees and agricultural crops (with or without animals) occupy the same piece of land. In agroforestry systems there are both ecological and economical interactions between the different components. One form of agroforestry of direct relevance to the U.K. hills and uplands is *silvopastoralism* in which animals are grazed between widely spaced trees managed intensively for quality timber production. The grazing enterprise maintains cash flow during the early years of tree production whilst in later years its importance will decline.

Figure 1. Land in Scotland currently used in cereal-grass enterprises in LCA Class 3 Division 2.

On-farm forestry is less well defined but relates to more traditional forms of forestry being practised on a smaller scale, perhaps on good agricultural land, with a greater intensity of management and forming a part of an overall farm enterprise.

Land suitability for tree production

Agricultural land classification techniques permit the identification of agricultural areas which have sufficient flexibility and regularity of yield to enable the user to change his enterprise to encompass crops still in demand. Areas with less flexibility can also be identified, of which those based on cereal-grass and wholly grass enterprises are the most important. The first of these reduced flexibility categories, that including cereals, is encompassed in Class 3.2

Figure 2. Land in Scotland currently used in grass-based enterprises in LCA Classes 4, 5 and Class 6 Division 1, within areas covered by the 1:250 000 LCA map series.

(Figure 1) of the LCA system. If current EEC support for sheep-meat continues, a return to grass-based enterprises is the likely result of pressure against arable cropping. In addition, if the support given through the Less Favoured Areas Directive to hill and upland sheep farms continues, this will intensify competition between the two sections, such that farm forestry may increase on this land type.

The second of the less flexible categories, LCA Classes 4, 5 and 6.1 (Figure 2) is primarily upland and hill land, where grass-based enterprises are the only viable agricultural options. Here changes in the regulations governing financial support to agriculture, or of land-use for sheep production in the lowlands, may encourage tree production as an option enabling farm income to be maintained. Partnership schemes between farmers and 'small' investors may fund such forestry enterprises.

At present 2.1 million hectares of woodland exist in Britain representing 10 per cent of the land area compared to an EEC average of 21 per cent. The predominantly maritime climate of western Britain favours the production of conifers as they grow rapidly (which may influence quality adversely) compared to many other regions within the Community. In contrast, broadleaved species benefit from the warm summers found in continental Europe where as a result, quality hardwoods can be produced more readily. There are, however, some areas in the UK where suitable conditions prevail for some species of broadleaves. The increased need to favour forestry in areas hitherto excluded, together with the encouragement of farm woodlands on better agricultural land, now clearly provides opportunities for a wider diversity of tree species and production systems.

The historic presumption against forestry, which often had a strong economic base, on all but the poorest agricultural land has led to much of the post-war afforestation in Scotland being confined to the poorer Class 5 and 6 land. As a result, silvicultural options have been severely limited and frequently confined to large scale plantings of Sitka spruce. More sheltered sites on better soils supported Douglas fir. Larch was also often used on the better soils, as a firebreak and to break up monotonous landscapes, although its use results in lower production. The scope for broadleaved species in such environments has been confined mainly to birch and rowan, planted for amenity effect. Changes in the current climate of thought now allow a much wider choice of species. It is now likely that better Class 5 land, Class 4 land and even some Class 3 land will become available for planting.

The classification of land for forestry

The classification of land for forestry gives an indication of possible choices of species available to the farmer. Work at MLURI on behalf of the Forestry Commission has established guidelines for all climatic regions, soil types and topographic variants in Britain (Bibby, Heslop and Hartnup, 1988). Maps at 1:250,000 scale have been completed for the whole of Scotland and are currently being prepared for publication.

The greatest scope for farm diversity is for the planting of trees on LCA Class 4 land or better. On Class 4 land high yields of a range of conifers, e.g. Douglas fir, spruce, larch and pine, can be expected while the potential for the planting of broadleaved trees also increases. Sycamore and beech may be suitable for many sites, perhaps together with a conifer where exposure is a problem. On sheltered sites with deep soils the production of oak, ash, cherry and southern beech may be viable. Coppicing of alder or birch, in poorer upland areas, or of willow or poplar, on arable land, may be an attractive farm option.

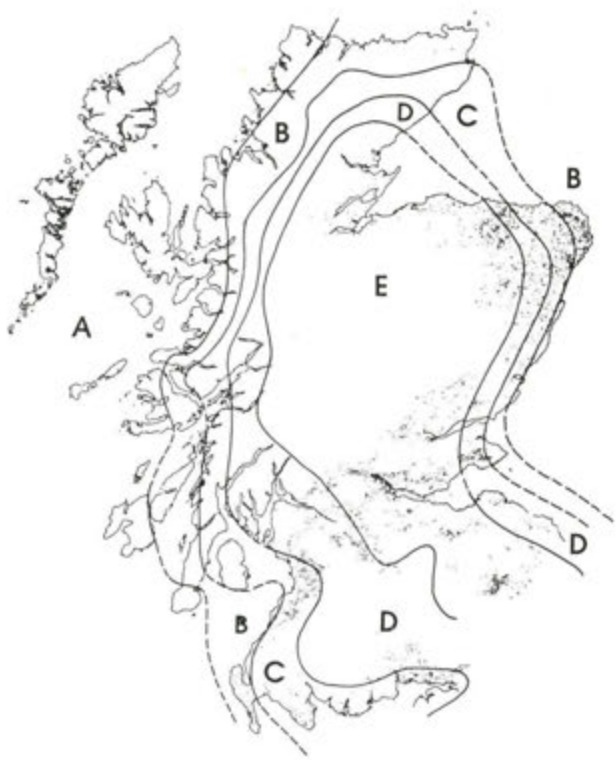

Figure 3. Wind zonation of Scotland superimposed on a map showing soils with wetness limitations in Class 3 Division 2. The risk of serious windthrow decreases from Windzone A to Windzone E.

The land in LCA Class 3 likely to be released in the lowlands will be mainly clayey, very stony or sandy, or chalk land. Each of these soil types has a different capacity for commercial forestry: as a consequence of lime-induced chlorosis, chalk land, although useful for beech and some other hardwoods, is unsuited to conifers. Options on dry sandy soils near to the sea may be restricted to pine. Windblow on wet soils, where rooting is shallow, reduces the production of most species, and exposure to wind may still distort small blocks of woodland. Not all land classed broadly as of similar value for agriculture will necessarily be equally uniform for forestry (Figure 3).

Types of production systems

A range of tree production systems is possible in an agricultural context. The major options seem to be:

a) Small-scale conventional forestry.

Conventional forestry is based primarily upon large-scale plantations with rotations of between 40 and 90 years for conifers (longer for broadleaves) depending upon species and sites (Figure 4). In areas

Figure 4. A conventional coniferous forest.

of high exposure with restricted rooting, rotation lengths may be shortened to reduce the risk of windthrow, and no-thin rotations may be necessary. In addition to the large trees removed as the final crop, regular thinning operations normally yield smaller timber and provide an intermittent income between 15 and 30 years from planting onwards, in areas where thinning is possible.

Markets for the output from forests of this type vary with the size and type of wood produced and their location relative to major wood-using industries. Small conifer roundwood is well suited for woodpulp and can be chipped or flaked for use in chip or particleboard. More locally, the timber may provide firewood or fencing. The logs removed in later thinnings and at clearfelling usually go to sawmills for conversion into a range of products. Small-scale on-farm planting will require that added-value "farm" enterprises are established.

Farm plantings of forestry of this type could remove large amounts of land from agricultural production. However, if this involved a substantial

area of individual farms, or several farms where farm size is restricted, it could adversely affect cash flow. As a result it seems likely that this option would not be used on the best land and so its influence on the production of those crops currently in surplus may be small. At some point this type of tree system grades into :b) On-Farm Forestry

Where plantations of trees are established within existing farm boundaries, on-farm forestry is relevant to all classes of farmland and farm types and may provide a vehicle to increase the diversification of farm activity. In the past trees were grown for a variety of uses, to provide shelter, to enhance the landscape, to encourage game or to provide timber for on-farm use, e.g. fuelwood or fencing. There are now financial inducements encouraging farmers to plant and manage trees more effectively within the above range of management objectives, but with quality timber production as a major object, especially on better land. Conventional conifer production on small areas of farmland, however, will need to compete directly with larger-scale commercial forestry, which itself must compete in the international market, even for domestic sales. Farm production of this type would therefore require co-operation between individual farmers in order to gain access to markets. In order to compete with larger-scale forestry operations the intensity of management in farm plantations, seems likely to increase and should enhance timber value. On-farm processing and the growing of quality hardwoods may add value. There is, also, potential for planting broadleaved species for purposes with an indirect income generation, i.e. shelter, conservation, amenity and game cover; oak, beech, ash and cherry are all suited to fertile soils and sheltered sites (Figure 6). Sycamore, alder, birch and rowan may be successful on poorer sites. It is difficult to predict how hardwood production in northern Britain would compete with that in the south and commercial farm woodlands in northern Britain seem more likely to be dominated by productive conifers such as Douglas fir, Sitka spruce, Corsican pine and larch.

One type of broadleaved production which may become attractive on the farm is coppicing (Figure 7). On sheltered, fertile sites coppicing of willows and poplars may yield between 12 and 20 Mg (tonnes) dry matter per hectare annually (Dawson 1987). In more exposed areas with poorer soils alder and birch may have to be used resulting in reduced yields. The major outlet for this type of material is local supplies of renewable energy. On the best sites cutting cycles of between three and five years are possible. Cycles generally extend to eight years or more as site quality declines .

New block plantings of trees on farms are likely to lead to the improved management of existing small farm woodlands and shelter belts some of which may have been neglected.with positive attempts to encourage regeneration. New farm-forestry plantings may include mixtures of species. These mixtures may have a uniform canopy or they could be multi-layered. Such plantings may improve the landscape and conservation value of these woodlands with an added benefit of product diversity. Mixtures allow for species to be harvested at different times.

Figure 5. A farm showing a mixture of arable crops (grassland production) and forestry.

Figure 6 (left). Silver Birch well adapted to poorer sites N. Britain.
Figure 7 (right). A coppice production system close to the line of recutting.

Increases in the quality and intensity of management will clearly depend upon the knowledge of the farmer (a considerable retraining element is required) and upon whether potentially available "spare" labour exists on the farm. In particular it will be necessary to assess whether the farm-woodland's need for management inputs, e.g. for weed control, thinning, pruning, chemical growth regulation, etc., is required concurrently with the needs of other, more result income from the livestock will be reduced to a minimal extent over this period and thus farm income should be maintained. This combination of features may well make silvo-pastoral systems attractive to UK farmers with no tradition of farm/forestry. In the longer term this type of system may become an attractive means of securing the provision of quality timber and of reducing animal production. This type of system, like conventional forestry, grades into a

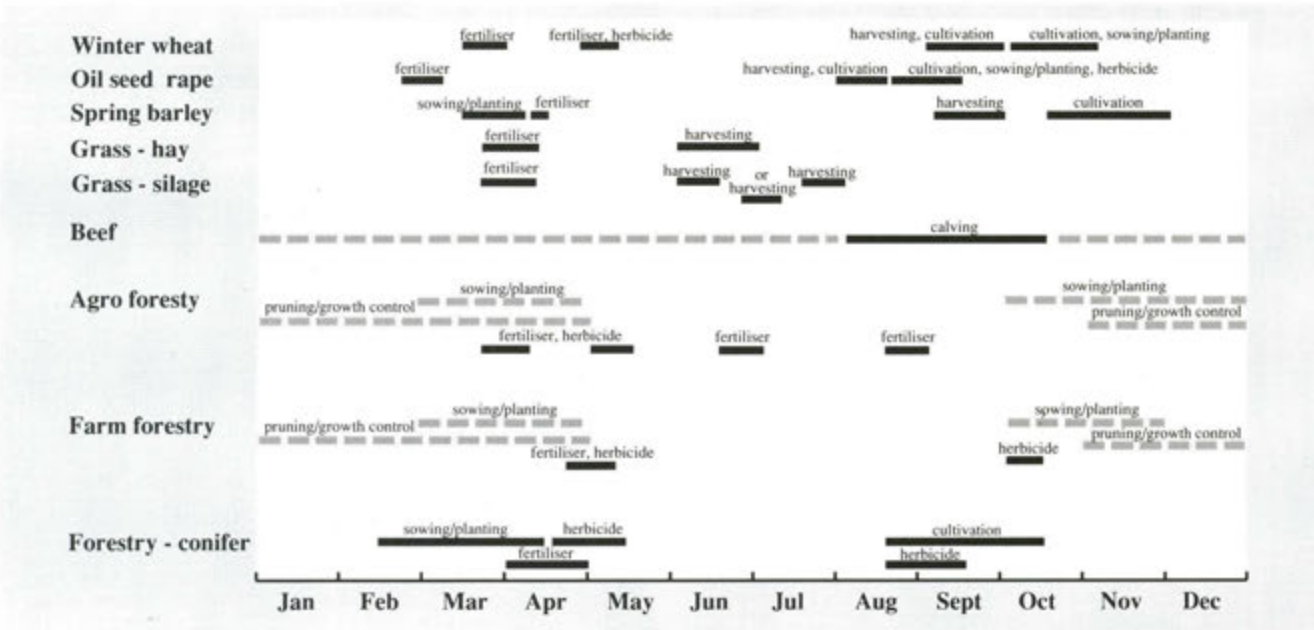

Figure 8. The periodicity of the major farm inputs likely to be needed for farm-forestry and agroforestry systems and for comparison indication of the peak labour needs for other farm enterprises.

immediately cash yielding enterprises (Figure 8). If such farm enterprises are able to attract investment from "small investors" via partnership schemes or conservation packages, this will aid their acceptance and the standard of management they receive.

c) Agroforestry

It is clear that scope exists for the production in the UK of high quality timber, for building, furniture manufacture and the production of veneers. Trees can be grown to produce timber with these qualities on the better soils of the uplands and on a range of lowland sites and by the use of wide spacings in existing permanent pastures where individual trees can be more carefully managed (e.g. by pruning). In the UK silvopastoral systems seem more likely to be popular than silvo-arable systems. The introduction of trees, at wide spacing to an existing pasture, is likely in the early years to have little adverse effect on the stock-carrying capacity of the pasture (Figure 9). As a number of farm-forest production systems. Reference is made to current agroforestry research at MLURI in later sections of this report .

The need for more biological information

Research should be related to those physiological processes which underlie important practical problems and to species with major potential. Current and proposed research at MLURI and associated institutes emphasise the following:

a) Wood quality

Most farm-timber production systems seem likely to involve higher levels of chemical or management inputs than are common in conventional plantation forestry; these inputs are likely to increase growth-rates. The relationships between growth rate and timber quality are imperfectly understood, although it has been suggested that in coniferous species high growth rates can adversely influence quality (Bevege 1984). At a more basic level understanding of the links between cellular differentiation and wood quality is imperfect. As a

consequence currently available models are equivocal in predicting effects of increased nitrogen fertiliser additions on wood quality. Better understanding is needed, together with a system of testing, which will allow effects of management to be both predicted and monitored. Exact effects seem likely to depend on the relationship between mineral nutrition and water supply and the duration of shoot extension relative to cambial activity. The length of time needed to complete field studies of this type suggests that the production of mechanistic models based on comparison of model systems with the performance of mature trees is likely to be particularly useful for

Figure 9. A newly established agroforestry system being grazed by sheep. The use of the tree tubes is important to improve the growth of the newly planted wild cherry trees.

providing management guidelines in the next 20 years.

b) Rhizosphere interactions

The basis of the interactions of trees with ground cover of other species is imprecisely understood. They clearly involve the use of common resources, e.g. water, nitrogen, but also interactions with the soil microflora and perhaps the release of allelomediatory substances. Studies previously carried out have shown that when trees are grown with grass the form of the root system and the periodicity of new root production is changed (Figure 10). Ground cover species, especially perennial weed species, are also known to have very large negative effects on the amount and quality of wood produced. Aspects of competition are being emphasised in agroforestry studies. In monoculture systems the aim of management is to optimize the supply of resources to the single economic component of the system at the

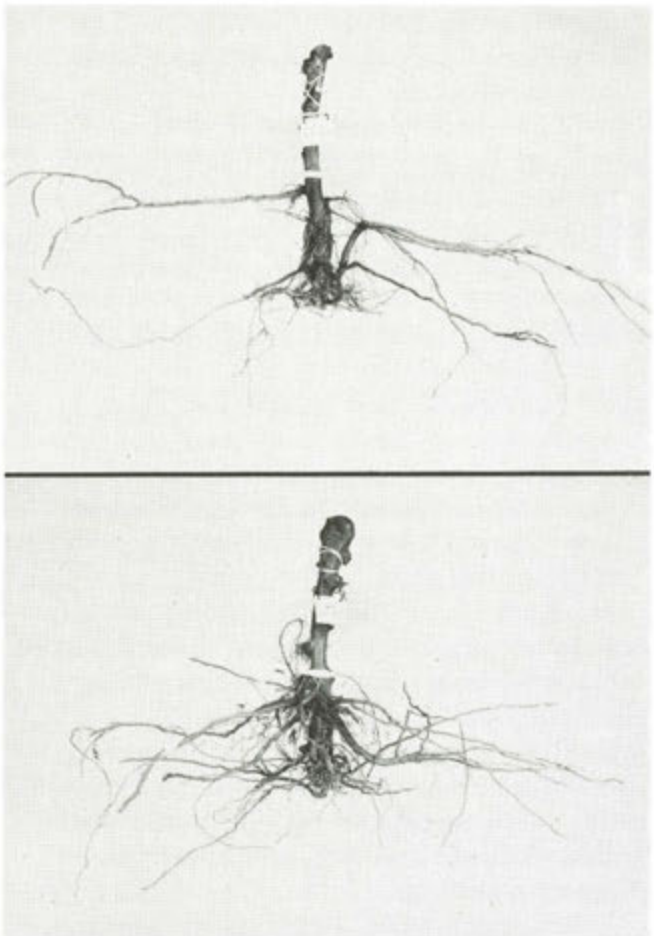

Figure 10. Effect on the form of the root system of 5-year trees (*Malus* sp.) of being grown under grass (above), or in a 1.2 metre herbicide treated area in grass (below). Ground vegetation management in the early life of the plantation is likely to be important. *(Photos IHR East Malling)*

expense of all other species. In an agroforestry system it is necessary to optimise the production of two very different crops, which occupy and use the same volume of soil. In shelter belts and small farm woodlands with an amenity purpose there is also the need to manage in parallel more than one tree species. Information is needed to ensure the success of initial establishment and to plan weed control and fertiliser strategies.

c) Shelter effects

In systems of on-farm forestry, the range of biological interactions between the farming and forestry enterprises is limited, although the shelter

effects of the trees on the farming enterprise are clearly vital. There is therefore scope for research on shelter as it applies directly to livestock, from shelter belts and from access within plantations and as it applies to pasture and other crops. Results from these studies will also guide optimum spacings and configurations.

d) Studies relevant to specific farm options

i) Agroforestry

In silvo-pastoral systems where trees are planted at wide spacing in fertile upland soils which also support grazed pasture, interactions arise which could affect both trees and pasture. These include possible shading effects of trees on grass growth, effects of competition from grass on tree growth, effects of nitrogen fertiliser on growth rate and timber quality, the grazing of tree foliage and bark, treading damage to tree roots and effects of shelter on animal energy expenditure.

Recent research (Ingestad 1982) has shown that trees respond positively to applications of nutrients closely related to their growth rates and periodicity. The applicability of this type of system to trees in the field is being assessed by studies of whether cherry trees will respond to applications of nitrogen supplied in low amounts on a regular basis. This is being compared with standard patterns of fertiliser application. In addition it is necessary to establish the maximum rates of production possible for a range of tree species in the field and thus to establish a basis against which to assess the potential production of commercial plantings.

Reference is made to other current agroforestry research at MLURI in later sections of this Report .

ii) Farm Forestry

Since plantations on farms can be planted for a range of purposes ranging from pure amenity to maximum timber production, the information needed will be equally variable. For amenity plantings the integration of trees into an overall conservation plan with a substantial emphasis upon wildlife populations will be important. The successful implementation of this type of planting needs better information on the effects of choice of tree species, vegetation mosaics and the proximity of farm crops on wild life, e.g. insect, wild flower, small mammal population dynamics. For production plantings, information on the extent of improving growth form and carbon partitioning to the trunk by pruning methods and chemical plant growth regulator treatments will be necessary. These plantings are likely to be established on more fertile upland soils than have been planted in the past and as a consequence a wider range of tree species will be possible. Information, especially that which can be used in predictive models, on the interactions of mixed tree species in a range of configurations and planting/harvesting time sequences will be important.

The environmental impact of small-scale forestry is largely unknown. When traditional forests on low fertility upland soils are clear-felled, levels of nitrate in the water of streams and rivers draining from the catchment can rise dramatically (Stevens and Hornung 1988). The effect on water quality of felling trees grown in small blocks on more fertile soils could also be significant. The establishment of new blocks of trees in bare soils can also result in substantial nutrient losses. These may be minimised in silvopastoral systems although here relatively high levels of nitrogen input could result in increased losses to ground water unless the systems are coupled with efficient recycling pathways. Effects of small-scale intensive forestry on soil and water quality need to be quantified.

The number of both broad-leaved and conifer species where a range of provenances have been extensively tested is limited. New systems seem likely to require -

a) conifers which respond well to high quality sites and high management inputs without a decrease in timber quality

b) broadleaved species (and provenances) well suited to defined regions, on a wide range of sites in lowland hill and upland areas

c) the selection and testing of specimens with good form and timber quality when grown at wide spacings.

Integration of tree production into the farm system

A modelling approach has assessed the implications of the integration of trees into farms, especially in the hills, with particular reference to the viability of farming enterprises through the provision of improvement opportunities, if necessary, and the sharing of roads and fences. The procedure is based upon farm units, since it is at this level that decisions to change land use are generally made. The consequences of a range of patterns of land allocation and the consideration of landscape requirements can be assessed in economic terms.

Existing models are based upon an assessment of the existing land resource described as a distribution of vegetation, soil, roads and fencing within the farm. It is intended to extend these models by enhancing the forest input section which is presently based on a direct economic evaluation of yield class potential. The enhancement will base forest production on site descriptors (altitude, soil type, etc.) and will allow a more detailed evaluation of forest production potential to be made. It will, in addition, allow an accurate assessment of labour profiles to be made throughout the lifetime of the farm/forest scheme. It is also intended to extend the agricultural component of the model to cover farming systems on land of higher quality and to include, in the land-allocation decision-making procedures, consideration of conservation requirements.

Conclusions

Given a favourable economic climate, increases in tree production on farms now seem likely to occur on a major scale and will include a varied range of management options depending upon the aims of the producer.

If this is to be done successfully, information derived from a wide range of scientific disciplines will be essential. The science involved will cover aspects of soil, pasture, trees and livestock and the many interactions among them and will include investigation of the economic and social consequences of the alternatives.

MLURI has already embarked upon a programme of research to satisfy many of these needs.

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Surface Water Acidification

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

Introduction

In remote, temperate areas of the world, the average acidity of the rainfall is typically about pH 5.0, with individual episodes ranging from pH 4.5 to 5.6 (Galloway *et al.*, 1982). The range of acidity of unpolluted rain can be accounted for by factors such as equilibration with atmospheric carbon dioxide to form carbonic acid and by variability in the natural sulphur cycle. The mean pH of the rainfall in large areas of Europe is, however, less than 4.5 and in a large expanse of Central Europe is less than 4.1, and since pH is expressed on a logarithmic scale, this is about 8 times more acid than the rainfall of remote areas. In Britain, and in Scotland in particular, there is a well-defined gradient in mean rainfall pH, from pH 5 in north west Scotland to 4.5 or less on the east coast of the country (U.K. Review Group on Acid Rain,1987).

It is now widely accepted that such observed increases in rainfall acidity are due primarily to the emission of sulphur dioxide and nitrogen oxide gases during the combustion of fossil fuels. These gases may be removed from the atmosphere as dilute sulphuric and nitric acids by rain, hail or snow, by vegetation interception of fog and cloud droplets, and by dry deposition or adsorption of gaseous particles on soil or vegetation surfaces. All these mechanisms lead to the input of acidity from the atmosphere and are encompassed by the general term "acid rain". It is more correct, however, to describe these processes as "acid deposition".

The effects of acid deposition on terrestrial ecosystems, and even on human health, have been the subject of much research, debate and controversy in recent years. For some aspects at least, a consensus is now beginning to emerge that in some areas atmospheric acid deposition is implicated in the acidification of surface waters, causing loss of fish stocks. Declining fresh-water fish stocks have been widely reported and, in Southern Norway in particular, over 1,700 lakes across 13,000 km^2 have become fishless. A similar phenomenon has been reported from some areas of Scotland, particularly in certain lochs and streams in Galloway and the south-west Highlands. In general, these effects tend to be confined to areas of thin, acid, poorly buffered

soils developed from poorly weatherable parent materials such as granite.

The detailed effects of processes leading to the acidification of surface waters are complex and diverse and, to address these and other related questions, the power generating industry in the UK has sponsored a major study known as the Surface Water Acidification Programme (SWAP). SWAP is collectively administered and managed by the Royal Society, the Norwegian Academy of Science and Letters and the Royal Swedish Academy of Sciences. The UK part of this study is based almost entirely upon an integrated, experimental catchment approach, involving collaboration between MLURI, the Institute of Hydrology, the Fresh Water Fisheries Laboratory (Pitlochry) and the Department of Civil Engineering (Imperial College, London). The MLURI involvement centres upon detailed investigations of the changes in chemical composition of incident precipitation as it interacts with and percolates through vegetation and soils, taking into account rates of flow and pathways through the soil and the effects of the various acidifying and neutralising processes. This work integrates with the hydrological, fisheries and computer modelling aspects that are being studied by the other participants in the Programme, and moves forward from the traditional "black-box" approach to soil and vegetation processes that has characterised many previous catchment studies. Three specific catchment areas subject to different pollution loadings have been selected and by constructing detailed input/output budgets for each, coupled with an understanding of the major controlling processes involved, it is hoped to predict using computer models how the surface water chemistry will be affected by changes in acid deposition.

Experimental Catchments

Studies are being made at three sites chosen to represent high, intermediate and low levels of acidic deposition. The site receiving the highest levels of acid deposition is located in the Loch Ard catchment about 8 km west of Aberfoyle in Central Scotland. Here, streams are generally incapable of supporting fish. Of two selected sub-catchments, largely similar with respect to overall geology, soil type and vegetation, one (Loch Chon) sustains a much-reduced fish population, but the other (Kelty Water), does not. Both sub-catchments are developed mainly on Dalradian quartz-mica-schists with the dominant soil types being humus iron podzols, peaty podzols, peaty gleys and peat. Major areas of both sub-catchments are forested with Norway spruce at Loch Chon and Sitka spruce at Kelty Water. The site receiving an intermediate level of acid deposition is at Allt a' Mharcaidh in the Cairngorms. These streams sustain a fish population which is occasionally stressed by acid episodes, for example following a snow melt. The catchment is underlain entirely by granitic rocks, with the main soil types being alpine podzols, peaty podzols and peat and the dominant vegetation is heather. Finally, the catchment receiving the lowest levels of acid deposition feeds into a productive lake (Stor Gronningen) and is located at Høylandet, Nord Trøndelag north of Trøndheim in Norway. This catchment can be regarded as a pristine, reference site. It is developed on granitic gneiss with occasional inclusions,of basic rocks, the dominant soil type is a well-developed iron podzol and the major vegetation is Norway spruce/birch forest.

Monitoring Instrumentation

Each of the experimental sites has been instrumented in a similar manner for the collection of bulk and interception deposition, vegetation and litter throughflow and soil drainage waters from selected horizons and stream waters (Figures 1 and 2). The vegetation throughfall and soil water collectors are installed in three replicated plots. During periods of prolonged rainfall or snowmelt, event samplers are connected to all components of the plot system, providing synchronised sequential water samples.

Periodic monitoring and composite two-weekly sampling over 15 months have been used to determine hydrochemical budgets, allowing calculation of inputs, throughputs and outputs as kg/ha/yr for a wide range of elements, both major and trace, as well as weighted mean elemental concentrations. For about 6 months, daily samples have been taken from all parts of the systems under study to determine seasonal variations. Selected storm events, both rainfall and snowmelt, have also been monitored in Scotland and Norway at greater intensity using the event sampling equipment (Gaskin *et al*, 1988). Detailed hydrology data have been obtained using tipping bucket gauges connected to 8-channel MLURI digital loggers. Soil and air temperatures have been continuously monitored using similar analogue loggers

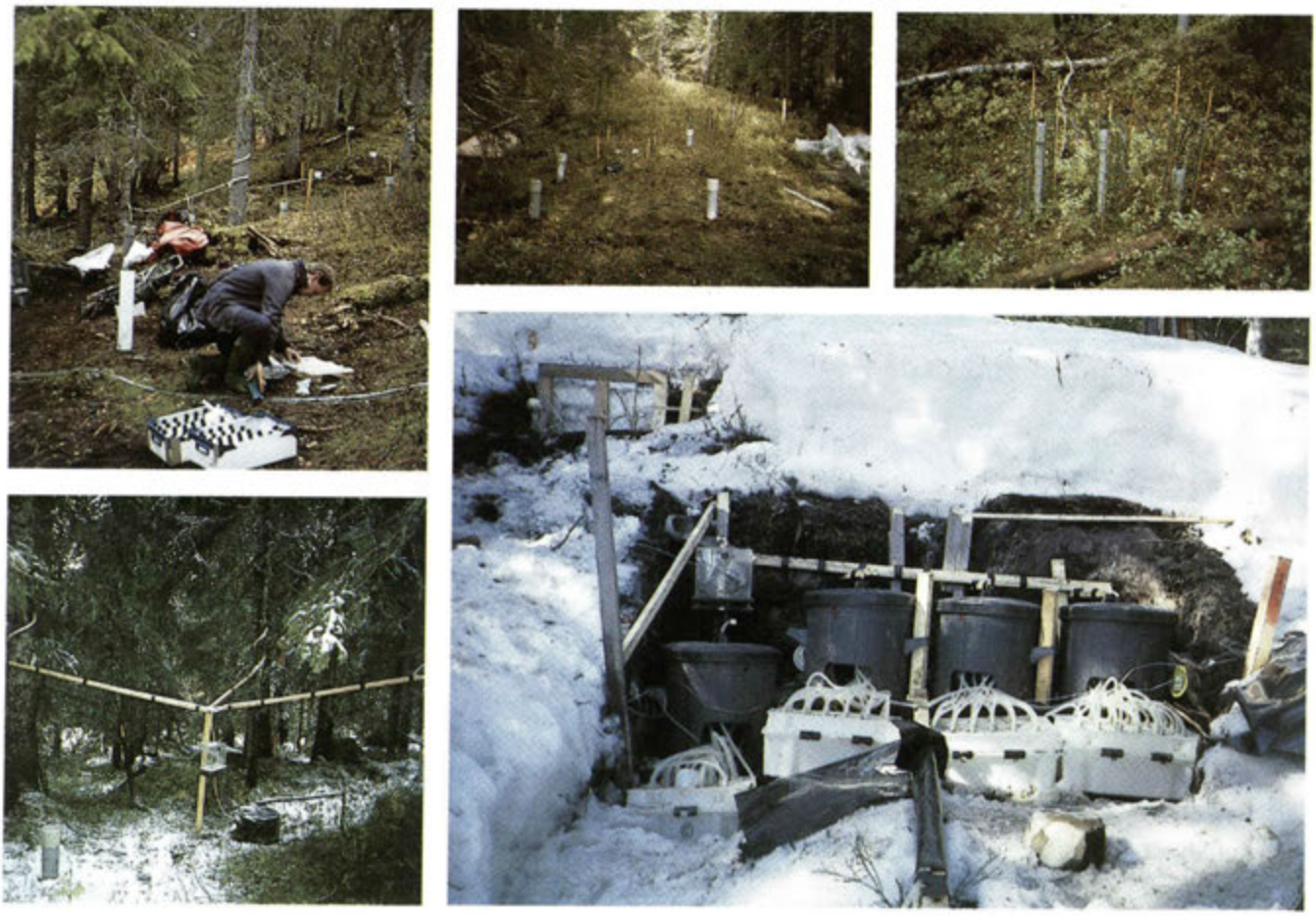

Figure 1. The experimental equipment (bottom right) installed on the SWAP sites is capable of sampling all of the available water passing into, and through, the system. All parts of the plot systems (inputs, throughputs and outputs) can be connected to event samplers, which provide synchronous discrete water samples. Here the drainage from four different soil horizons in a soil pit at Høylandet is being collected during the first soil water throughflow after snowmelt in 1987.

Site-specific measurements (top left) additional to the main programme often entail on-site construction of samplers.

The grey pipes (top centre) contain the bulk throughfall samplers and collection bottles, while the trays inserted under the topmost organic layers collect litter leachates.

In addition to the collection of soil water (top right) at periods of high flow in the assembly shown in Figure 2 on opposite page, soil solutions are also sampled in porous cup tension lysimeters, into which the water is drawn under vacuum. These samples can have chemistries quite different from those from the soil pit samplers.

In a forested site (bottom left), rainfall can pass through the tree canopy to give crowndrip or throughfall or drains down the trunks of the trees (stemflow). Stemflow sampling is accomplished by fixing a spiral gutter to the trees and combining the drainage from several trunks. Again, tipping-bucket gauges are used as volume-measuring devices.

Inputs

The main input to the study catchments is wet deposition in the form of both bulk and interception (mist and fog) deposition. The mean chemical compositions of these inputs is in general agreement with previous assessments of pollution loadings, and H-ion concentrations and amounts of excess sulphate (in excess of sea salt contributions) clearly follow the order Kelty/Chon > Mharcaidh > Høylandet (Table 1). Interestingly, both nitrate and ammonium follow the same pattern. There are a range of factors, particularly altitude and exposure, that modify the amounts and chemistries of inputs. This has necessitated the use of different types of gauges, some of which are illustrated in Figure 3,to determine

	H	SO_4	SO_4^*	Cl	NH_4	NO_3
Kelty	30	60	45	145	25	10
Chon	25	55	43	130	15	10
Marcaidh	20	50	41	100	7.5	5
Hoylandet	5	20	15	150	2	3

* Sulphate in excess of contributions from sea salts

Table 1. Selected data showing mean chemical compositions (µ eq/l) of inputs to the SWAP catchments.

	Altitude	Ground level gauge	Nipher gauge	Filter gauge
Site 1	550m	896	736	538
Site 2	760m	956	798	3446

Table 2. Effects of altitude (m) and collectors on the amounts (mm/year) of inputs to the Allt-a-Mharcaidh catchment.

Figure 2 . Soil water throughflow is collected from a vertical soil face, as exposed in the pit at Høylandet (left). Water is sampled at the different levels, or horizons, of the soil and volumes are measured by passing the separate drainage tubes into tipping-bucket gauges mounted in front of the completed assembly shuttered framework backfilled with inert polythene beads (right).

both hydrological and hydrochemical inputs and to augment the standard IOH gauges. Table 2 illustrates the dramatic altitudinal effect that has been observed in the Allt-a-Mharcaidh catchment, highlighting the crucial role of interception deposition as assessed by filter gauges in determining the hydrological inputs in the upper part of the catchment. This reflects too on the hydrochemical inputs where for all elements other than H the amounts caught by interception deposition were on average almost three times greater than for bulk deposition.

	Input	Throughfall	Stemflow
K	7.5	48.3	105.6
Na	112.4	183.08	237.58
Cl	130.5	216.69	312.41

Table 3. The modifying effects of vegetation on input chemistry (μ eq/l) at Loch Chon.

Vegetation effects

Vegetation modifies the chemistry of precipitation by a range of processes, all of which are capable of producing either an increase or decrease in acidity. These processes are also influenced by vegetation type and age, seasonality and form of input. It is particularly important to distinguish inputs due to passive interception of precipitation by vegetation, which can be assessed by interception gauges, from effects due to crown leaching. The latter is involved with nutrient cycling, which may involve uptake as removal of ions from the canopy. Table 3 shows vegetation modifying selected input chemistry in throughfall (crown drip) and stemflow in the forested Loch Chon catchment. The figures suggest that the enrichment in potassium is due to canopy exchange/release by the tree foliage, especially in summer, probably followed by subsequent root uptake, whereas the variations of sodium and chloride reflect only the different seasonal sources of inputs, as well as changes due to evapotranspiration.

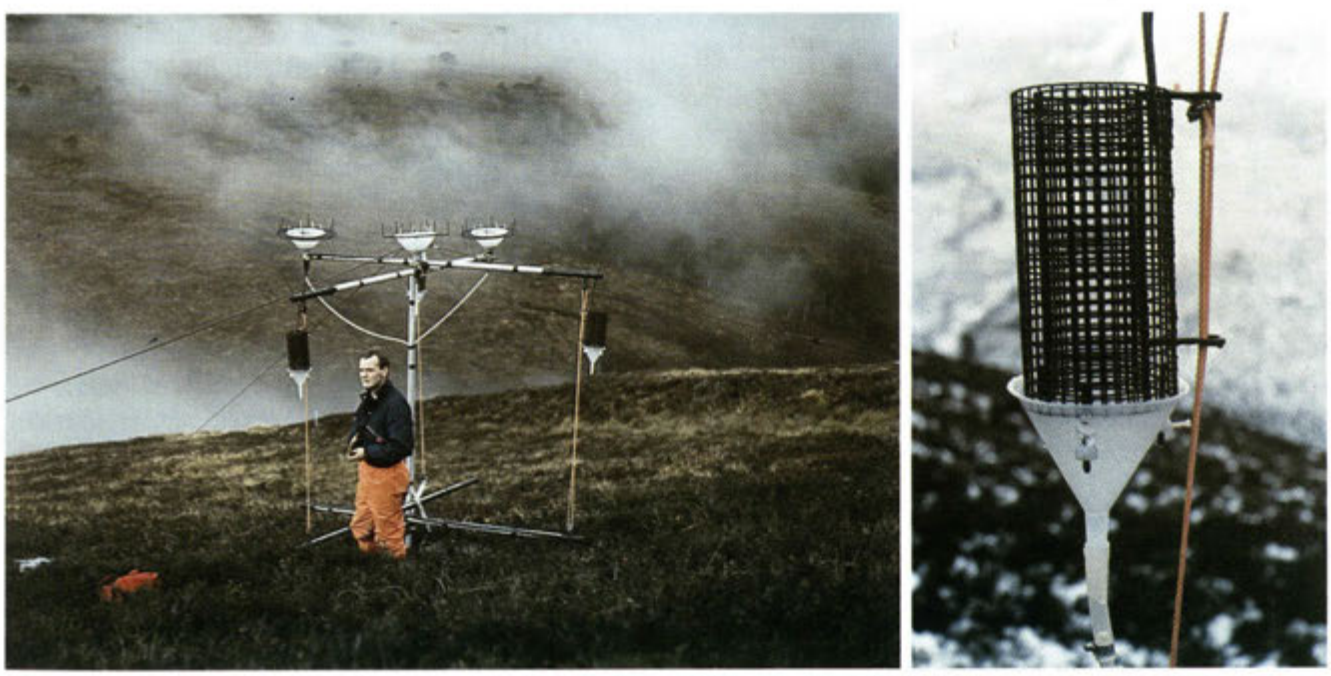

Figure 3. Input monitoring assembly at Allt a'Mharcaidh. The larger white funnels are nipher-shielded bulk precipitation collectors, while the smaller interception gauge funnels (shown at a larger scale on the right) have a coarse mesh superstructure to enhance the trapping of mists and other aerosols.

Soil Effects

The changes observed in the hydrology and hydrochemistry of soil waters depend upon a variety of factors but the general pattern found in the three catchment areas is that hydrogen ion concentrations are highest in waters from the surface and organic horizons and lowest in waters from the lower B or B/C horizons. Evidently, the flow paths and retention times of water moving through soil profiles are crucial in determining the transfer of acidity from soils to surface waters and the extent of interaction with organic and inorganic soil components. In the soils

	Chon		Hoylandet	
	Monomeric	Total	Monomeric	Total
Soil horizon				
-organic	n.d.	n.d.	120	200
-mineral	650	800	300	400
Stream	225	300	60	70

Table 4. Monomeric and total soluble aluminium (μ g/1) for soil and stream waters sampled from September to November, 1986 at the Loch Chon and Høylandet catchments.

under study, most soil water is routed through the sub-surface mineral horizons during passage to the surface water network, but the overall hydrochemical response of the catchments cannot be understood without knowledge of soil water-organic horizon interactions, particularly with regard to the behaviour of aluminium, sulphate and heavy metals.

The organic acidity in soil drainage waters arises from simple organic acids as well as from macromolecular dissolved humic substances. Leaching from plant and animal biomass releases simple acids, whereas organic matter decomposition releases more complex types, such as fulvic acid. The latter are the major source of organic anion activity in "brown-water" streams, of which Kelty Water is one. The acids can remove base cations from vegetation leachates or soil minerals, concurrently releasing protons and leading to acidified soils.

Certain mobile forms of aluminium are toxic to fish and studies are being made of how this element is associated with soil constituents in the SWAP catchments and is released to surface waters.

Fractionation of exchangeable and readily hydrolyzable aluminium from soil horizons containing variable amounts of organic matter (Table 4) shows the marked differences that occur between the Chon and Høylandet catchments. The salt treatment releases labile monomeric aluminium associated with inorganic components and weak organic complexes, whilst the acid treatment releases more strongly complexed organic and polymeric aluminium species, in addition to the labile forms. The results suggest that dilute salt solutions, such as are introduced as a sea-salt component of storm inputs, are capable of exchanging Na for Al, thus bringing about a pulse of dissolved aluminium, with increased acidity, in soil drainage and surface waters. There is much more exchangeable aluminium in the lower mineral horizons of the Chon soil compared with that from Høylandet, although the reverse is true for the more strongly complexed acid-soluble aluminium.

Table 5 shows that the soil and stream waters of the Chon site contain much more aluminium than those at Høylandet. The results also illustrate a common pattern found in the SWAP catchments, namely that drainage waters from the organic or B horizons contain the highest concentrations of aluminium, and that considerably lower levels occur in adjacent stream waters. It is believed that the higher levels of dissolved aluminium species in the Chon and Kelty stream waters are associated with their greater organic loading.

A widely accepted conceptual model of the acidification of surface waters by acid rain assigns a key role to sulphate, which acts as a mobile anion and transfers soil acidity - including soluble aluminium - to the drainage network. It is important, therefore, to determine the sulphate status of the SWAP catchment soils, particularly the levels of soluble and adsorbed sulphate. The results obtained highlight the difference in pollution levels arriving at each catchment. The Loch Chon site has the highest levels of sulphate input and this is reflected in the fact that there has been substantial sulphate adsorption throughout the soil profiles examined. In contrast, a similar soil type in

Table 5. pH and elemental concentrations (μeq/1) in output (stream) waters.

	pH	SO_4-S	NO_3-N	Cl^-	Na^+	Ca^{2+}	Mg^{2+}
Hoylandet	5.5	15-25	0.5-1.5	120-150	100-120	5-15	10-20
Loch Chon	4.6	70-100	3.0-5.0	150-200	120-150	30-50	40-60

the pristine Høylandet site, contained very low levels of both soluble and adsorbed sulphate, whilst four soils of the Mharcaidh catchment were of intermediate sulphate status. Very few soils were fully sulphate-saturated but the results obtained showed that the sulphate concentrations with which the soils have equilibrated in the field followed the pollution gradient between the catchments of Loch Chon > Mharcaidh > Høylandet.

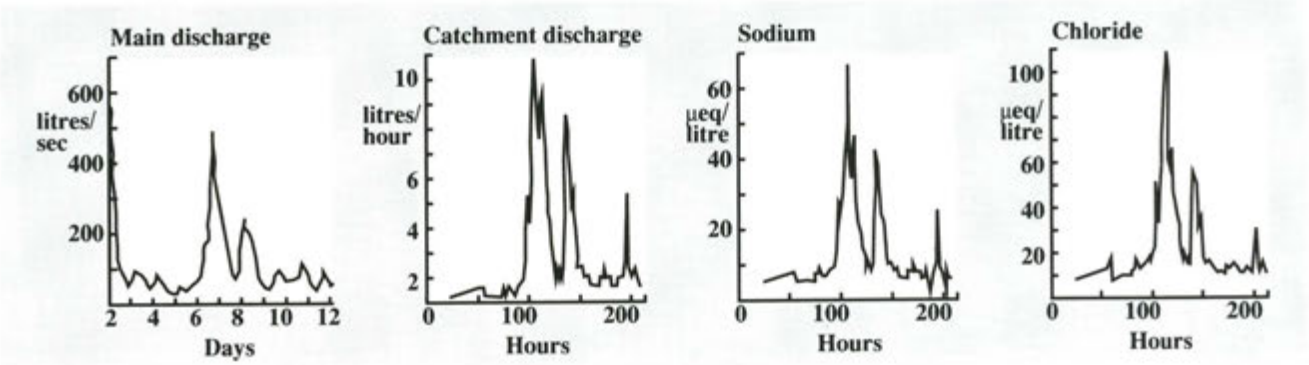

Figure 4. Changes in hydrology and hydrochemistry during snowmelt.

Analysis of the amounts of heavy metals, including lead, copper, zinc and cadmium, found in the SWAP catchment soils confirm that the Loch Ard sites are the most polluted, in agreement with their proximity to industrial activity in the Central Valley. For example, the overall mean values for total lead in dry matter in topsoils are 167 and 104 µg/g in Kelty and Chon respectively, compared with 21 µg/g for Mharcaidh and 17 µg/g for Høylandet. In general, the heavy metal contents of the Kelty and Chon soils suggest a degree of pollution similar to that affecting southern areas of Norway, where widespread lake acidification has occurred. The high amounts of metals extractable by EDTA and acetic acid suggest that lead, and particularly copper, are held largely as organic complexes in the topsoils.

Mineral Weathering

An understanding of the rates at which soil minerals decompose and release base cations is crucial in predicting the future course of soil and surface water acidification, given different levels of acidic emission. In general, most catchments that have undergone acidification are developed upon very slowly weathering geological materials. It is presumed that the amounts of base cations released by weathering are insufficient to compensate for the removal by leaching of similar bases from the exchange complex of the soil. In these circumstances, it might be anticipated that both soil and surface waters would tend to acidify, although it could also be argued that eventually acid deposition would speed up mineral weathering, so automatically regulating cation losses. It is important, therefore, to determine weathering rates on both a long term and a short term basis. Long-term weathering rates for calcium calculated by chemically analysing soil profiles from both the Loch Ard and Mharcaidh catchments and by determining element losses, turn out to be exceedingly low, ranging from 0.6 to 2.0 kg/ha/yr. Similar low rates have been found on a short term basis in Scandinavia and at present the evidence seems to suggest that weathering is not able to compensate for base cation losses through leaching.

Outputs

The stream chemistry of the study catchments varies widely because of the complex range of soil effects previously described. Nevertheless, outputs from the Scottish and Norwegian catchments show differences that are consistent with different pollution loadings to which the sites are subjected. Thus, Table 5 shows that bulk stream waters from Loch Chon are nearly ten times more acid than those from Høylandet and that they also contain much more SO_4-S and NO_3-N. On the other hand, the chloride contents of the output waters are rather similar, reflecting similar inputs of this anion.

Short-term changes in water chemistry as a result of meteorological events are also being studied, and an example of the close relationship between the stream flow and dissolved sodium and chloride of the Høylandet experimental site after snow-melt is shown in Figure 4.

Modelling

Data from the sampling systems together with soil survey and soil analytical information are being used to model changes in acidity in upland catchments using the MAGIC model of Cosby *et al*, (1985). Essentially, the model explores changes in catchment buffering capacity that occur over long periods assuming negligible short-term hydrological response. The yearly averaging of deposition levels provides the principal driving force of MAGIC. The model has been applied to the Mharcaidh catchment and Table 6 shows that present day observed stream chemistry is adequately reproduced. Although the Mharcaidh catchment has not yet been seriously acidified, the model predictions suggest that a drop in streamwater pH will occur even if acid deposition levels are maintained at present values. Further MAGIC simulations are being constructed for other upland catchments in Scotland and Scandinavia.

	Predicted	Measured
pH	5.4	5.7
	µeq/l	
Ca	38.0	37.1
Mg	31.0	39.9
Na	117.2	116.1
K	9.7	8.4
NH_4	2.0	-
SO_4	50.2	50.1
Cl	111.0	111.0
NO_3	2.1	2.1
Total Al	3.8	-
Alkalinity	35.7	33.0

Table 6. Predicted and observed present day stream chemistry at Alt-a-Mharcaidh.

Conclusions

The actual and potential deleterious effects of acid deposition on the quality and biological productivity of surface waters in upland catchments with thin, poorly buffered and nutrient deficient soils is generally accepted in Scandinavia and is now becoming more widely recognized in the UK. The MLURI studies that are being conducted under the aegis of SWAP are aimed at understanding and quantifying the processes and interactions that occur when precipitation waters pass through vegetation and soil en route to the surface drainage network. The information obtained is being used in computer models which will help to predict the likely effects on soils and waters of upland catchments, under various land managements, given different scenarios of atmospheric acid emissions.

Acknowledgements

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Radioactive contamination and agricultural systems

R. W. Mayes, D. Atkinson and H. Shepherd

Introduction

Soon after the discovery of radioactivity, about 100 years ago, it was recognised that the ionising radiation emanating from radioactive substances could have harmful effects on living organisms and that there was a need to protect humans from exposure. The acute effects of high radiation doses have been known for a long time. However, it has more recently been accepted that even very low doses increase the risk of contracting cancer or producing genetic defects in offspring. Thus, although the average UK inhabitant receives only about 13% of the total ionising radiation dose from man-made sources (the remainder comes from naturally-occurring radionuclides in certain rocks and cosmic and γ radiation from outer space), limitation of the release of radioactive materials into the environment will assist in minimising radiation doses to the human population.

Radionuclides which can have important environmental consequences

The majority of artificially-produced radionuclides have very short radioactive half-lives and thus have little environmental significance. In general, the radionuclides which are cause for concern have half-lives of at least one month. Those produced by the nuclear industry are summarised in Table 1. The radionuclides presently used as nuclear fuel or weapon components are forms of uranium or plutonium. As

they are primarily α-emitters, they are highly toxic if they enter the body. The remaining radionuclides in Table 1 are products of reactions occurring in (or in the vicinity of, after an accident) a nuclear reactor. Most of these are both β- and γ emitters; thus they can be dangerous both when external and internal to the body.

Radionuclide		Radioactive Half-life	Type of Radiation	Energy Level
Tritium	(^{3}H)	12.3 years	β	very low
Carbon-14	(^{14}C)	5730 years	β	low
Sulphur-35	(^{35}S)	87 days	β	low
Cobalt-60	(^{60}Co)	5.3 years	β + γ	very high
Strontium-90	(^{90}Sr)	29 years	β	high
Ruthenium-106*	(^{106}Ru)	367 days	β + γ	high
Iodene-131	(^{131}I)	8 days	β + γ	high
Caesium-134	(^{134}Cs)	2.1 years	β + γ	high
Caesium-137	(^{137}Cs)	30 years	β + γ	high
Cerium-144	(^{144}Ce)	285 days	β + γ	high
Trasuranics (eg.plutonium)		Mostly >10,000 years	α (+γ)	very high

* The major radiation hazard is from a "daughter" of ^{106}Ru, Rhodium-106 which has a very short radioactive half-life.

Table 1. Some radionuclides of environmental importance.

The impact of radionuclides on the environment and on living organisms depends not only on the radioactive half-life but also on the physical form in which the radionuclide is released and its chemical behaviour in different situations. Thus, for example, the mobility of a particular radionuclide throughout various systems or its tendency to accumulate in a particular body organ may have important consequences regarding acceptable levels of pollution.

Man-made radionuclides enter the environment either through controlled release as low-level waste, or by accident. With strict control of release of waste, the study of the environmental impact of the component radionuclides is relatively straightforward. Prediction of the implications of accidental release of radioactive materials is more difficult. The radionuclides released and their form and quantity may vary considerably, according to the circumstances. The development of strategies for coping with the environmental consequences of future nuclear accidents depends upon detailed prior knowledge of the behaviour of relevant radionuclides. Such knowledge may be obtained from experience gained from previous occurrences and from direct experimentation.

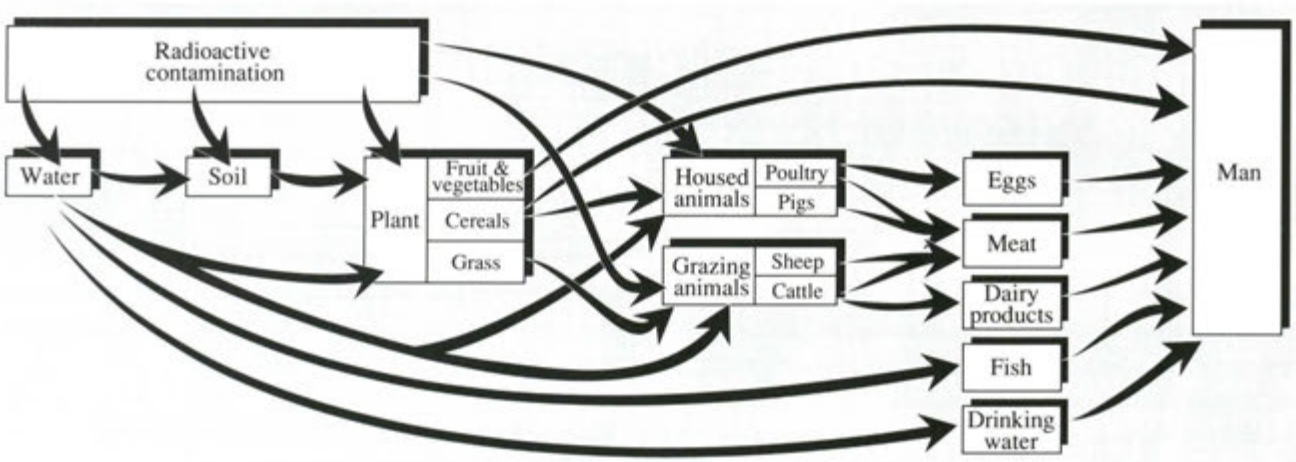

Figure 1. Pathways into the human food chain.

The prediction of the environmental effects of radionuclide release, either through controlled waste disposal or through accident is best effected by the development of suitable mathematical models.

The human food chain and agricultural systems

Except in the close vicinity of a very serious accident, the direct external radiation doses received by a human population in the aftermath of an accidental release are likely to be very small; external doses received following the controlled discharge of waste can be considered to be negligible. Of much graver concern is the possible incorporation of radionuclides into human food. As many radionuclides can accumulate in different body organs, localised radiation doses may be far higher than a generalised dose estimate. The route by which pollutant radionuclides pass into human foodstuffs, the human food chain, must be well understood in order to construct reliable prediction models. Figure 1 summarises the way that radionuclides may enter the food chain after accidental release. Different food sources will be contaminated to varying degrees depending upon the systems of agricultural production. The relative impact, in general terms, of an accidental release on various agricultural production systems is summarised in Table 2. It is clear that indoor systems of food production will be less affected than extensive systems.

ISOTOPES & RADIONUCLIDES

The atomic nucleus of a chemical element consists of protons and neutrons. Different elements have differing numbers of protons in the nucleus, but although the number of protons for a particular element is always the same, the number of neutrons can vary. Such forms of the same element, differing in atomic mass, are known as ISOTOPES. The nuclei of some isotopes are unstable and may disintegrate at any time. These elemental forms are known as radioisotopes or RADIONUCLIDES since they emit radiation upon nuclear disintegration in the form of α - or β-particles, or γ-rays. The stability of the nucleus of a radionuclide depends upon the particular nuclide and is expressed as the radioactive half-life, which is the time taken for half of the nuclei to disintegrate. The radioactive half-lives range from fractions of a second to millions of years for different radionuclides. Apart from any radioactive properties, the physical and chemical behaviour of all isotopes of the same element is virtually the same.

For prediction purposes, quantitative information is required on rates of transfer between adjacent stages in the food chain. The simple representation of pathways shown in Figure 1 is inadequate since many other pathways, mainly those concerned with recycling, have not been included. A much more complex understanding is required. As radionuclides of different elements behave differently from each other, separate models are needed for each radioactive element.

It is convenient to consider the movement of a radionuclide through the food chain as a series of processes which can be subdivided; these stages can later be recombined to form an overall predictive model. A typical subdivision for a grazing ruminant may be as shown in Figure 1. An example of the degree of complexity necessary for predicting the behaviour of a radionuclide and its entry into the human food chain is the examination of the factors affecting the movement of radiocaesium from Chernobyl into sheepmeat.

The effect of the Chernobyl nuclear accident on UK agriculture

Over the period 2-5 May, 1986, airborne radioactivity, originating from the accident at the Chernobyl nuclear power station (26 April 1986), passed over the United Kingdom. Whilst most of southern England received very little radioactive fall-out, greater levels of deposition occurred in parts of Wales, northern England and much of Scotland as a result of light, intermittent rainfall. Greatest contamination took place in isolated areas of north Wales, Cumbria, SW Scotland and the Scottish Highlands, where there were heavy rain showers. Parts of northern Scotland received further deposition two days later. The predominant radionuclides in the fall-out were iodine-131 (^{131}I), caesium-137 (^{137}Cs), ruthenium-103 (^{103}Ru), caesium-134 (^{134}Cs) and barium-140 (^{140}Ba). Shortly after the Chernobyl event the analysis for total radioactivity of samples of rain, dew, milk and herbage from north Scotland by MLURI helped the Scottish Development Department (SDD) to form a picture of the deposition patterns throughout the UK. The results showed very low levels of total radioactivity in milk and indicated the rapid decline in total radioactivity in samples of rain and dew but not of herbage. Although a considerable proportion of the radioactivity appeared in rainwater, the greatest impact upon agriculture was the contamination of rough grazing land; fortunately, vegetables and other food crops were little affected by the fall-out.

Despite its short radioactive half-life, ^{131}I caused the greatest initial concern because of its dominance and its ability to accumulate in the thyroid. Iodine-131 from contaminated herbage readily passes into cows' milk. In much of Scotland, most dairy cattle were still housed when deposition occurred, and thus levels in

ASPECTS OF RADIONUCLIDE TRANSFER
about which knowledge is required to derive a model for predicting radionuclide levels in a grazing ruminant.

Form of release - interception by plants, soil, water (rain, cloud, surface water), animals.

PLANTS - foliar uptake and adsorption; root uptake and interaction with soil conditions; translocation and storage within the plant; differences in uptake between plant species; uptake in relation to seasonal growth patterns; effect of the presence of stable isotopic forms of the same and related elements; effect of grazing or harvesting on uptake.

SOIL - rate of transfer to soil; effect of soil characteristics upon availability to plants; rate of leaching from soil; ability to form complexes with soil components; effect of soil organisms on fate of radionuclide; effect of fertiliser application.

ANIMALS - diet selection by grazing animals and intake of radionuclides; factors affecting transfer of radionuclide across the gut wall; transfer coefficients and biological half-lives of the radionuclide in different organs of the body; effect of physiological state and nutrient intake; relative excretion rates in faeces, urine and milk; impact of excretory returns on soil and pasture radionuclide levels; effect of changing management regimes.

milk were generally very low. Even in areas where many cows were exposed to relative high fall-out levels, ^{131}I levels in milk were well below the agreed level at which emergency action would be necessary (Derived Emergency Radioactivity Limit). Environmental levels of ^{131}I rapidly declined due to radioactive decay. Similarly the ^{103}Ru and ^{140}Ba soon disappeared.

The radionuclides of caesium-(134 and 137). being longer-lived, became the most important radionuclides from Chernobyl. Since both were released in the same chemical form and thus would behave similarly in the environment, they can be regarded as a single entity, radiocaesium.

Chernobyl and radiocaesium

Radiocaesium (predominantly ^{137}Cs) has been a common radioactive pollutant prior to the Chernobyl accident. Caesium-137 was the major long-lived adionuclide released from nuclear weapons tests; it was also released from the Windscale fire in 1957, and small quantities have been routinely discharged from the Sellafield nuclear fuel reprocessing plant. As a result, much research on the movement of radiocaesium through the environment (both terrestrial and marine) had been carried out and prediction models had been prepared. From these models, immediately after the release of Chernobyl fall-out over the UK, early predictions suggested that the fall-out radiocaesium would have little impact on the environment and almost negligible amounts would enter human food chains. Subsequent events showed that some of these predictions were inaccurate.

Soon after the scale of the Chernobyl accident was realised, the European Economic Community (EEC) imposed restrictions on imported food products

Table 2. Relative impact of accidental radionuclide release on different agricultural food production systems.

	Short term (0 - 1 month)	Medium term (1 - 6 months)	Long term (> 6 months)
Plant products			
Glasshouse crops	Very low - negligible (entry of contaminated air)	Very low - negligible (contaminated water supply)	Negligible
Mushrooms			Very low - negligible (contaminated compost)
Outdoor crops (cereals, fruit, vegetables)	High - very low (surface deposition)	Medium - very low (translocation and uptake from soil)	Medium - very low (uptake from soil)
Animal products	(Largely dependent on time of harvest relative to release date)		
Housed animals	Very low - negligable (entry of contaminated air)	Very low - negligable (contaminated water supply)	Very low - negligable (contaminated diets)
Grazed animals	High - very low (direct contamination; ingesting surface-contaminated grasses and water)	Medium- low (eating grass contaminated by translocation and uptake from soil)	Medium - low (eating grass contaminated by uptake from soil)

from eastern Europe showing a level of contamination greater than 600Bq/kg; restrictions were extended to movements across national borders within the Common Market. The Ministry of Agriculture, Fisheries and Food (MAFF) accepted the restrictions and imposed a 1000Bq/kg limit on food products for home consumption. About 3 weeks after the deposition of fall-out, radiocaesium levels in some lamb tissues were found to exceed the 1000Bq/kg limit.

Throughout the summer and autumn of 1986 radiocaesium levels in herbage on lowland and improved hill and upland pastures fell quite rapidly, whereas the levels in unimproved hill and upland vegetation fell more slowly. With the failure of the models in predicting the persistence of radiocaesium in unimproved hill and upland pastures new research studies (largely funded by MAFF) were initiated. From such studies, levels of contamination in hill ewes and in vegetation in the restricted areas of the Cumbrian fells were found not to fall over the winter period 1986/87 (Howard and Beresford, 1988). By removing large soil-blocks, with the associated vegetation, from a Cumbrian hillside to heated greenhouses in December 1986, it was shown that the radiocaesium levels in induced new vegetation growth were similar to those observed in summer 1986 (MAFF Press Release 1987).

Predictions from this work, of radiocaesium levels expected in new growth on hill and upland areas in summer 1987 were relatively accurate. However, only slow reductions in herbage contamination levels occurred throughout 1987. The realisation that the radiocaesium remained available for uptake by plants in the peaty soils of the hills and uplands of Wales, Cumbria and Scotland made it apparent that radiocaesium levels in certain sheep will probably exceed 1000Bq/kg for some years to come. It is thus likely that research on behaviour of radiocaesium in hill and upland sheep-producing areas will continue.

UNITS of RADIOACTIVITY and RADIATION DOSE

The unit of RADIOACTIVITY is the BECQUEREL (Bq) which is one nuclear disintegration per second. Since this is a very small unit KILO- (10^3), MEGA- (10^6), and GIGABECQUEREL (10^9Bq), and even larger units may be used. An older unit, equivalent to 3.7×10^{10}Bq, was the CURIE (Ci), which had the sub-divisions MILLI- (10^{-3}), MICRO- (10^{-6}) and PICOCURIE (10^{-12}Ci).

The unit of RADIATION DOSE is the GRAY (Gy), and represents the radiant energy of 1 Joule falling on an area of 1cm. In order to relate this to effects on human tissues, which takes into account the different effects of the various types of radiation, the SIEVERT (Sv) is the unit used. Both the Gray and the Sievert are very large units. Thus the most commonly-used units for radiation dose to man are MILLI-(10^{-3}) and MICROSIEVERTS (10^{-6}Sv).

The work of MLURI relating to radioactive pollutants in agricultural systems

MLURI has carried out work relevant to radioactive pollution since the mid 1960's with involvement in national schemes to monitor radioactive fall-out from nuclear bomb tests and from the Windscale accident as well as background levels in Grampian Region. More recently the Institute has been involved in detailed studies of the uptake of radionuclides by sheep in collaboration with both the Rowett Research Institute (RRI) and the Institute of Terresterial Ecology (ITE) at their Merlewood Research Station in Cumbria. In the latter, collaboration two scenarios of radionuclide contamination have been investigated; pollution derived from routine radionuclide release from Sellafield, and Chernobyl fall-out. In both cases ^{137}Cs has been the major radionuclide of interest.

Throughout the summer months sheep graze estuarine saltmarshes in west Cumbria close to Sellafield. Low-level liquid waste, routinely discharged through a pipeline into the Irish Sea, contains ^{137}Cs; some becomes adsorbed on to silt particles, which can be deposited on the saltmarsh at high tide. Studies by ITE in the early 1980's indicated that, despite being on the saltmarshes for a shorter period, lambs had higher ^{137}Cs tissue levels than ewes. MLURI collaborated with ITE in a project designed to explain these differences. When housed ewes and lambs were fed contaminated saltmarsh vegetation, ^{137}Cs uptake was low; despite similar apparent absorption values, tissue transfer coefficients were higher in lambs than in ewes. It was found that after removal from the saltmarsh and feeding on an uncontaminated diet, lambs had shorter biological half-lives than ewes. From estimates of ^{137}Cs levels in the milk of ewes grazing the saltmarsh and, using housed lambs, determinations of tissue ^{137}Cs uptake from contaminated ewes' milk, it was shown that milk can be an important source of ^{137}Cs to the lamb.

MLURI was fortunate in having facilities available to study the uptake, by sheep, of

radionuclides derived from Chernobyl and much valuable information was obtained.

Contaminated ryegrass was harvested two days after the deposition of Chernobyl fall-out. The grass, which was frozen, was fed to lactating ewes for 34 days; the lambs had been removed and lactation maintained by twice-daily hand-milking, and urine and faeces were quantitatively collected. Transfers of ^{131}I and radiocaesium to milk were estimated, with over 45% of ingested ^{131}I appearing in the milk; the milk transfer coefficient for ^{131}I was 0.228 d/l. These values for ewes' milk were much higher than ^{131}I transfers reported for cows' milk (Lengeman 1969). Observed transfers of ^{134}Cs and ^{137}Cs to ewes' milk were also higher than in cattle. The radiocaesium from Chernobyl appeared to be about ten times more available to ewes than ^{137}Cs from Sellafield associated with saltmarsh vegetation. Evidence is given in Figure 2, which shows the fate of radiocaesium in excretory products (a), and milk and muscle transfer co- efficients (b), in ewes fed vegetation contaminated with radiocaesium from Chernobyl or Sellafield. Clearly, the Sellafield radiocaesium, bound to silt particles, is less well absorbed than Chernobyl caesium.

The Chernobyl-contaminated grass was also fed to 9-week-old lambs for 6 weeks. The lambs also received uncontaminated ewes' milk from artificial feeders. Other lambs received contaminated milk and uncontaminated hay. The tissue transfer coefficients for lambs receiving radiocaesium from the milk or grass are depicted in Figure 3. The radiocaesium from milk was about 2.5 times more available than that from ryegrass contaminated with Chernobyl fall-out. This implies that the maximum degree to which Chernobyl caesium can be truly absorbed was only 40% (assuming that the radiocaesium in milk can be completely absorbed).

MLURI has also been involved in collaborative work on investigating methods by which the levels of contamination of sheep tissues can be reduced. Whilst

IONISING RADIATION

The radiation emanating from a radioactive source is ionising because of the nature of the disturbance to the medium through which it passes; it causes ions and free radicals to form. If the medium is living tissue, damage can result.

There are three main types of ionising radiation produced by nuclear disintegration:

ALPHA PARTICLES: α-particles are relatively heavy, consisting of two protons and two neutrons (the same as a helium nucleus). They are highly energetic. Whilst they can travel only small distances, even in air, they can be very damaging inside the body.

BETA PARTICLES: Two types of β-particles exist. A negative form is identical to an electron. Of the same mass, but with opposite charge, the other type is the same as a positron. Both penetrate further than alpha emissions, but cause less damage inside the body.

GAMMA RAYS - As protons of electromagnetic radiation, γ-rays have no mass. They travel long distances, with lead shielding being needed to stop them. They impart relatively little damage to living tissues.

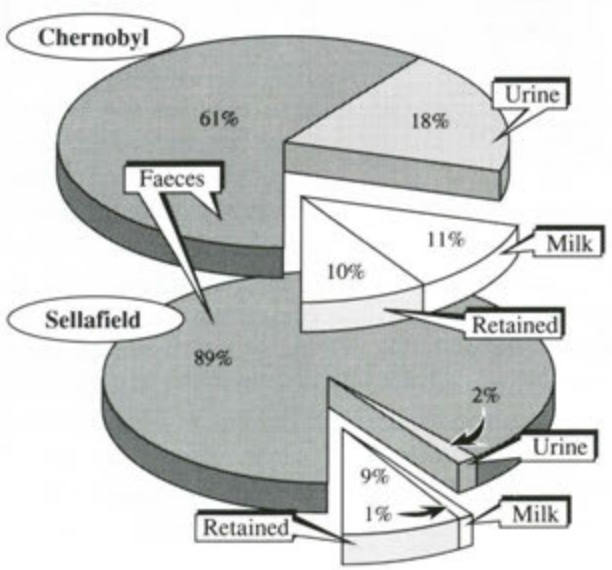

Figure 2a. Routes of ^{137}Cs excretion for ewes fed vegetation contaminated from Chernobyl or Sellafield.

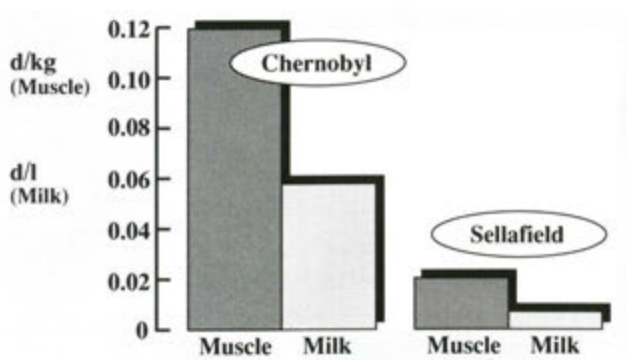

Figure 2b. ^{137}Cs transfer coefficients for muscle and milk for ewes fed vegetation contaminated from Chernobyl or Sellafield.

the removal of sheep to relatively uncontaminated pasture is an effective means of reducing tissue levels, there are situations where such a practice is difficult to undertake. Thus it would be desirable to have methods of restricting radiocaesium uptake by sheep grazing contaminated pasture. Difficulties arise with hill sheep since they cannot be handled at very frequent intervals. Methods have been developed in Scandinavia (originally for reindeer) to give animals a pellet which slowly releases a caesium-complexing agent, a hexacyanoferrate salt (Prussian Blue-type compound) into the rumen over many weeks; studies both in N. Ireland and in Continental Europe are under way to apply this approach to sheep. Various clay minerals are also effective in reducing the absorption of caesium. Tests at MLURI suggested that the mineral, clinoptilolite, would be an efficient binder for radiocaesium; subsequent animal tests at the Rowett Research Institute indicated that clinoptilolite was effective, but less so than hexacyanoferrate, in reducing caesium uptake.

The major problem with using clay minerals to reduce radiocaesium absorption in sheep is that doses of at least 10g/day are needed. One possible method of dosing hill sheep is to spread the mineral on the pasture. In a collaborative experiment, in which ITE had the major role, the effects of treating Cumbrian hill pasture with the bentonite clay were studied. Such treatments successfully reduced body ^{137}Cs and ^{134}Cs levels. However, part of the effect was due to reductions in herbage intake. Whilst multiple applications of bentonite caused greater reductions in tissue radiocaesium levels, the resultant reductions in herbage intake were responsible for substantial losses in liveweight (Beresford *et al* 1988). Since the application of bentonite to hills and uplands would be not only difficult, but also may be environmentally unsatisfactory and impair animal performance, it is unlikely that this method would be used to reduce radioactivity levels in sheep.

Dosing with stable caesium or potassium may be an effective means of "flushing out" radiocaesium from contaminated animals. An experiment carried out by MLURI in conjunction with the University of Manchester, Department of Chemistry, ITE and the Scottish Universities Research and Reactor Centre, investigated the effects of dosing sheep with caesium chloride or potassium chloride upon whole-body radiocaesium levels. A single dose of 400mg of CsCl caused, within 6 days, a 20% reducion in body ^{134}Cs + ^{137}Cs levels in lambs on mildly-contaminated pasture; smaller reductions occurred for a dose of 10g KCl. Subsequent doses of CsCl or KCl failed to reduce body radiocaesium any further (Oughton *et al* unpublished work). More work is required on the effects of stable caesium (normally present, but at very low levels) upon transfers of ^{134}Cs and ^{137}Cs.

The role of MLURI in relation to future research on radioactive pollutants and agricultural systems

With the continuing need to carry out research on the fate of radiocaesium in the environment a number of new studies are being initiated, on important factors which presently limit accurate prediction of radiocaesium levels in grazing sheep. MLURI is in a position to use its expertise in the chemistry of organic soils, grazing ecology and in ruminant physiology to study these topics.

Whilst it has been established that much of the radiocaesium in organic soils remains available for uptake by plant roots (in contrast with mineral soils) more work is required to examine the effects of soil organic matter, pH and other conditions on the speciation of the caesium and on root uptake by indigenous hill vegetation.

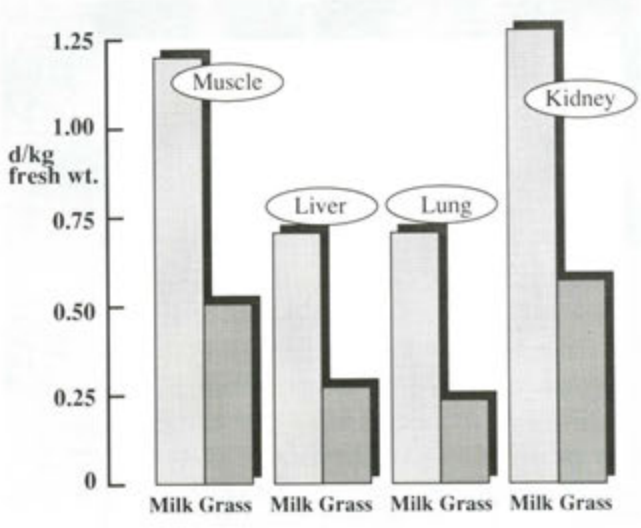

Figure 3. Caesium-137 transfer coefficients for the tissues of lambs fed contaminated milk or Chernobyl contaminated ryegrass.

The major problem in predicting radiocaesium intake in grazing animals is assessing what the animal will choose to eat; this is important since radiocaesium levels have been found to differ in different plant parts and species. A research project, supported by the Natural Environment Research Council (NERC), has been initiated to study the

transport and turnover of radiocaesium in pasture plants, so as to explain its distribution within plants, and to describe the factors influencing the ingestion of radiocaesium by animals grazing indigenous and improved hill pastures.

Recent evidence from joint studies with ITE suggest that the radiocaesium in herbage which was harvested two days after the deposition of Chernobyl fall-out (probably surface contamination) was less available than that in herbage grazed by sheep, 15 months later. Milk and tissue transfer coefficients probably reflect differences in availability, since it is likely that, after absorption, radiocaesium probably behaves the same, irrespective of source. The estimation of tissue transfer coefficients requires the attainment of equilibrium tissue radiocaesium levels; this can rarely be achieved. Methods will be developed in sheep, to determine the true absorption of radiocaesium (the ability to cross the gut wall) from contaminated diets. Other aspects of caesium metabolism in sheep will also be studied.

PARAMETERS DESCRIBING RADIONUCLIDE TRANSFER IN ANIMALS

If an animal receives a constant daily intake of a radionuclide, radionuclide levels in its tissues (and, if lactating, in milk) will rise to a maximum which will stay constant; the animal is then considered to be at EQUILIBRIUM. Conventionally, uptake is expressed as the TRANSFER COEFFICIENT, which is the equilibrium tissue activity relative to intake.

$$\text{Transfer Coefficient} = \frac{\text{Equilibrium tissue activity}}{\text{Daily radionuclide intake}}$$

If the same animal were to be returned to an uncontaminated diet, its tissues would lose radioactivity at a decreasing rate. This is conventionally expressed as the BIOLOGICAL HALF-LIFE, which is THE TIME taken for the radioactivity level in the tissue to decrease by one half. Note that this parameter differs from the radioactive half-life.

As a result of the Chernobyl disaster our understanding of the behaviour of radiocaesium in the hills and uplands, and its transfer to hill sheep, has been greatly enhanced. However, had the circumstances of the accident been different, it is likely that potential effects on UK agriculture would have been very different; in the 1957 Windscale accident ^{90}Sr was a major pollutant radionuclide whereas very little ^{90}Sr was released over the UK after Chernobyl. Thus we must, as far as is possible, be prepared for future accidents which may release different radionuclides over a diverse range of systems of agriculture. In a joint project with ITE, funded by MAFF and Central Electricity Generating Board (CEGB), MLURI is investigating the long-term changes in sheep tissue levels in response to single doses of various long-lived radionuclides which may be released after an accident at a nuclear power station; these include ^{3}H, ^{14}C, ^{35}S, ^{60}Co, ^{106}Ru and radiocerium. The ultimate aim of this type of work is to gain information in similar detail to that obtained on radiocaesium after Chernobyl.

Conclusion

It has been estimated that the deposition of Chernobyl fall-out increased the mean radiation dose of inhabitants of the UK by about 4% in 1986. Although such doses are not considered to have a measurable effect upon the health of the population, the imposition of restrictions on the slaughter of sheep grazing certain areas of the UK is an acknowledgement of the need to minimise the radiation dose from man-made sources. The experience of the environmental impact of an accident at Chernobyl, some 2000km distant from the United Kingdom, reinforces the need to have a detailed understanding of the behaviour of radionuclides in the environment and their entry into the human food chain, so that the consequences of an accident can be accurately predicted. The close proximity of large sections of the UK population to nuclear installations emphasises this need.

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Soil structure

M. V. Cheshire, J. F. Darbyshire, L. A. Dawson, A. C. Edwards,
J. H. Gauld, E. Paterson

Introduction

Soil scientists have devoted much effort to analysing the composition of the materials which constitute soils. More emphasis must now be placed on understanding the distribution and physical relationships of the components of soil which play a major role in chemical, physical and biological processes relevant to land use problems.

Soil structure may be defined as the spatial arrangement and distribution of particles and voids. Primary particles are associated together, to a greater or lesser extent, in aggregates with varying morphology, size, strength and resistance to dispersion. Soil porosity depends on voids within and between these structural units. However, aggregation and porosity are not static properties but change in response to natural, biological and anthropogenic processes.

Descriptions of soil structure may range from qualitative definitions of macrostructure in the field, using the naked eye or a hand lens, to quantitative measurements of microstructure in the laboratory, using more sophisticated methods. Both approaches deal with particular aspects of the study of soil structure and have much to contribute to our attempts to understand and rationalise natural systems. For example, in the study of soil/water interactions, crucial in nutrient transport and the quality of potable

water supplies, macrostructure largely determines the rate of water movement through the soil. Microstructure may influence the amount of water held and, through its effect on the extent to which chemical equilibrium may be attained, the composition of drainage water .

Field observation of macrostructure

In the field, soil structure is defined by reference to the degree of development, and the size and the shape of the structural units or peds. Thus, the description consists of separate sets of terms designating each of these three qualities which, by combination, form the name of particular types of structure. Examples are given in Figure1. Structureless horizons can be qualified as either massive, if the material coheres together and does not form aggregates, or single grain, as in many sandy soils which consist of individual sand grains.

Figure 1. Different types of soil structure. Left to right: Sourhope series (brown forest soil) with well developed crumb and subangular blocky structure; Scaurs series (peaty gleyed podzol) with poorly formed, indistinct peds and Fraserburgh series (calcareous regosol) with a massive structure, designated as single grain.

Work on the comprehensive soil mapping programme undertaken by the Soil Survey at MLURI has produced a considerable amount of qualitative data on the macrostructure associated with particular soil series and types of land use. Such data is generally to be found in the soil memoir published to accompany particular soil maps (for example Futty and Dry, 1977). Further field descriptions of soil macroscructure have been collected for the 3000 profiles held in the National Soil Inventory and for approximately 1500 profiles currently held in the Institute soil data base.

In addition to its use in the characterisation of soils, macrostructural data is relevant to the management of soils, particularly their need for specific drainage treatments and the field identification of compacted horizons. Such compaction may occur in the subsoil and represent an inherent property of the soil, or be present in the topsoil, where, as a product of management, its presence will seriously affect root growth, crop establishment and performance. Interpretations of the effect of different types of macrostructure on soil conditions are incorporated into the land capability for agriculture guidelines (Bibby *et al.*, 1982), which give guidance on the range of crops which might be grown on a soil and represent one of the principal elements of advice given to planning authorities on land use policy.

Although soil texture is the principal determinant of the amount of water held by a soil, it is the structure that determines the rate and pathway of water movement through the profile (Paterson and Mitchell, 1977) and the moisture release characteristics of the soil. For example, soils with a well-developed blocky structure throughout have sufficient pores and fissures, in both horizontal and vertical directions, to establish good drainage conditions (Wetness Classes I and II). In contrast, the absence of vertically aligned macropores in soils with massive or platy subsoils inhibits downward percolation of water and can contribute to seasonally defective drainage conditions (Wetness Class > III).

Laboratory investigations of microstructure

Observations of microstructure in the laboratory involve the use of both light and electron microscopy. Until recently, both required that soil samples be dried before examination - a process that can result in considerable structural changes. For light microscopy, samples are dehydrated with acetone, impregnated with resin and cut into thin sections where the distribution of mineral grains, organic matter and roots can be observed (Figure 2a on the next page). Similar procedures have been used to characterise soil porosity (Darbyshire *et al.*, 1985). To preserve the delicate fabric of biological samples the soil needs first to be fixed in buffered glutaraldehyde (Tippkötter *et al.*, 1986) and then dehydrated in a graded series of acetone/water mixtures. Plaster of

Paris has been used to assess soil under field conditions. It fills and stabilises macropores so the resulting sections can be used for image analysis and computer modelling of the pore system (Mackie, 1987).

Critical point drying, which is widely used for the drying of biological samples, has been assessed for

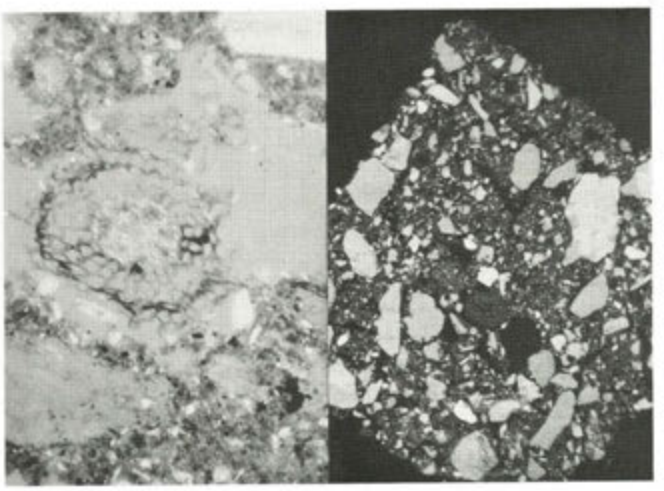


Figure 2a (left).Light micrograph of a soil thin section showing a root within a pore and a root hair penetrating an adjoining aggregate. 2b (right) is a backscattered electron image of sectioned aggregate showing distribution of mineral grains, roots and pores.

electron microscopy of soils and soil-related materials (McHardy and Birnie, 1987). Shrinkage and distortion are reduced and this has been confirmed using mercury intrusion porosimetry, which gives a quantitative size distribution of soil micropores. Backscattered electron imaging on the scanning electron microscope (MISR Annual Report No 55, page 41, 1985) can give a much clearer indication of the various structural features within the soil than conventional imaging techniques (Figure 2b).

In addition to micromorphological observation, laboratory studies also involve the physical and chemical characterisation of aggregation and porosity. Investigations of aggregate stability are of two types 1) those dealing with the resistance of aggregates to physical disruption which simulate the stresses exerted on aggregates in the field, and 2) those dealing with aggregate stability to chemical and physical disruption and aimed at a fundamental understanding of the mechanisms of aggregation and the binding agents involved.

As a result of raindrop impact and the rapid ingress of water into air-filled pores, rapid wetting of soil can cause considerable stress on aggregated structures. Trapped air is compressed and the aggregate explodes in response to the internal pressure generated. This rapid wetting effect is the basis of

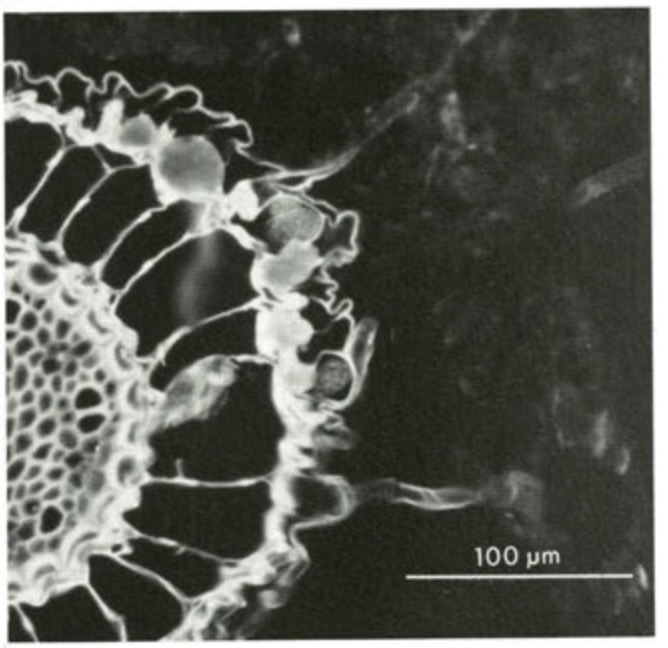


Figure 3. Transverse section of root of perennial ryegrass *(Lolium perenne)* in soil thin section. Note root hairs inside soil aggregates.

several methods which characterise structural stability. The particle size distributions obtained by subjecting 2-5 mm air dry aggregates from a topsoil to increasing intensities of disruption allow a macroaggregate stability index, less arbitrary than some currently in use, to be derived (Figure 4). The

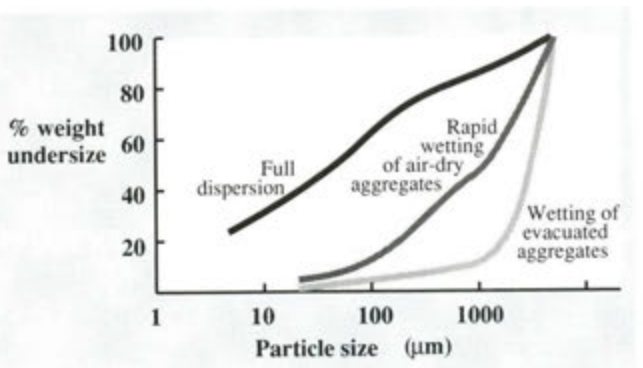


Figure 4. Size distribution curves obtained for 2-5mm aggregates after the treatments indicated.

numerical values obtained can be correlated with other soil properties (MISR Annual Report No 55, page 40, 1985). Extension of this approach to obtain a microaggregate stability index is feasible but has yet to be fully tested.

Significance of soil structure on root development and plant growth

Variation in the size and shape of structural units with depth can markedly influence the distribution of plant roots. The rate at which roots elongate is much reduced if they have to exert pressures to enlarge pores smaller than themselves. Recent investigations at MLURI have shown that whilst most roots lie in the pore space between aggregates, transient root hairs penetrate into the aggregates (Figure 3 on previous page).

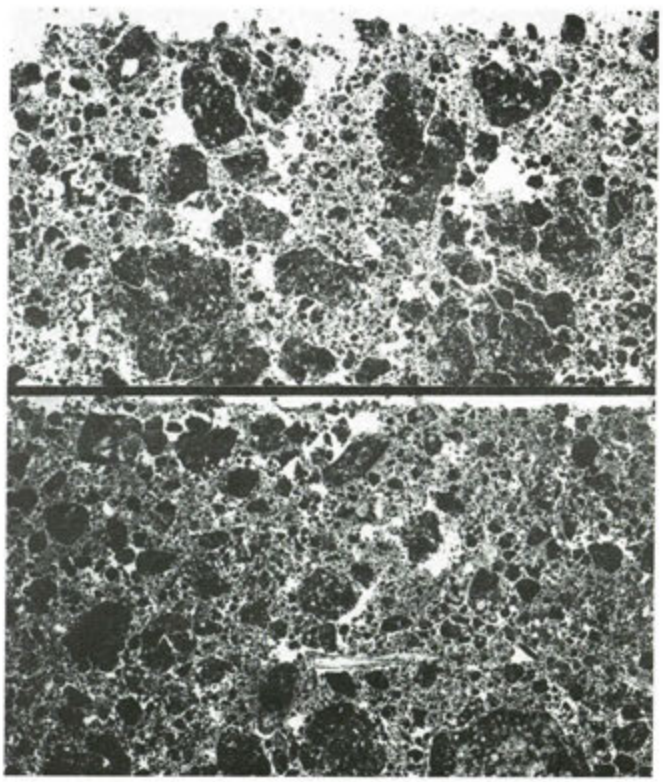


Figure 5. Consolidation (top) and overconsolidation (bottom) of a seedbed in a sandy loam soil.

In topsoils, good structure is necessary for seedling establishment. This is generally achieved by cultivation. The objectives of cultivation are the maintenance of aerobic conditions in the seedbed, the supply of adequate moisture to encourage germination and the provision of a density which allows the penetration of roots and shoots. With some hill and upland soils, and with coarser textured soils in general, this may require consolidation of the seedbed (Newbould, 1985). Over-consolidation, however, (Figure 5), can reduce the yield of spring barley by 8%. In finer textured soils, the effect is much more dramatic (MISR Annual Report, No 55, page 145, 1985). The changes in structure induced by cultivation are, however, transient (Figure 6). Inter-aggregate porosity immediately after ploughing can be greater than that found in a similar soil under grass. After "settling", interaggregate porosity in a tilled soil quickly decreases to a valuelower than that in grassland. In addition, the continuity of pores produced by cultivation decreases more rapidly than that produced by natural processes, eg earthworm activity (Mackie, 1983). In a sandy silt loam soil a range of methods of cultivation influenced root development by changing soil structure. The more open, subangular blocky structure of a ploughed topsoil resulted in deeper and more prolific early root growth than occurred in the denser, massive structured topsoil resulting from discing or rotospiking (Mackie-Dawson and Morrice, 1988).

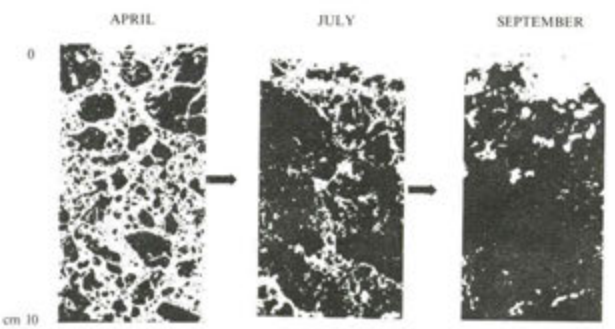


Figure 6. Settling of inter-aggregate porosity after ploughing on a clay-loam soil.

Soil structure also influences the incidence of disease in crops. For example, potato tubers showed a lower incidence of powdery scab in a soil with a subangular blocky structure where ped size had been increased by cultivation (Mackie and Munro, 1986).

Seedling emergence and grass production are primarily affected by the structure of topsoils. Subsoil structure, however, plays a significant role in the establishment and growth of deeper-rooted species such as trees. Here iron pans and indurated horizons may severely limit rooting depth, either directly by mechanical impedence or by producing a perched water table which some roots will not enter. The susceptibility of trees to windthrow is markedly influenced by such effects (Figure 7).

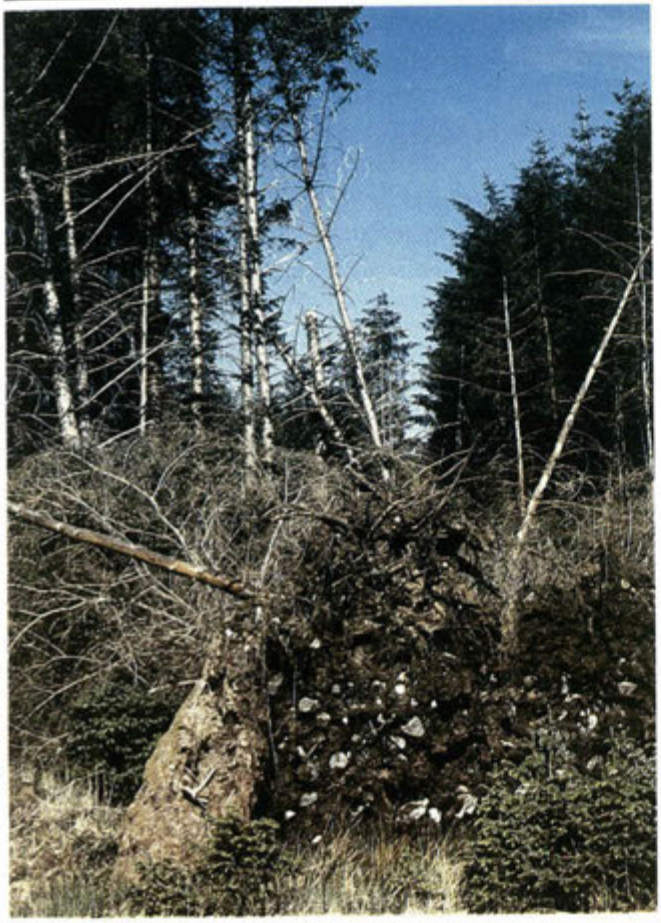


Figure 7. Windthrow of trees is a serious problem in soils where structural problems at depth contribute to shallow rooting.

Significance of soil structure for the microbial community

Different microorganisms seem to colonize the outside and inside of aggregates, (Hattori, 1973). The outside is colonized mainly by fungi, actinomycetes and spore-forming bacteria whilst non-sporing bacteria and actinomycetes dominate the interior. Within 35 µm aggregates the pores are too small to contain micropredators, such as protozoa and so bacteria, fungi and soil organic matter are protected from predation (Kilbertus, 1980). Recent investigations at MLURI have shown that ciliate protozoa and nematodes are likewise excluded from 1-2 mm aggregates, probably with similar consequences. Microorganisms colonizing the interiors of aggregates are thus more likely to withstand added toxins than those on the outside.

Effect of organic matter

Natural and biological processes, eg wetting/drying and freezing/thawing cycles, root and faunal activity create fissures and pores which lead to a well-developed structure. Processes such as slaking, swelling and untimely management tend to close fissures and pores producing structural damage.

In topsoils, organic matter binds primary soil particles. Current thinking is that individual clay, silt and sand particles are aggregated into microaggregates, < 250 µm diameter approximately, by amorphous organic matter. Microaggregates are the building blocks for macroaggregates (> 250 µm diameter), with binding brought about by the surface secretions of plant roots, fungal hyphae, and the soil fauna.

The organic matter content and the aggregate stability of soil are directly related. The water soluble fraction of the soil polysaccharide ("microbial gum") is a prime candidate as the active principal and generally shows a similar relationship to aggregation. The known properties of similar polymers, the basis of many glues, give support to this theory. Furthermore, the addition of polysaccharides, and substances of similar chemical structure to soil, enhance aggregation. However, polysaccharide forms a relatively constant proportion of soil organic matter in different types of soil and so any relationship may simply be with organic matter. In addition, a number

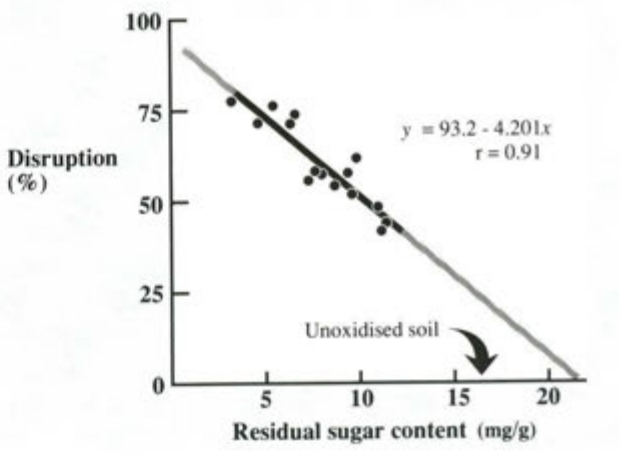


Figure 8. Relationship between the increased proportion of >45 µm particles as a percentage of sonicated soil (% disruption) and the residual reducing sugar content of the soil after periodate treatment.

of soils do not respond to treatment with periodate/sodium tetraborate, which specifically oxidises and releases carbohydrate, although reagents which dissolve more humified organic substances do disrupt aggregates. Periodate may react slowly with carbohydrate under laboratory conditions and so the

effects of extended treatment have been examined at MLURI. This was effective in all the soils studied (Cheshire *et al.*, 1983). By varying the time of treatment an inverse linear relationship between the degree of disruption of microaggregates, measured turbidimetrically (Sparling *et al.*, 1985), and residual carbohydrate was obtained (Figure 8). With short periods of treatment periodate did not affect macroaggregates from old pasture soils although the extended treatment disrupted these aggregates also (Cheshire *et al.*, 1984).

In theory, not all carbohydrate structures are susceptible to periodate. The reagent oxidises the bonds in the sugar molecule between carbon atoms

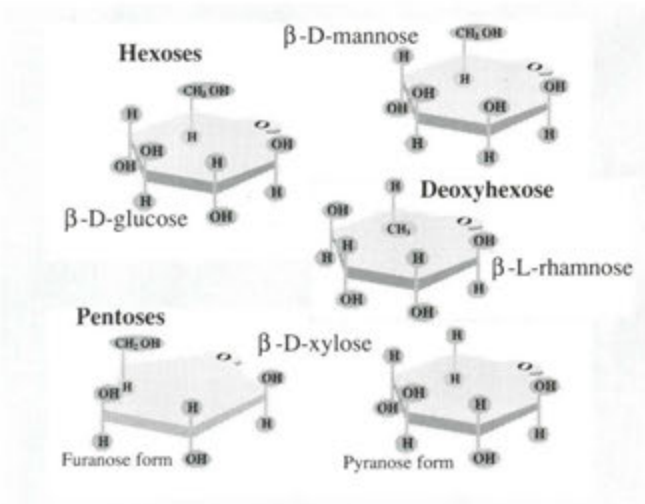


Figure 9. Chemical structures of some sugars commonly found in soil..

carrying adjacent hydroxyl groups although sugars with these linkages are common constituents of the plant residues found in soil, accounting for much of the glucose, xylose and arabinose present. The (1-3) linked glucose residues, which are a major constituent of fungal hyphae are, however, resistant to periodate. The relative resistance of old pasture soils to periodate treatment may therefore be accounted for by the prevalence of fungal hyphae in these soils. Treatment of an arable soil of a kind typical of the north east of Scotland with periodate resulted in the removal of 51% of the carbohydrate and caused disruption of 74% of microaggregates. Analysis of the composition of the residual sugars showed that the pentoses and glucose had the greatest persistence (Cheshire *et al.*, 1984). This implies that the hexoses and deoxyhexoses, which are major microbial products, are responsible for the binding action removed by this treatment. The residual pentoses appear to be of mixed microbial and plant origin (Cheshire *et al.*, 1985). The structures of some of these sugars are shown in Figure 9.

Macroaggregate stability appears to be related to the carbohydrate and lignin products characteristic of non-humified plant residues (MISR, Annual Report No 55, page 39, 1985). This gives added emphasis to the importance of plant roots. The beneficial effects of roots on soil microaggregate formation is clearly a long term process. It has yet to be established however whether these polymers are of plant origin, e.g. mucigel, synthesised by the microflora using plant products as substrates, or faunal products (Figure 10 overleaf). Short term effects of plants have been studied, and although, with a range of plant species, polysaccharide concentrations were markedly increased in the rhizosphere during a six-week growth period, there was little effect on the quantity of water-stable microaggregates (Sparling and Cheshire, 1985). The adsorption of polysaccharides on clay particles is crucial to aggregation. Polysaccharide molecules are sufficiently large to become adsorbed on to the surfaces of two clay particles and to form a bridge between them. The interactions between clay and polysaccharides are complex and reflect the surface properties of the clay and the charge (Cheshire and Mundie, 1986), shape and size of the polysaccharide. There is a clear need to extend laboratory studies on clay-polysaccharide interactions to typical soil systems. Soil polysaccharide is a complex mixture of polymers from many sources, which still defies complete structural analysis. Nevertheless, information on the types of linkage and degree of branching (ie shape) of the molecules may be obtained by methylation analysis techniques adapted for soil (Cheshire *et al.*, 1983).

Incubating soil with glucose results in the formation of aggregates which lack long-term stability. Stability can be promoted by the prior addition of humic acid, in a form easily adsorbed on clay. Non-adsorbed humic acid is ineffective (Chaney and Swift, 1986). This effect seems at variance with the clay-polysaccharide theory. The function of humic acid clearly needs further investigation. Humic acid may form a link between clay and polysaccharide, or may cover only part of the clay surface. In this way, it may prevent the action of hydrolysing enzymes on the polysaccharide or have a protective tanning action (Cheshire, 1979). Evidence

that humic substances rather than polysaccharides are involved in aggregation has come from studies of the disruptive effect of sodium pyrophosphate, an effective humic extraction agent, on periodate-treated soil (Hamblin, 1980). However, after an extended periodate treatment effects are small, suggesting that the two components act together. In preliminary experiments which attempted to relate polysaccharide

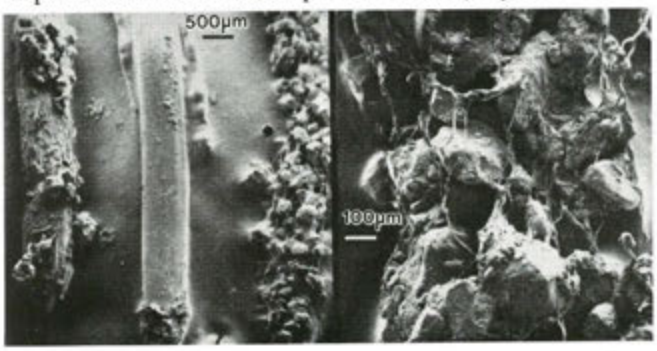


Figure 10. Electron micrographs showing (from left to right) a) Retention of soil on middle aged, young and old roots after gentle washing. b) Enlargement of the old root and adhering soil in a) showing the binding together of the soil particles by a network of root hairs and soil fungi. c) A large soil particle or aggregate adjacent to a root surface. d) Enlargement of the boxed area in c) showing the nature of the mucilaginous material forming a bridge between the root surface and the soil particle.

characteristics to stable aggregate formation by using monocultures of selected microorganisms effects with topsoil, which contains more organic matter content, were greater than with the corresponding subsoil (MISR Annual Report No 56, page 104, 1986), a parallel to the humic acid experiments.

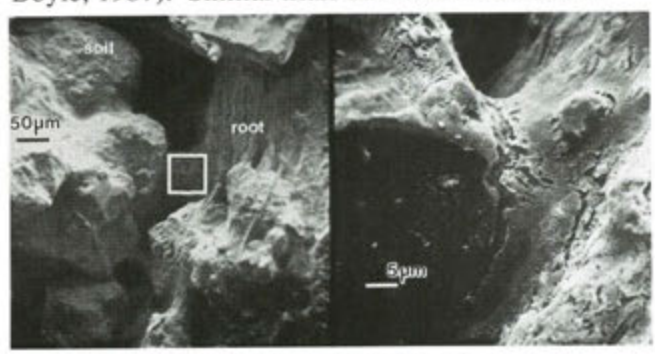
It is tempting to conclude that the two types of polymer, polysaccharide and humic substance, may each be effective aggregating agents. Although the substances have very different chemical compositions they may possess relatively similar molecular size and charge, for many of the polysaccharides contain uronic acid components.

Such charged molecules may bind mineral particles together through cationic linkages, providing an additional mechanism to those where adsorption depends on Van der Waals interactions and hydrogen bonding.

Effect of soil fauna

The fertility of a soil depends on a pore system in which water and air can circulate. Many soil animals contribute to such a pore system and are continually creating new soil pores by their burrowing and excavations. Earthworms are particularly important in this process.

Soil structure is usually satisfactory for plant growth when there is an abundant earthworm population (Edwards, 1985) and inoculations with earthworms have improved soil structure and increased grass production in Holland, New Zealand and Ireland (Hoogerkamp *et al.*, 1983; Stockhill and Cossens, 1966; Syers and Springett, 1983; Curry and Boyle, 1987). Similar trials have been initiated on



French heathlands (Tréhen and Bouché, 1983).

Earthworms can be classified into three major ecological groups; *epigeic* litter dwellers, *anecic* topsoil mixers and *endogeic* lower soil species, depending on their feeding behaviour and general distribution in the soil. There is some evidence that earthworms in these different ecological groups have different effects on soil structure. For example, Springett (1985) introduced a topsoil-mixing earthworm into sheep-grazed hill country in New Zealand, where only the other two ecological types were present, and increased the rate of water infiltration, total porosity and root biomass. In some seasons pasture growth was also increased. Shaw and Pawluk (1986) studied the micromorphological effects of anecic topsoil mixers and endogeic lower soil earthworms in Canadian prairie soils. Where only the topsoil-mixing species were active the grass litter was completely removed from the surface and intimately mixed with mineral components of the soil. The earthworms secreted organic compounds which firmly bound the soil components together. The micromorphological modifications were largely confined to the linings of the earthworm channels and surface casts; with the rest of the soil unaltered. The endogeic earthworms however were active throughout the soil, formed more ephemeral channels, homogenised the soil fabric, but had little contact with the surface litter. The two types of earthworm therefore had a synergistic effect on soil structure. Both species increased the concentration of clay-bound neutral sugar residues in faeces. In

addition other organic substances secreted by earthworms can bind clays and form microscopic aggregates. Recent studies at MLURI, illustrated in Figure 11 show the speed of litter incorporation into soil by earthworms and the rapid changes that can occur in earthworm burrows.

Many other animals besides earthworms influence soil aggregation. Current evidence suggests that the surface layers of most soils have been consumed and reworked many times by a series of soil animals with existing soil aggregates probably being destroyed during ingestion. Most soil animals ingest plant material in varying stages of decomposition and mix it with clays and other mineral material. Coprophagy is also common. As the faecal pellets of many animals have a characteristic appearance, it is often possible to trace some of the feeding regimes in soil. The details of these transformations and their effects on soil structure in many soils, however, remain to be determined.

Figure 11. Earthworm vivaria, just after the addition of apple leaves (left) and seven days later.(right) Note the disappearance of the leaves from the soil surface and the network of earthworm channels.

Effect of inorganic components

Inorganic soil components, such as the hydrous oxides of iron and aluminium, may also play a part in aggregation either in-concert with organic molecules or as cementation agents in their own right.

Future prospects

It is clear from this brief review that soil structure arises from a complex series of interdependent processes and subsequently plays a critical role in soil/plant interactions. In addition, soil structure is not a fixed, immutable property but one that may be manipulated and improved. However, structural conditions can also deteriorate and consideration must be given to soils in danger of structural breakdown.

Within the context of an integrated soil/plant/animal approach to the use of the hills and uplands the structural damage caused by animal treading is important. This can severely limit the use of valuable pastures, particularly in early autumn. In addition, changes in soil physical conditions within the rooting zone can result in changes in pasture composition and nutrient cycling.

Another area, potentially significant in view of present trends towards increased afforestation, is the impact of changes in land use on the environment, particularly with regard to water quality and soil erosion. Efforts in this area include assessments of the effects of cultivation, during the establishment of forests, on soil stability and the structural changes accompanying the drying-out of highly organic soils.

Within the broad spectrum of nutrient cycling and availability, the importance of inherent fertility and the effective utilisation of natural soil resources is clearly important in an economic climate that does not justify major nutrient inputs. In this regard the importance of structure is two-fold. Firstly, the physical inaccessibility of the interior of soil

aggregates acts as a major limitation to the chemical and biochemical transformations of organic matter and its associated nutrients. A balance is needed between the benefits of nutrient release and the increased risk of erosion. Secondly, the distribution of the soil solution within the pore system will influence the availability of dissolved nutrients, and particularly those concentrated in finer pores.

Although earthworms are recognised as one of the major natural cultivators of soil, large scale inoculations of earthworms into field trials in Britain have been relatively neglected by zoologists and soil scientists. Further detailed studies of the effect of earthworms combined with other soil animals on soil structure now seems to be merited, particularly where, as in many hill and upland situations, mechanical cultivations are not feasible.

It should now be clear that soil structure depends on a complex interplay of natural forces which include the expression of chemical and physical characteristics by organic polymers, mineral particles, oxides and cations as well as soil biological activity by a multitude of living organisms ranging from microorganisms to plants. Future studies planned, whilst concentrating on events occurring at a molecular level, must attempt to relate these to a comprehensive conception of structure in soil.

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Alternative animal enterprises for the hills and uplands

J. A. Milne, A. J. F. Russel and W. J. Hamilton

Introduction

The hills and uplands of the UK have limitations of soil and climate which, historically, have made these areas unsuited for the production of cereal and protein crops and appropriate for the conversion of grazed herbage into meat by sheep and cattle. Currently approximately 20% of the beef and 40% of the lamb produced in the UK originate in these areas and the stratified nature of the UK sheep industry is highly dependent on the rearing of sheep in hills and upland areas. Although beef cow numbers have declined by 29% between 1974 and 1987 and 70% of these are found in the least favoured areas (Wright 1987), there has been a large increase in the number of breeding

ewes (25%) over the same period, with 60% of these animals found in hill and upland areas (MLC, 1987). These changes are a consequence of EEC policies of price support and headage payments which are likely to be modified in the future, so that it will be less financially attractive to produce sheep and cattle from these areas. There are a number of reasons for these changes in policy, not all of which need be of concern in this article; but those related to the need to create a

Figure 1. Red deer at MLURI's Glensaugh research station near Laurencekirk.

balance between production and supply of meat within the EEC and to the desire to manage the unique resources of the hills and uplands to meet a range of agriculture, wildlife and amenity objectives are of relevance in the development of alternative animal enterprises.

The current supply-and-demand position for beef in the EEC and the projection that sheep-meat supply will meet demand within the EEC in the next 5-10 years implies that there is likely to be only a moderate demand for red meat from alternative animals. However this is an overly simplistic analysis. Consumer preferences are for lean meat and for foods that are easy to prepare and there is likely to be a demand for such meat products, albeit partly at the expense of consumption of traditional beef and sheep products. Such arguments presuppose that the objective is self-sufficiency within the EEC for red meat. Depending upon the rate of growth of the world economy in the future, there could develop an export market for beef and sheep-meat in countries with a rapid increase in standard of living but with no indigenous meat-producing agriculture. However, much of any increase in production is likely to originate from areas other than the hills and uplands because of economic and conservation considerations, implying that there will still be a need to find alternative forms of animal production.

The development of alternative products to meat, which could become an extremely competitive sector of the agricultural industry, has, therefore, considerable attractions. Traditionally this product in the hills and uplands has been wool from sheep. With present price structures wool only amounts to 5% of total income from lamb, cast ewes and wool. Demand for carpet wool, which is the wool produced by most hill sheep, is declining but that for semi-fine wool is relatively strong. If the balance between lamb and wool prices alters in favour of wool, the production of semi-fine wool could increase in its attractiveness once its feasibility in hill areas, in particular, has been tested. However it is likely that this will be as a means of supplementing income from sheep meat and thus halting the decline in the number of sheep grazed in the hills and uplands rather than in increasing numbers. There appears to be a strong demand from the high-fashion market for high quality animal fibre which is currently imported from all over the world; cashmere from China, the Middle-East and Australia, mohair from South Africa and alpaca from South America. There would therefore appear to be some potential for import-substitution if such fibres could be produced economically in the UK.

While it is crucial that there is a demand in the UK for these alternative animal products at prices which relate closely to those of imported products of similar quality, the cost structure of alternative animal enterprises requires to be such that an adequate return on investment is obtained. The cost structure is determined by the necessary investment in animals and fixed equipment and the optimal arrangement of resources to produce efficient production systems. Economic and biological efficiency of production systems with grazing ruminants is governed by the reproductive rate, the replacement rate of breeding females and the proportion of the total feed requirement that can be provided from grazed herbage. This latter component (of efficiency) is comprised of a number of factors, such as the efficiency of nutrient conversion into animal product, the extent of the maintenance costs in nutrients of the adult male and female breeding herds and flocks and the age at which breeding animals enter the herd or flock. These factors interact with the seasonal pattern

of nutrient supply from grazed herbage to determine feed efficiency. Obviously the relative costs of nutrients from grazed herbage to those from conserved forage and purchased concentrate feed will determine the optimal mix of resources, but at projected future costs it is likely that the efficient use of grazed herbage will remain a high priority. Moreover, in any consideration of alternative animal enterprises, the impact on other forms of land use, such as wildlife and amenity, must also be considered. In the case of the grazing ruminant in hill areas this principally involves considering the effect of grazing behaviour on the indigenous vegetation.

It is against this background of product demand, product price and biological efficiency that alternatives to sheep and cattle as utilisers of the resources of the hills and uplands must be judged. The production of red deer meat and of animal fibre from goats and camelids is judged against these criteria below.

Red Deer

The farming of red deer has been investigated experimentally since 1970. It has been shown that they can be managed successfully under farming conditions (Blaxter *et al,* 1974) and that efficient management systems can be developed for hill and upland resources (Blaxter *et al,* 1988). Ten years of component research have allowed systems of

Calving rate (%)	92.1
Weaning rate (%)	86.8
Weaning weight (kg)	38.6
Hind mortality (%)	0.3

Table 1. The performance of farmed red deer hinds in a West Highland environment (HIDB, Rahoy Deer Farm) in 1987. (MLURI, unpublished data)

production to be synthesised. Systems, suitable for hill environments, have been developed for the production of weaned calves at 4 months of age in September and these are being successfully tested on a large scale by MLURI with 600 breeding hinds at the Highlands and Islands Development Board's Rahoy Deer Farm.

Table 1 shows the high levels of breeding performance that can be obtained in a difficult environment. These systems are based upon the integration of an area of reseeded pasture, for use in lactation and over the mating period, with an area of hill where the hinds are wintered. Sown swards maintained at between 4 and 6 cm in the summer will provide higher levels of hind milk yields and of calf live-weight gains than those that can be obtained from

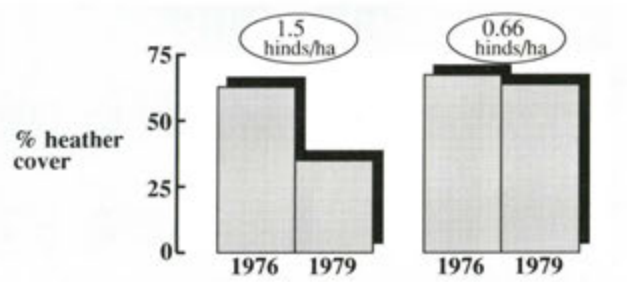

Figure 2. The effect of stocking rate of breeding hinds on a heather moor on heather cover following grazing for 3 years. (after Grant, Hamilton and Souter, 1981).

hill vegetation (Loudon *et al,* 1984). Current knowledge suggests that stocking rates on a heather hill to sustain the productivity of heather should be no greater than 0.66 hinds per hectare (see Figure 2) and that hinds should not lose more than 5% of their live weight over the winter period. To meet this latter criterion and depending upon the nature of the hill vegetation, additional feed requires to be given. Figure 3 shows how access to an area of hill in winter can reduce feed costs and provide adequate levels of performance and indicates the type of system which is likely to make the most efficient use of hill and upland resources. Gross margins per hind and per hectare of £40 and £400 respectively can be obtained with higher

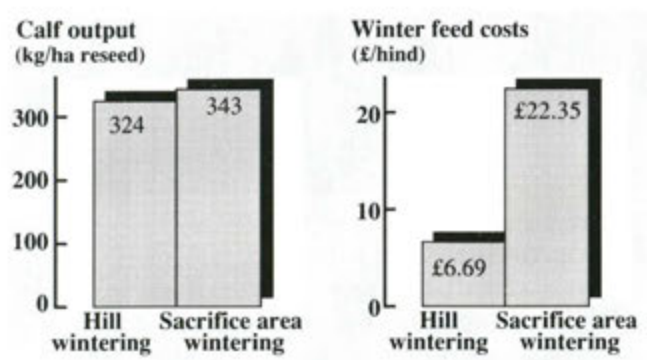

Figure 3. The effect of wintering system on the output per hectare of reseed and winter fed costs of systems of weaned deer calf production in an upland environment. (W J Hamilton, T J Maxwell and J Eadie, unpublished data).

gross margins being found on systems where the integration of hill and reseeded pasture can be achieved. Fencing costs are initially high and mitigate against solely hill systems compared to those where a proportion of reseeded pasture is included (Hamilton, 1986).

Weaned calves are grazed on autumn swards until housing in November or December or wintered on sheltered rough grazing, such as mature woodland. Calves are sold at this stage and a weaned calf trade has been created such that separate systems of rearing and finishing have developed. The objective of these systems is the production of animals for slaughter at approximately 16 months of age at 75-80 kg. Calves show compensatory growth as yearlings in the summer if they are maintained on a relatively low level plane of nutrition in mid-winter. This coincides with a natural period of inappetance which can be

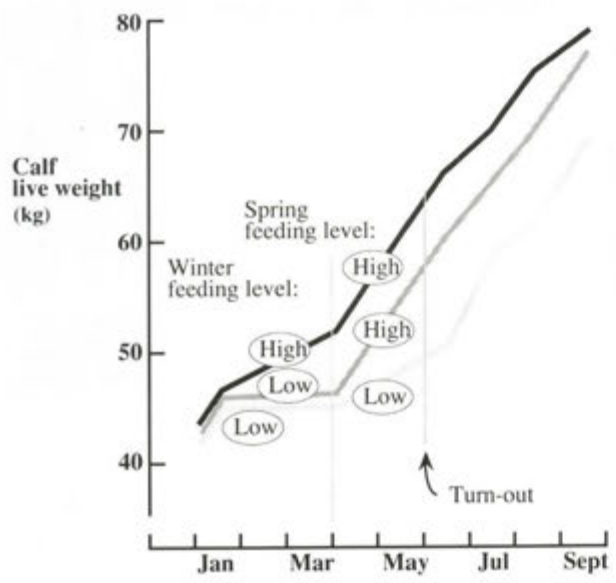

Figure 4. The effect of winter and spring patterns of growth of yearling stags on compensatory growth at pasture in the summer. (Milne *et al*, 1987)

followed by a period of a high level of nutrition in March and April before turn-out to pasture without losing the benefit of compensatory growth. This is illustrated in Figure 4, where such a system of feeding produces animals of similar live weight to that of animals given high levels of nutrition throughout the winter. Live weight gains at pasture are positively related to sward height and gains of up to 200 g/day can be achieved over the summer period.

There is little evidence to suggest that there are major differences between the red deer and sheep and cattle in the components of efficiency of conversion of feed to animal product. Advantages in one aspect are counterbalanced by a disadvantage in another. The red deer eats more digestible energy per unit of metabolic live weight than the sheep (Milne *et al*, 1978) but has higher metabolisable energy requirements when expressed on the same basis (Simpson *et al*, 1978). The red deer shows a greater seasonality of performance than sheep or cattle. This means that growth rates of red deer calves in their first winter are reduced and acts as a potential disadvantage by extending the period between birth and slaughter. The hind has a later date of parturition than the sheep which reduces winter feed costs but which limits the weaning live weight of the calf. Twinning is extremely rare in red deer, which makes it biologically less efficient than the sheep, but females enter the breeding herd at a relatively younger age than sheep or cattle in relation to the life-time performance of the hind. Yearlings reach puberty and are mated at 16 months of age if they have reached a live weight of 80 kg, and the adult appears to be able to produce 15 satisfactory calf crops. Mortality rates in both adult and young stock are similar to or less than those found for sheep and cattle. Consequently the combination of these factors produces a replacement rate of hinds (0.07) per annum, which is much lower than that for ewes (0.25) or suckler cows (0.15).

It has been demonstrated above that efficient systems of production exist which produce gross margins per hind of £40-60 with the current variable cost structure and prices, i.e. £2 per kg live weight for weaned male calves, £4 per kg for weaned female calves and £3 per kg dressed carcases weight for finished yearlings. The national herd of farmed red deer has reached 13,000 hinds, which will enable a moderately rapid increase in breeding animals to be obtained in the future. There is also the potential to increase this rate by the capture of stock from the 155,000 wild hinds in Scotland, the largest population of hinds ever recorded which is considered to be leading to over-stocking (Red Deer Commission, 1986). The availability of female breeding stock should ensure that prices for females will remain in line with end-product prices. There is a high initial setting-up cost in fencing and this is perhaps the major factor which has limited the expansion of deer farming in the UK.

Deer meat is currently sold as a high value luxury lean meat. There is a limit to the amount of deer meat that can be sold in such a market, unless there is skilful marketing of the product. Insufficient supplies and lack of continuity of supply have meant to date that marketing is in its infancy. The greater supplies now entering the market both from home

production and from New Zealand provide the opportunity for successfully marketing a range of products over most of the year. The future of deer farming probably rests on the maintenance of end-product prices, since it is difficult to envisage how costs can be reduced through large increases in efficiency.

Cashmere Goats

The initial interest in goats for use in the hill and upland areas of the UK was concerned solely with their grazing preferences and habits, and their potential to bring about changes in vegetation

Figure 5. A newly born cashmere kid at Sourhope research station in Roxburghshire. The Institute's goat breeding programme is designed to increase the production of high quality cashmere by crossing native feral goats with superior imported stock.

beneficial to sheep or cattle production. It was only after achieving convincing results from these early studies on goat grazing, that serious consideration was given in the last 5 years to the production of cashmere and goat meat from hill and upland resources.

The current interest in goats is largely concerned with fibre production. Goat meat is generally regarded as a by-product, although economic projections indicate that it is likely to constitute a major proportion of the income in commercial goat enterprises. The considerable potential to manipulate vegetation and, in particular, to control weed species and encourage clover in sown pasture has received insufficient attention; these advantages should not be ignored because of the difficulty in quantifying them in the short term.

One of the most common problems with reseeded hill pastures is infestation with rushes (*Juncus* spp). Goats readily graze rushes and the severity of the grazing is inversely related to the amount of grass available, i.e. the shorter the sward

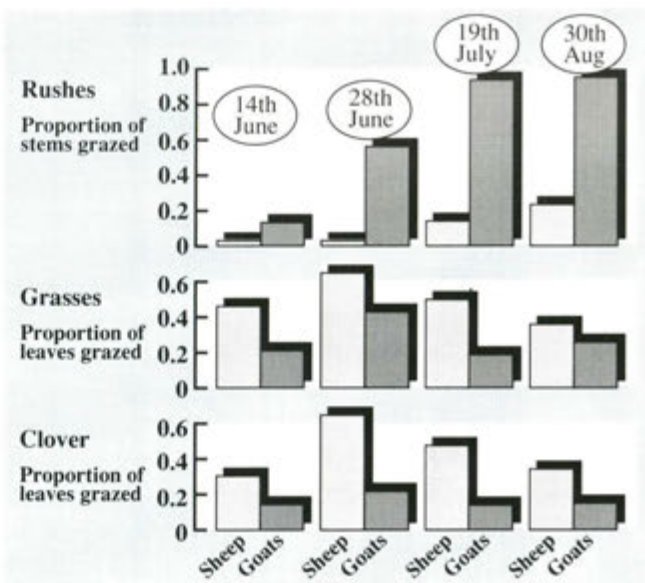

Figure 6. Reseeded pasture. The proportions of rushes, grass or clover grazed by sheep or goats.

the greater the extent to which the rushes are grazed (Grant, *et al.* 1984). Recent research has shown that where inter-tussock sward height is maintained at 5-6 cm, grazing by goats will progressively diminish the vigour and density of rushes over a period of 3 years. Rushes can, however, be effectively eliminated in one grazing season by a heavy stocking with goats (about 30 per hectare) supplemented if necessary with sufficient sheep to maintain the inter-tussock sward height at no more than 3-4 cm (Lippert, unpublished data).

The management of mosaic reseeds, areas of pasture which, because of problems of drainage and topography, are sown as patches within larger enclosed area s of indigenous vegetation, can be difficult under sheep-only grazing regimes.

Grant, *et al.* (1984) showed that goats grazed the sown grass and particularly the clover on mosaic reseeds to a lesser extent, and rushes to a markedly greater extent, than did sheep (Figure 6). On the unimproved areas the goats grazed the indigenous species heavily

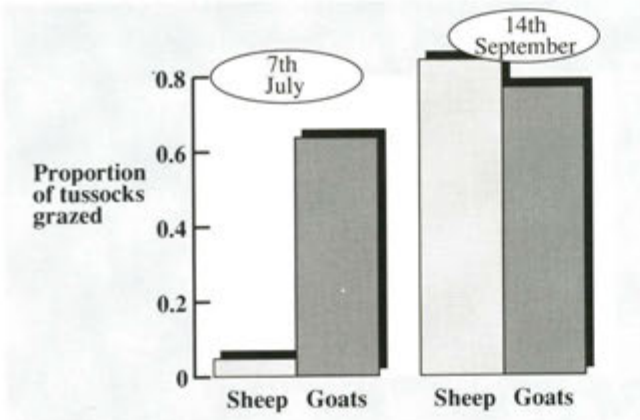

Figure 7. Indigenous pasture; the proportion of *Eriophorum vaginatum* tussocks grazed by sheep or goats.

when grass was plentiful earlier in the season and in contrast to the pattern shown by sheep (Figure 7).

Work by Grant, *et al.* (1987), showed that *Nardus*, which is not preferentially grazed by sheep, can be controlled effectively by grazing with goats. This, together with the results referred to above, indicate a considerable potential complementarity between sheep and goats in the grazing management of a variety of vegetational resources.

Goat meat, like deer meat, is leaner than other red meats and is attracting attention as a more 'healthy' meat from an increasingly diet conscious public. Although there appears to be a growing demand from the restaurant and hotel trade for the higher priced cuts of goat meat, much of it is eaten as stews and curries, and thus large joints and cuts are not a particular advantage. Data abstracted from a survey by Steele (1984) of the potential market for goat meat indicate a demand in the UK for some half million carcasses, equivalent to about 8,000 tonnes, per annum. The present goat industry, made up largely of dairy goats, is very fragmented and few producers have a sufficient number of animals to provide the continuity of supply which the market demands. As with the deer meat industry, a marketing structure is required to co-ordinate the output of the substantial number of small producers.

The main factors likely to be important in relation to goat meat production are the rate of live-weight gain and the cost at which that gain is obtained. Fibre producing goats are not noted for their milk production and kid growth rates tend to be low relative to those of dairy goats. Russel, *et al.* (1986) reported gains from birth to weaning in single-reared kids of only 77 g per day in feral fibre-producing goats compared with 145 g per day in dairy goats. However in more recent studies by Russel, White, Smith and Adkins (unpublished), much higher growth rates from birth to 10 weeks were recorded (Table 2). This work also showed that while ferals have low levels of milk production, the percentages of fat and protein in the ferals' milk were considerably greater than in milk from the dairy breeds.

Kids kept for meat production in dairy goat enterprises are generally artificially reared on a milk replacer as their dams' milk is required for sale. Frequently these kids are sold at a very young age, and in many cases the price obtained for the kids does not cover the rearing costs. Kids from cashmere goats are likely to be kept until they are at least 10-12 months old to allow one harvest of fibre to be taken before being sold for meat. There are thus opportunities for cashmere kids to be taken to heavier weights before slaughter and for most of the live-weight gain to be achieved inexpensively from grazing.

Dam genotype	No of kids suckled/doe	Milk yield (kg/day)	Milk fat (%)	Milk fat (g/day)	Milk protein (%)	Milk protein (g/day)	Kid live-weight gain (g/day)
Feral	1	1.3 (±0.41)	7.0	86 (±22.8)	3.4	43(±13.2)	165 (±25.2)
Feral x dairy	1	1.9 (±0.26)	4.9	92 (±14.3)	3.4	65(±10.2)	175 (±25.7)
Dairy	2	3.0 (±0.67)	3.1	91 (±22.1)	2.6	78(±16.3)	161 (±29.4)

Table 2. The mean daily lactation performance and kid growth rate (±se) in three goat genotypes (0 - 10 weeks).

The original interest in cashmere production was centred on Scottish feral goats. These animals produce signficant, but non-commercial, quantities of cashmere, averaging 80-100 g per head. It is of exceptional quality, with a mean fibre diameter of around 14 microns. Feral goats are also hardy, having bred and thrived in some of the climatically and topographically harshest areas of Scotland.

There is a high coefficient of variation (37%) in the weight of cashmere produced by Scottish feral goats kept under similar management conditions, indicating that the potential rate of increase in the production which could be achieved by genetic

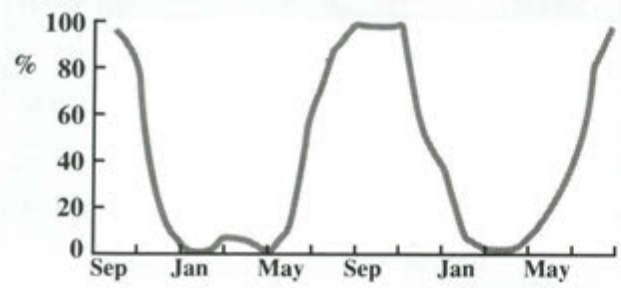

Figure 8. The seasonal pattern of activity of secondary skin follicles in Scottish cashmere goats.

selection is likely to be high. A co-operative group, Cashmere Breeders Limited, was constituted in 1986, with the Institute as a founder member and also acting as managing agent. This group, which now has 9 farmer members, is pursuing a 2-stage breeding policy to produce goats with larger yields of quality cashmere. In the first stage, superior genetic material in the form of either live animals, semen or embryos, has been imported from Iceland, Tasmania and New Zealand. These animals are currently being multiplied and crossed with each other and with native feral stock, using artificial insemination, superovulation and embryo transfer techniques, prior to the initiation of the second stage of the programme. This will involve a group breeding scheme in which superior animals from each of the members' farms will be selected to form an elite herd.

Studies on the seasonal pattern of growth of cashmere (Merchant, Russel and Ryder, unpublished) have shown that although the main period of growth, as judged by examination of the secondary skin follicles, is from the summer solstice to the winter solstice, there is a significant degree of follicular activity outwith this period (Figure 8). This indicates that the length of the growing season, and hence the amount of cashmere produced, may be amenable to change by genetic selection. This will necessarily be a long-term strategy, and work in progress is examining the potential to manipulate cashmere production by other means. The objective is not only to extend the period of growth of cashmere but to study the manipulation of the the natural shedding cycle of the fibre, which has important implications with respect to cashmere harvesting (see the research summary further on in this report).

It is difficult at this early stage in the development of the cashmere goat industry in the UK to make predictions. Breeding stock are still scarce and prices do not yet relate to productivity; future levels of production are, at this stage, a matter of speculation. Nonetheless, gross margins of around £35-40 per breeding doe could be achieved from combined cashmere and goat-meat systems. This does not include any value for the pasture improvement potential of such enterprises. Because of the goat's small size and consequent high stocking rate, gross margins per hectare could be considerable.

Much, however, remains to be done before cashmere production can become a viable commercial enterprise on UK farms. In addition to the breeding of

Figure 9. Harvesting cashmere fibre at Sourhope research station. The Institute is conducting research on the growth of cashmere and on the harvesting of this valuable fibre by combing (above) and by shearing.

superior goats referred to above, there is a need for research on the components of fibre and meat production so that efficient systems of management can be developed and in the longer term for marketing to be imaginatively developed.

Camelids

The South American camelids, the alpaca and the guanaco in particular, have many of the desirable attributes of an alternative animal species. They produce a high-value animal fibre for which there is a keen demand and which currently is all imported. The alpaca is domesticated and produces 2-4 kg per annum

of 20-30 micron diameter fibre. The fibre contains little kemp, has a low felting quality and can be woven into lightweight, soft and lustrous fabric (Novoa and Wheeler, 1984). The guanaco is relatively easy to domesticate and produces an inner coat (yield, 1-2 kg per annum) of 14-18 micron in diameter, which is similar to that produced by cashmere goats.

The alpaca is a gregarious, flocking animal and is managed like the sheep in Peru. It weighs about 70 kg, has a reproductive life span of 10-15 years and reaches puberty in 12-18 months (Stevens, 1982). Although the digestive tract of camelids differs from that of ruminants, the efficiency with which food is digested is similar (von Engelhardt, Rubsamen and Heller, 1979). In Peru they are reported to have been managed successfully on ryegrass/white clover swards, as well as on natural vegetation, which ranges from lush pasture in the wet season to highly lignified herbage in the dry season (Reiner and Bryant, 1983).

The guanaco in the wild lives in small family groups and can be managed easily in small numbers under farming conditions. The guanaco is intermediate in size between the llama and the alpaca. It is found over a wide range of habitats in South America and is considered to be well adapted both to the coastal plains and to high altitude pastures. Experience based on the few animals kept under grazing conditions in the UK and the evidence cited above support the view that alpacas and guanacos could readily adapt to UK conditions.

Camelids have only one offspring per annum and have a gestation length of 11-12 months. The principal difference between ruminants and camelids is in their reproductive physiology. Camelids are mating-induced ovulators, like the rabbit and cat. Ovulation occurs 24-26 hours after mating. Female camelids do not have regular oestrous cycles and when not exposed to the male, they can have a continuous oestrus for up to 36 days (Sumar, 1985). Female camelids enter a condition of oestrus 48 hours after birth and maintain this state until ovulation is successfully induced by mating (Stevens, 1982).

The different species of camelid hybridise with one another readily. By the use of artificial insemination, which is potentially facilitated by females being in continuous oestrus, and embryo transfer techniques, it may be possible to increase the numbers of alpacas and guanacos in the UK by the use of llama females as recipients for alpaca or llama embryos. Llamas are more readily available in the UK than the other two species, and current collaborative work between MLURI and the Rowett Research Institute is examining the possibility of such an approach since it is likely to prove difficult to import live animals into the UK from South America because of disease control regulations.

Insufficient information exists to draw any firm conclusions about the potential for developing an

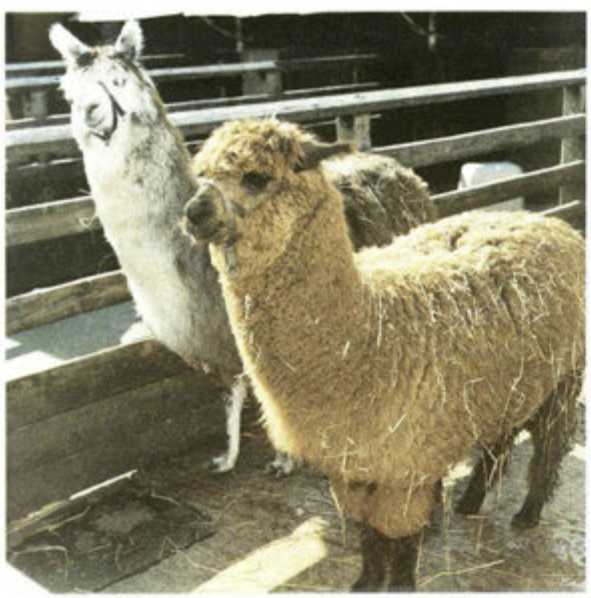

Figure 10. The alpaca, common in Peru where it is managed like sheep in Britain. It produces a high value fibre.

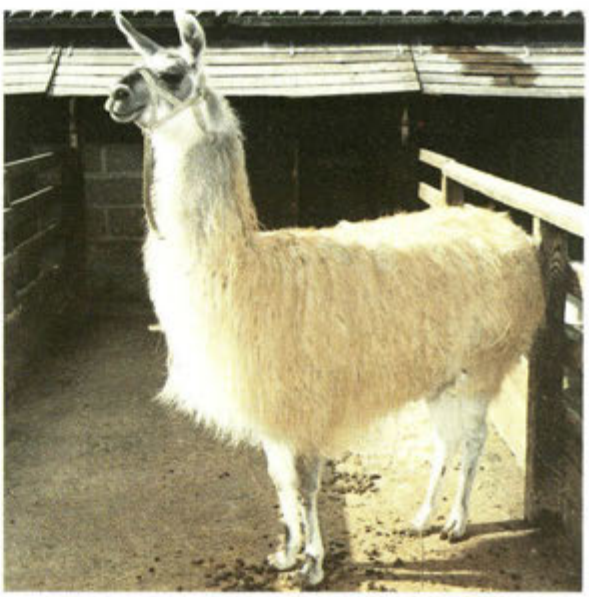

Figure 11. The llama, like all camelids has many of the desirable characteristics of an alternative animal species.

animal fibre production industry based on camelids in the UK. There would appear to be a market for the product at current world prices and the knowledge that exists on their biology suggests that efficient production systems could be produced, indeed alpacas and llamas have been successfully domesticated in South America for the last 6,000 years. However, the main drawback to the rapid development of such production systems is the scarcity of animals and the high prices that this encourages. Because considerable research and development work requires to be undertaken; the slow development of such an industry because of lack of available animals is desirable at this stage.

Summary

Sufficient information and animal numbers are available for the rapid development of the deer as an alternative animal species. Financial returns are adequate at present cost and price levels but the marketing of the products will be central to the long-term viability of deer production.

High value animal fibre such as cashmere and alpaca is likely to continue to be in demand. Increasing the fibre yield whilst retaining fibre quality is essential to the development of goat systems, which will require to be dual-purpose with meat as the other product. For both goats and camelids insufficient information exists to develop management systems and there will be a shortage of breeding stock for some time so that progress in developing these species as alternative animal species will be relatively slow.

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LAND RESOURCES

Survey and mapping of the soils of Scotland

The programme of coloured 1:63 360 and 1:50 000 map production (Figure 1) is being brought to a conclusion. During the year, the Golspie sheet

Figure 1. Soil maps 1:63 360 and 1:50 000.

(103) was published and colour proofs of the Blairgowrie and Achentoul/Reay sheets (56 and 109/115) checked. The Kirkcudbright and Maxwelltown sheet (5/9) completed the compilation stage. Soil survey on the Annan, Dumfries and Langholm (6/10/11) sheet has almost reached completion. The compilation of 1:25 000 maps from field data collected in the Grantown-on-Spey area is well advanced. A detailed soil survey of Gourdie and Mylnefield farms was undertaken for the Scottish Crop Research Institute (SCRI). In addition to providing soils information to assist the design of experimental plots and help explain non-treatment variability in results, the exercise was an initial step in geostatistical analysis techniques, soil variability studies and the manipulation of soils and site data into a user-friendly form. It is intended to develop this work into a farm information systems package for use as an aid to management decisions.

Soil surveys have been undertaken for British Coal and DAFS at two proposed opencast coal sites. The information will assist in formulating plans for stripping, storing and subsequently restoring the soil resource of the areas.

Monitoring of soil properties and assessment of the extent of change subsequent to liming was carried out under contract to South of Scotland Electricity Board in the Loch Fleet catchment, Galloway.

A report was produced under contract to Grampian Regional Council describing the present and possible future agricultural practices on land overlying an aquifer in the River Spey valley from which the Grampian Regional Council propose to abstract water.

A major effort has been made to complete the collection of soil data for the National Soil Inventory, the framework of a Scottish soil database that links to a similar programme in England and Wales. They are essential to provide a datum from which soil change can be measured.

Contact name: **Cyril Bown**

Interpretative maps

During 1987 the range of interpretations of information gathered during the course of the survey of the soils of Scotland has expanded. The 1:50 000 scale maps, Land Capability for Agriculture, were published in June (Figure 2). The classification is now used by DAFS as the basis on which they tender advice to local government planning authorities on proposed changes of land use. The SDD circular 18/1987 notifies the authorities of the new guidelines. An ongoing contribution from staff in this field has been requested by DAFS and eight special surveys and reports, together with a number of site visits and consultations, have been prepared. The work has continued to attract wide interest from the commercial sector and North Eastern Farmers Ltd. sponsored the production of a poster for distribution throughout Scotland illustrating the system.

Drafting of a forestry capability classification continued and was assisted by collaboration with the Soil

Figure 2. Land capability maps 1:50 000.

Survey and Land Research Centre in England and Wales. The land capability classifications for both agriculture and forestry concentrate on the physical parameters governing crop production in various areas and express their results in terms of the ability of the land to carry the appropriate management. The relationship between land class and economics is now being studied under the Increased Flexibility Scheme in a project designed to identify those areas of the country where agricultural marginality may make the option of forestry attractive.

At the request of the Forestry Commission, land meeting criteria making it suitable for forest nursery use was identified.

Work has continued, in conjunction with the Soil Survey and Land Research Centre and the Institute of

Hydrology in England and Wales, on a classification of hydrological response of the soils of Britain. The results can then be used as predictive models for assessing potential flooding risk in each major river catchment in Britain.
Contact name: **Don Futty**

Soil moisture status of the principal soils of Scotland

Work has concentrated on the Balrownie Series, one of the more extensive series in Scotland. The sites investigated lie along a transect from Brechin in the east to Buchlyvie (near Loch Lomond) in the west. Monitoring has indicated that the soil wetness class increases westwards from II to IV; however, the extreme westerly sites have a lower wetness class than those around Auchterarder and Crieff, despite having a higher rainfall. Clearly factors other than rainfall are important in determining soil wetness class, e.g. ratio of potential evapotranspiration to rainfall, distribution of rainfall throughout the year, inherent or man-made soil factors. There is a need for long-term monitoring to assess annual climatic variation and the link between soils, climate and farm economics.

At Drumdowie Farm, Auchterarder, two sets of dipwells have been installed, one in a drained field and the other in an undrained field. Both sites have the same site drainage characteristics and are about 5 m apart. Throughout the three-year period of monitoring the undrained soil has consistently been one wetness class higher than the drained soil.

Two sets of dipwells have been installed at Hartwood Farm in the Rowanhill Series. The wetness class varied over three years from III to V depending on the annual rainfall, V being the more usual. The slowly permeable clay loam subsoil leads to the development of a perched water-table within the topsoil. The results emphasise the need for the development and maintenance of sufficient, continuous fractures through subsoiling to alleviate the problems associated with saturated topsoils, e.g. high poaching risk and low trafficability.

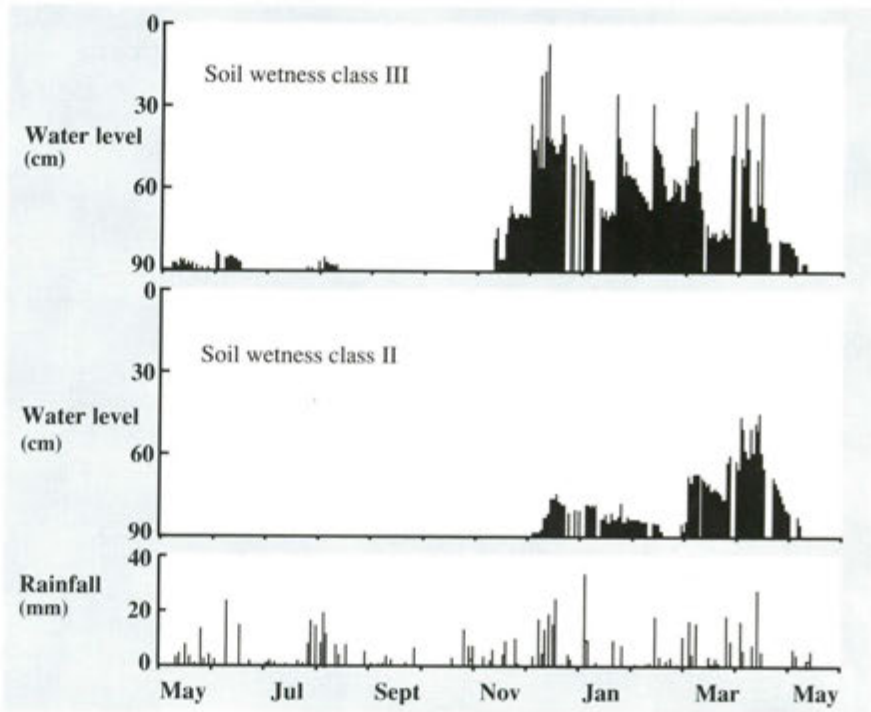


Figure 3. Dipwell water levels at MLURI, Craigiebuckler.

At MLURI Craigiebuckler, three sets of dipwells (Figure 3) were installed about 15 m apart. The results showed local variation and further detailed monitoring and investigation into the short-range variability of hydraulic conductivity and water-table levels will be necessary to explain them. The use of dipwells, simple to install, allows quantification of the soil water regime as well as the examination of the spatial and temporal nature of the fluctuating water-table under differing climatic conditions and soil types.
Contact name: **Allan Lilly**

Soils databases

In 1979 the Macaulay Institute started to compile a computerised soils database, containing detailed site and soil profile descriptions collected during systematic soil survey. Two distinct types of data are included:
i) point information derived from site and soil profile examination at all 5 km intersects of the National Grid (the National Soil Inventory for Scotland database)
ii) data from other sites collected primarily for research and soil correlation purposes ('purposive' data).
Management of the soils database during the past year has been the responsibility of Soil Survey data processing staff with much effort being spent on data expansion, bulk data validation and systematic updating of the relevant INFOS data dictionaries and database loading macros.

Due to the limitations of the existing system both regarding hardware and software, alternative data abstraction procedures from existing database files have been considered. Evaluation of several relational database management systems, running on Apple Macintosh micros, is being undertaken and preliminary studies using mainframe files transmitted directly to these packages.

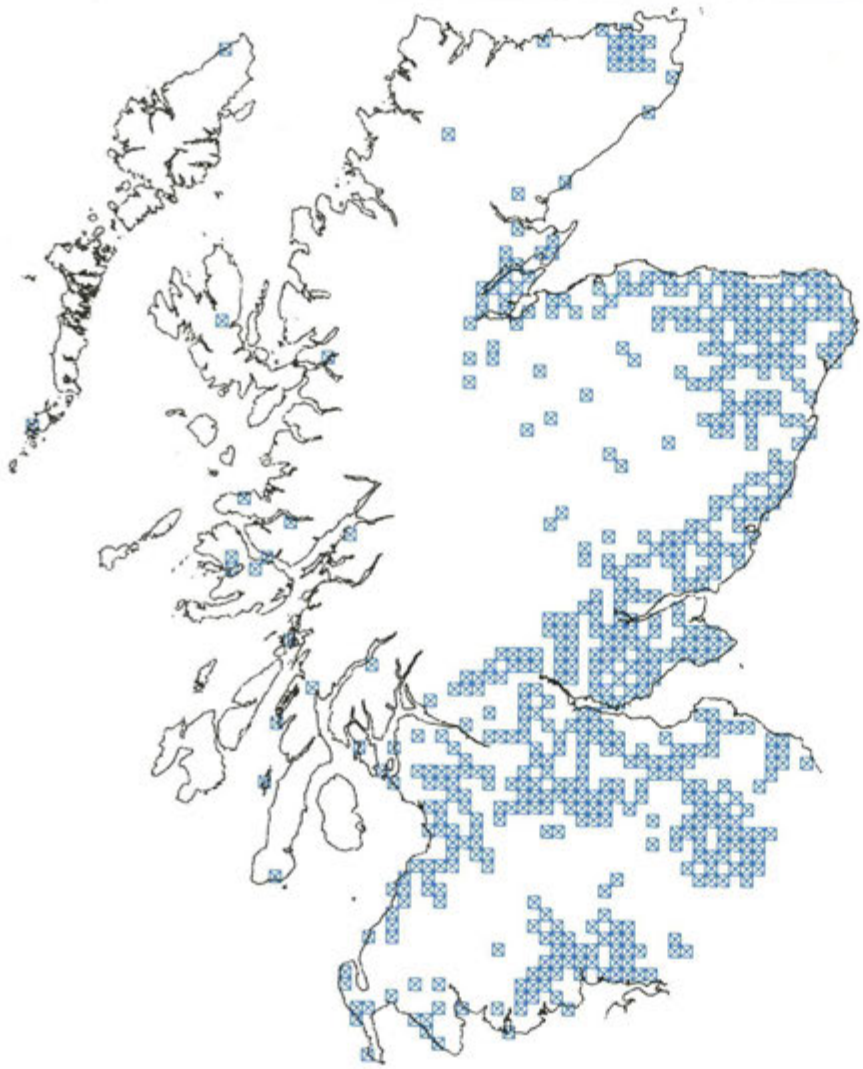


Figure 4. Topsoil pH values in the range 5.0 - 5.9. Any appropriate range can be plotted and, by using data subsets, spatial-temporal change can be economically assessed.

In addition, relational database management applications employing graphics overlay facilities are being examined, and are proving particularly useful with regard to farm survey applications and soil variability studies.

This database represents the only national Scottish soils inventory, and will form an invaluable aid in assessing national and regional relationships between soil, vegetation, land use and environment.(Figure 4). Although a much more extensive MLURI land use and soils information database is currently being discussed in the context of the proposed new programme units and research objectives, it is envisaged that the existing database contents will form the core data, and existing and future development work will continue to be conducted with this aim in mind.

Contact names:
Lindsay Robertson, Basil Smith, Geoff Reaves

The survey, classification and evaluation of peat resources

Investigations were conducted into peat and peatland resources, peat soils and peat inception and developmental processes.

MLURI was commissioned to carry out a peat survey of specified areas of Islay. Areas of peat with a depth greater than 2 m which could be regarded as a long term resource were identified and assessments of peat quality and quantity presented.

In Shetland ten peatland categories, based on vegetation, land use and hydromorphological features, have been identified and mapped (MISR Annual Report No 56). An analysis of over 200 vegetation quadrats was carried out to produce a detailed characterisation of the plant communities associated with each peatland category. The analysis was based on TWINSPAN and associated programmes in the VESPAN package developed for the national Vegetation Classification project by Andrew Malloch of Lancaster University.

A peat soil classification has been developed for use in investigations of the relationship between peat soil profile development and land use practices. The classification is based on internationally accepted criteria and descriptive methods and is compatible with classifications used elsewhere. Raw, dehydrated and moulded (reclaimed) peat soils are recognised at Class level. Groups and Subgroups are determined by the degree of decomposition and botanical composition of the peat respectively. Work has also continued on the survey of peat soils to provide information for inclusion in the Memoirs of the Soil Survey of Scotland.

Studies of successional development during peat inception and of the relationship between the botanical composition of peat and the structure of peat forming plant communities have continued. This work is based on sites previously sampled in northern Finland (MISR Annual Report No 56). Macrofossil analysis of peat cores has been completed and the results are being processed.

Contact name: **Peter Hulme**

LAND USE SYSTEMS

Provide an advisory and application centre for remote sensing within AFRS and facilities for contractual research

The Institute continues to act in the capacity of Scottish regional Remote Sensing Centre and routinely provides both advice and facilities to external users. In addition, the Remote Sensing Unit have been involved in three extramural contracts. The first is a joint Department of Energy and Commission of the European Communities funded project to provide an assessment of the peat resources of the UK, under a general programme on "Peat as Fuel". The second is a collaborative contract with the University of Aberdeen to investigate the radar backscattering characteristics of snow at millimetric wavelengths. The third was an NCC-sponsored project in Sutherland and Caithness.
Contact name : **Richard Birnie**

Monitor the distribution of bracken in Scotland

Several areas in Scotland were used for testing a mapping approach for increasing knowledge of factors influencing bracken infestation. The data derived from the tests were then used for improving the quality of mapping of bracken.

For each area soils, altitude, and forestry data was digitised from graphical map copies. Each soil polygon from a 1:250,000 soil map of the area was digitised, rasterised and coded, creating a digital thematic map of soils. From the soil map areas were selected upon which bracken would not grow, for example basin peat. Bracken growth is limited above 450 m so land of a higher altitude was excluded. Similarly land already under forestry, or approved grant-aid for fresh planting was excluded. Landsat MSS imagery was geometrically corrected to overlay each area, for deriving land cover information. The satellite imagery was corrected for illumination distortions caused by the areas' topography.

The imagery was then processed to produce a likelihood image of bracken presence. After field checking, the bracken image was correlated with the soils and topographic data to provide more information on the combination of physiographical elements contributing to bracken presence in the area. The weightings of these elements were then altered to produce an improved bracken likelihood map.

Complementing the bracken mapping exercise was a questionnaire aimed at indicating where, if at all, bracken was considered to be a problem by farmers. Forms were sent to a sample of 1600 farm holdings in Scotland which had 'rough grazing' or 'grass not for mowing'. Of the 1127 replies received from the survey, 323 reported bracken on their land. Bracken was considered to be a problem on 203 holdings, of which 199 had attempted to undertake control measures. Ninety four farmers who replied attributed livestock illness or death to bracken poisoning.

The results from the mapping exercise indicated that the success of mapping bracken-infested areas in the uplands is improved by combining remote sensing and ancillary map-based data. The responses to the questionnaire provided information on farmers perception of bracken. The approaches adopted allow profiles of the type of farm or geographical area where bracken is a problem to be easily produced.

Land cover type (LCT)	% total area	Aberdeen		Old Machar		Peterculter		Dyce		Nigg		Newhills	
		District	LCT	District	LCT	District	LCT	District	LCT	District	LCT	District	LCT
Urban	**14.49**	10.97	74.47	1.30	8.97	0.46	3.17	0.91	6.28	0.40	2.76	0.63	4.35
Woodland	**4.51**	0.67	14.86	0.42	9.31	1.94	43.01	1.19	26.39	0.07	1.55	0.22	4.88
Heathland	**0.89**	0.14	15.73	0.13	14.60	0.16	17.98	0.02	2.25	0.02	2.25	0.42	47.19
Rough grazing	**4.51**	0.39	8.65	0.65	14.41	1.06	23.51	1.10	24.39	0.02	0.44	1.29	28.60
Cropland	**68.42**	11.68	17.07	12.10	17.69	19.53	28.55	7.33	10.71	4.62	6.75	13.16	19.23
Grassland	**6.65**	0.44	6.62	0.92	13.83	2.05	30.83	1.12	16.84	0.15	2.26	1.97	29.62
Water	**0.46**	0.29	63.04	0.09	19.57	0.01	2.17	-	-	0.07	15.22	-	-
Bare sand	**0.03**	0.01	33.0	0.01	33.0	<0.01	17.0	<0.01	-	-	-	-	-
Unclassified	**0.04**	0.02	50.0	0.01	25.0	0.01	25.0	-	-	-	-	-	-
Parish as % district :		24.43		15.63		25.22		11.67		5.35		17.69	

Table 1. Land cover types within parishes in City of Aberdeen District, shown as percentages.

The results obtained indicate that mapping of bracken-infested areas in the UK can be successfully undertaken using remote sensing and that the extent of potential spread could be mapped.
Contact name: **David Miller**

Apply environmental remote sensing techniques for resource survey and agricultural monitoring operations.

Work on the integration of satellite agricultural and land cover classifications with map images has continued along lines previously reported (Annual Report, 1985 and 1986). A major effort has been made to extend the use of spatial geographic information systems to regional

applications. This work is an expansion of the methodology and techniques developed for the Scottish Crop Research Institute Pilot Geographic Information System for the Potato Crop (Wright and Morrice, 1988).

The geographic database for Kincardine and Deeside District test area now comprises the following spatial information: agroclimatic areas, urban areas, woodland, moorland, potential water deficit, rainfall, altitude, soil units, administration boundaries and the classified potato fields from the Landsat satellite imagery. All the above map images have a 50 x 50 m spatial resolution and are corrected to the British National Grid.

Statistical analysis using the GEMS image processing techniques has shown that only 9.4 percent (200 ha) of the potato crop is growing in drought prone soils. Of this total some 113 ha were growing on two soils, 63 ha. on Stonehaven freely drained soil (with a PWD > 75 mm) and 70 ha. on Forfar freely drained soil (PWD 50-75 mm). The altitude images have shown that 95.6 percent of the crop is growing below 180 m with almost no crop above 300 m. Similarly rainfall data has indicated only 32.9 percent of the crop is grown in a < 800 mm rainfall area whereas 65.7 percent has 800-1000 mm rainfall with less than 1.4 percent in a higher rainfall area.

Using some of the methodology and techniques developed for the potato project, the scale of investigation has been expanded to a regional level.

A geographic information system has been put together on the north east river catchments. Map images and satellite classifications used include:
a) Land cover classifications of a 1978 Landsat image,

b) Soil acidity spatial map based on Soil Survey 1:250,000 Soil map units and

c) major water catchments within the North East River Purification Boards area. All these map images and classifications have 50 m spatial resolution. Provisional statistics have been produced and results of this work will shortly be prepared for publication.

A dataset for Grampian Region is being compiled to produce strategic regional and local parish statistical information. A map image of parishes has been added to the Grampian Region land cover and soils images produced for the water catchment studies. Work is in progress on altitude, rainfall, land capability for agriculture, and forestry. Provisional statistics on land cover within all 143 parishes of the region are now available. As an example of the data available, Table 1 presents the land use cover (as a percentage) for each parish within the City of Aberdeen District.

Contact name: **Richard Birnie**

Evaluate systems of upland sheep production

Upland sheep systems based on controlling swards to a predetermined seasonal sward surface height profile have been tested experimentally in such a way that comparisons of any management effects, imposed as treatments, can be quantified in production terms. Management effects tested in current experiments include sheep breed, stocking rate, level and pattern of N-fertiliser and number of lambs carried per ewe.

Sward surface height is controlled by rules which allow for the conservation of surplus areas of pasture for winter fodder. Other rules determine the amount of supplements fed at pasture, date of first application of fertiliser, weaning date and date of housing ewes in winter.

Two such experiments have been undertaken. One, sited at Hartwood

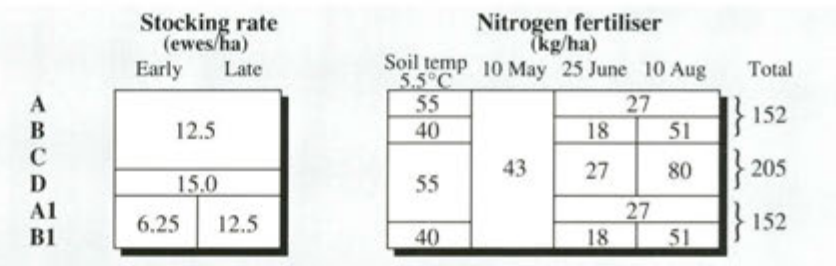
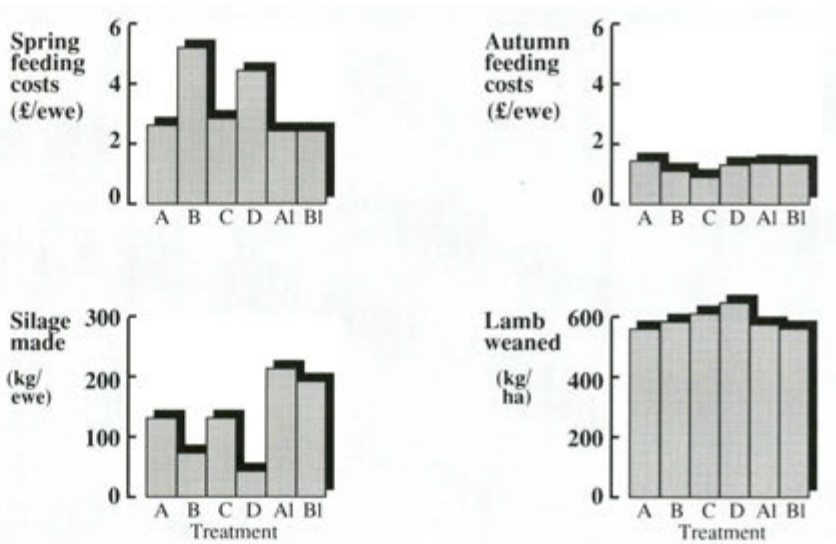


Table 2. Summary of treatments, Hartwood.

Figure 1. Hartwood upland sheep systems.



Research Station, was designed to investigate variations in early-season stocking rate and level and pattern of N-fertiliser use. The other experiment sited at the Bronydd Mawr Research

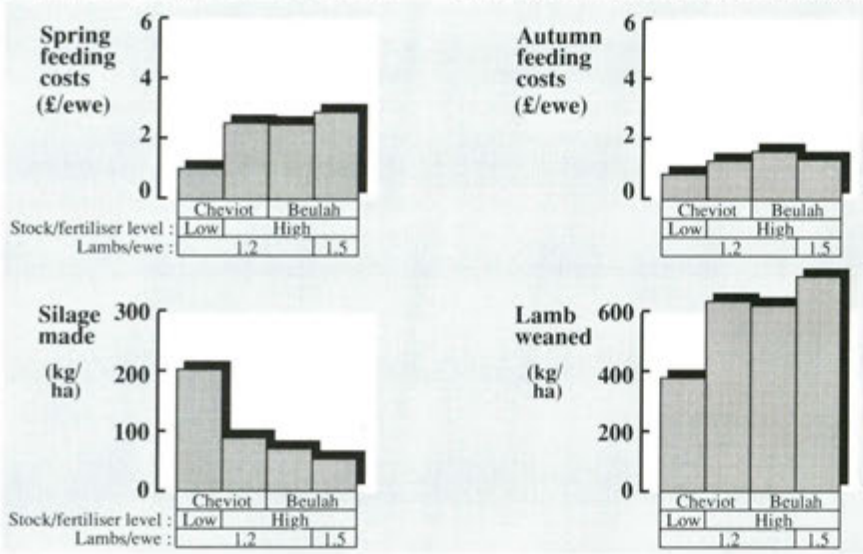


Figure 2. Bronydd Mawr upland sheep systems, summary of results (1985-1987).

Centre and conducted in collaboration with the Institute of Grassland and Animal Production's Welsh Plant Breeding Station, was designed to compare the performance of the Brecon Cheviot and Beulah Speckle-faced breeds, in addition the experiment is designed to investigate the effects of low and high N-fertiliser input systems based on the Cheviot breed.

In the experiment at Hartwood Research Station the Greyface ewe is mated to the Suffolk ram and grazes predominantly perennial ryegrass swards. Table 2 shows the treatments imposed. The results are quoted for 1987 only.

Control of sward surface height between lambing and weaning results in very similar levels of individual animal performance regardless of treatment. Live weight of lambs at weaning, body condition of ewes at mating and subsequent reproductive performance in the following year are not significantly different.

Since individual animal performance is held constant across treatments, differences between systems emerge in the yield of winter fodder and in the amount of supplementary feeding supplied at pasture. Assessment of the viability of a range of systems is tested through an interpretation of these variables. Figure 1 shows levels of feeding, yields of silage and weight of lamb weaned for the treatments in 1987.

Supplementary feeding costs in the spring were greatest when the normal annual fertiliser rate was biased towards autumn and when the higher rate of fertiliser was used with the higher stocking rate. Halving the early-season stocking rate made no difference to feeding costs at that time; pattern of fertiliser application has no effect within these treatments. Autumn supplementary feeding costs were very similar for all treatments.

The amount of silage made per ewe is greatest with the halved early-season stocking treatments. There is a reduction in silage when fertiliser is biased towards late season and with the higher stocking rate.

In the Bronydd Mawr experiment the two breeds, the Brecon Cheviot and the Beulah Speckle-faced, were mated to the Suffolk ram and grazed permanent ryegrass-based swards with a significant clover content. Table 3 shows the treatments which were imposed between 1985 and 1987.

As with the experiment at Hartwood Research Station, control of sward surface height resulted in very similar levels of individual animal performance regardless of treatment. Live weight of lambs at weaning, body condition of ewes at mating and subsequent reproductive performance in the following year were not significantly different within breeds. Figure 2 shows feeding costs, silage yields and weight of lamb weaned from the treatments.

Supplementary feeding costs in the spring are least with the low N fertiliser-input, and low-stocking rate with the Cheviot breed. There was no difference between the breeds at the same lamb:ewe ratio but the costs of supplementary feeding the Beulah ewes at the higher lamb:ewe ratio was slightly greater.

Ewe breed	Lamb:ewe ratio	N-fertiliser/ stocking rate level	
Cheviot	1.2 : 1	Low	12 ewes/ha, 100kgN/ha
		High	
Beulah	1.2 : 1	High	20 ewes/ha, 200kgN/ha
	1.5 : 1		

Table 3. Summary of treatments, Bronydd Mawr.

Autumn supplementary feeding costs were generally low with the low-input, and low-stocking rate with the Cheviot ewes being the least.

The yield of silage made per ewe is greatest for the low N fertiliser-input, low-stocking rate treatment. It is of interest to note that systems with Beulah ewes produce less silage per ewe, at the same lamb:ewe ratio as for Cheviots. The Beulah system with the higher lamb:ewe ratio produces least silage. The amounts of silage made per ewe for the higher-input, higher

stocking rate systems are probably insufficient to supply winter fodder requirements. Stocking rates of 18 ewes/ha would be more appropriate.

Live weight of lamb weaned per hectare is least for the low-input, low-stocking rate system. There is no difference between the Cheviots and Beulahs at the same lamb:ewe ratio. The highest yield of lamb comes, as expected, from the higher lamb:ewe ratio treatment with the Beulah breed.

Annual patterns of climate greatly influence all of the production parameters referred to above. These patterns are often unique and a number of years must be assessed before confidence may be placed in the interpretation of the results. The current experiment at Bronydd Mawr Research Centre has now run for three years and preliminary comparison of the complete data together with those from the experiment at Hartwood Research Station indicate that yield of winter fodder and supply of supplementary feeding vary greatly from year to year. However levels of animal performance are consistent despite the differences in climate.

Viability may be expressed in terms of self-sufficiency, in required levels of animal production or required levels of winter fodder supply, for example. Studies of the type described will eventually enable farmers to select systems matched to their resources, input levels and production requirements and with some confidence in the levels of production that will be achieved.

Contact name: **Alan Sibbald**

IMPACT OF LAND USE CHANGES; SOIL CONSERVATION AND POLLUTION

Identify and measure organic nitrogen compounds in soil and establish the factors affecting their transformations

^{15}N-labelled fertiliser was applied to a potato crop and the gradual immobilization of the nitrogen into soil organic matter was followed over an entire growing season. There was a very rapid translocation of ^{15}N down the soil profile, probably as nitrate which was then taken up into organic matter. The major component, humic acid, gradually accumulated almost 50% of the label present in the soil, while there appeared to be a residual pool of label resident in the hydrophilic acid fraction, generally associated with biomass. Losses of nitrogen in the procedure used in the potato experiment has led to new methods being applied to a similar grass experiment, whose results are being evaluated.

A source of easily-hydrolysed ammonium appeared in culture filtrated from an amoeba/bacterium predation experiment. The source of the ammonium seems to be of medium molecular size and is associated with the peptide fractions in the medium.

Preliminary experiments have been carried out examining the factors governing mineralization of N in an upland pasture soil and in a soil under a coniferous tree mixture.

Contact name: **Hamish Anderson**

Relationship between land use and the nitrate-nitrogen concentration of river water

Modern agricultural systems rely heavily on the use of fertilisers, particularly nitrogen to maintain high outputs. The levels of nitrate nitrogen in drainage and ground waters is thought to be increasing and there is growing concern over this with regard to both public health and environmental considerations. While nitrogen can obviously originate from a number of sources, including atmospheric deposition, biological fixation and mineralization of organic matter, fertilizer inputs often tend to dominate.

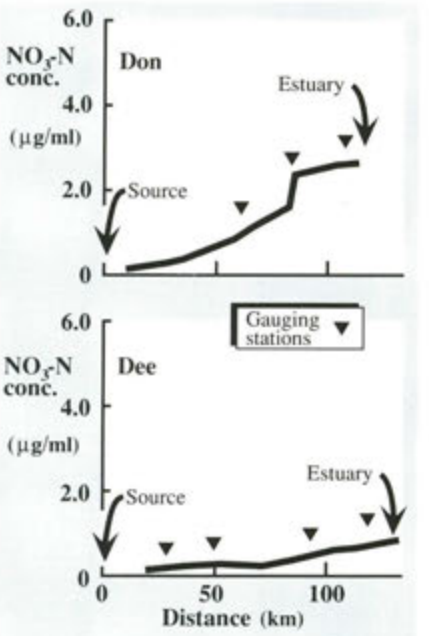


Figure 1. The content of nitrate in the Dee and Don with distance from their sources.

A comparison has been made of nitrate levels in the rivers Dee and Don (Grampian Region). An attempt has been made to relate the differences observed both between and within each catchment area to the dominant land use. River discharge and solute chemical data has been supplied by the North-East River Purification Board.

There is a considerable difference in mean nitrate values not only between the two rivers (2.4 and 0.8 mg/l for the Don and Dee respectively at Aberdeen) but also as we move down each river individually (Figure 1). Total nitrate yields are greatly dependent on annual discharge. An estimate of the gross total annual output of nitrate-nitrogen (between 1980-86) for the Dee is approximately 4 kg/ha compared to 15 kg/ha for the Don. These differences closely reflect the differences in soil type and land use between the catchments.

Contact name: **Anthony Edwards**

Determine factors contributing to the passage of rainwater acidity into streams and suggest appropriate control

a) To determine the input, retention and loss of nutrients and other elements in a forested catchment.

Weekly composite samples taken from the outflow streams from the forested Kirkton catchment, which is being clear-felled, and the Monachyle catchment, which is being forested, continue to show the effect of the limestone intrusions on pH, calcium

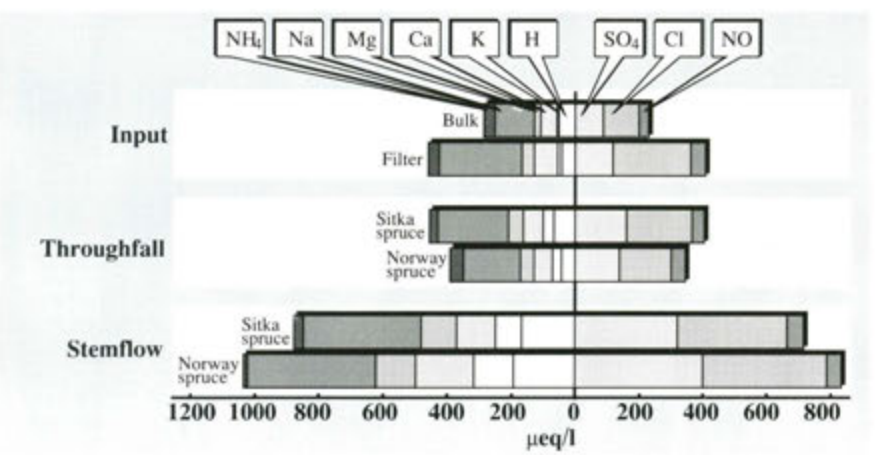


Figure 2. Weighted mean concentration of major ions in inputs, tree throughfall and stemflow.

and alkalinity (Table 1). The Kirkton stream consistently shows higher nitrate values whereas the Monachyle stream has higher iron and colour, on

	Monachyle	Kirkton
pH	5.5-7.4	6.8-7.8
Alkalinity	10-250	100-500
Ca	10-200	200-500
SO_4	80-200	80-200
Al	10-90	5-50
Fe	100-300	10-100
NO_3-N	1-10	10-50

Table 1. Chemical analysis of outflow stream water from Balquhidder catchment (all µeq/litre pH).

occasions exceeding the recommended potable values. Current data have not yet shown any of the expected changes following felling e.g. increased potassium, nitrate and phosphate nor have any changes been observed following afforestation.

Rainfall, tree throughfall and stemflow data have been assembled from a 2-year period from a range of species including Sitka spruce, Norway spruce, Scots pine and European larch.

Interception losses, for all species, are around 30% and chemical data indicate the relative similarity between open-gauge and filter-gauge inputs.

Throughfall shows the expected increases in potassium and magnesium with corresponding higher increases in stemflow (Figure 2). At this site there was little acidification of the incoming rainfall (weighted annual mean pH 4.4) by any tree throughfall (pH 4.3-4.5) but tree stemflow from all species was more acidic (pH 3.7-4.0).

Estimates of the contributions to inputs by crown leaching and interception deposition were obtained by calculating the ratio of chloride beneath the trees to the amount collected in the filter gauges, and applying this ratio to other elements. From the results in Table 2, it can be seen that calcium, sodium and nitrate are, like chloride, derived from interception deposition whereas potassium and magnesium are mainly derived from crown leaching. In the context of related acidification studies it is interesting that not all sulphate may be derived from interception, but in fact 20-30% may be crown leaching.

b) Measurement of soil water throughflow and associated hydrochemistry in response to a variety of inputs

Recent improvements in instrumentation and data capture have enabled more effective monitoring of soil water throughflow. This, with related studies on the measurement of inputs along with vegetation effects, should provide more information in the study of the processes leading to surface water acidification. These monitoring schemes have been installed at a range of SWAP funded sites in the UK and Norway but they could also be used to monitor a variety of plot and catchment responses, including effects of changes of land usage, changing patterns of pollution, fertiliser losses etc.

	Predicted	Measured	Predicted	Measured
	K		Ca	
Sitka spruce	2.5	12.6	12.2	13.1
Norway Spruce	2.1	11.0	10.3	13.1
	Mg		Na	
Sitka spruce	4.1	5.4	43.4	45.7
Norway Spruce	3.5	4.6	36.6	38.9
	SO_4 as S		NO_3 as N	
Sitka spruce	15.9	26.2	4.3	4.4
Norway Spruce	13.4	23.7	3.6	3.6

Table 2. Amounts of elements (kg/ha/year) predicted in throughfall and stemflow using the chloride ratio compared to measured amounts.

Selected examples of the use of these monitoring systems during SWAP studies are given in Figures 3 and 4 (overleaf).

Figure 3 illustrates the changes in both flow and selected concentrations during the major spring snowmelt in Norway in 1987. Figures 3(a) and (b) are the patterns of flow from a main discharge stream and the major soil water throughput during this period. Figures 3(c) and (d) are examples of selected chemistry from this soil throughflow showing the strong correlation between increasing flow and concentration during this period.

Figure 4 shows the changes in hydrology and hydrochemistry during selected rainfall events at a U.K. site in autumn 1987. Figure 4(a) is the pattern of stream discharge, 4(b) is soil throughflow through the major pathway at this site in response to a rain input of about 7 mm at hour 11, and about 11 mm at hour 17. Associated hydrochemistry for this horizon throughflow and synchronised stream samples are given in Figures 4 (c) and (d) showing that at this site, the soil has considerable cation exchange capacities leading to little change in calcium concentrations with flow. Chloride, which is mainly atmospheric/plant derived, however does show some dilution with flow.

These examples show the capability of the system to accurately monitor changes in both reaction rates along with altered flow paths.

c) Design and construction of control and data logging equipment for field studies

Discrete daily and hourly samples of inputs, vegetation and soil throughflows, and outputs have been

collected during selected rainfall and snowmelt events using event sampling equipment driven by custom-built control modules.

throughflow hydrology along with related changes in temperature.

Further storm and snowmelt event sampling along with improved

the catchment area. Loch Fleet is situated in the south west of Scotland (N.G.R. NX 560695) in a granite basin overlain with peaty soils. The

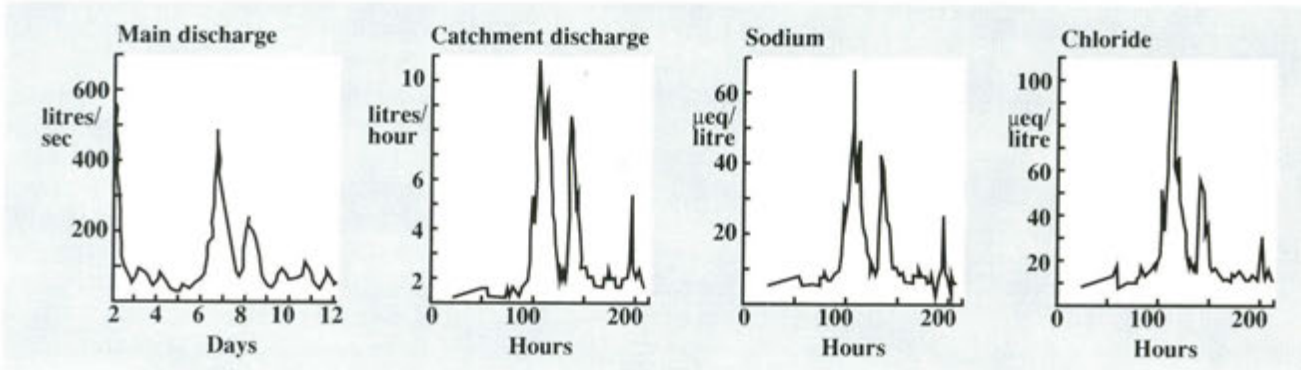


Figure 3. Changes in hydrology and hydrochemistry during snowmelt.

Volumes of water through selected systems, previously monitored using electro-mechancial counters, are now being monitored using MLURI designed and constructed solid state

monitoring are planned to take place using reduced sampling periods, particularly at onset of events. These

soils are very acid (pH 2.5-4.5 in 0.01 M CaCl2) and are low in alkalis (base saturation 3-19%). The dominant vegetation is *Calluna vulgaris* and *Molinia caerulea* but in 1962 about

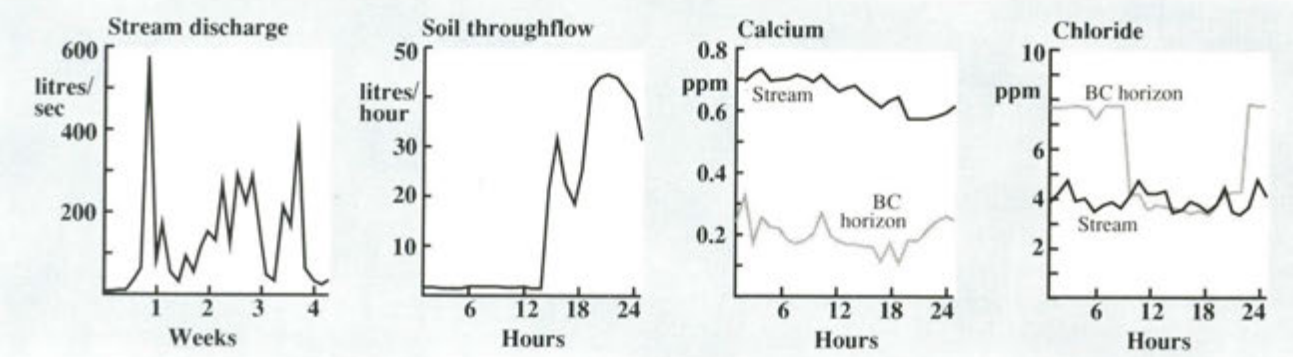


Figure 4. Changes in hydrology and hydrochemistry at Loch Chon.

loggers. These digital, eight-channel loggers are normally pre-set to accumulate data in 20-minute periods over 28 days.

Analogue eight-channel loggers were also designed and constructed using similar micro-processor based circuitry to record soil temperature data from assembled thermistor probes. These probes have been installed at a range of sites to monitor air, snowpack and soil profile temperatures. Examples of data collected by these analogue and digital loggers are given in Figures 3 and 4 which illustrate typical input and

data will be used to improve the understanding of the possible processes leading to potential surface water acidification.

Contact name: **John Miller**

The effect of lime treatment and water chemistry of the Loch Fleet catchment

A five year research project was initiated in 1984 by the electricity generating industry to investigate the acidity of the waters of Loch Fleet and demonstrate that these waters could be brought into range suitable for a self-sustaining trout population by appropriate manipulative treatment of

10% of the catchment was planted with Sitka Spruce and Lodgepole Pine. The brown trout population of this small loch began to decline around 1950 and had disappeared completely by the mid 1970s. The evidence suggested that this was due to acidification of the loch waters implying that the catchment soils had progressively lost their neutralising bases. It was thought that lime treatment of the catchment could be used to restore these neutralising bases and to reinstate the water quality of the loch.

The initial period of the experiment was spent in establishing baseline data before liming was carried out in three well-defined sectors of the catchment.

The chemistry of the soils, soil waters, input streams, loch waters and outflow waters were monitored on a regular basis before and after liming,

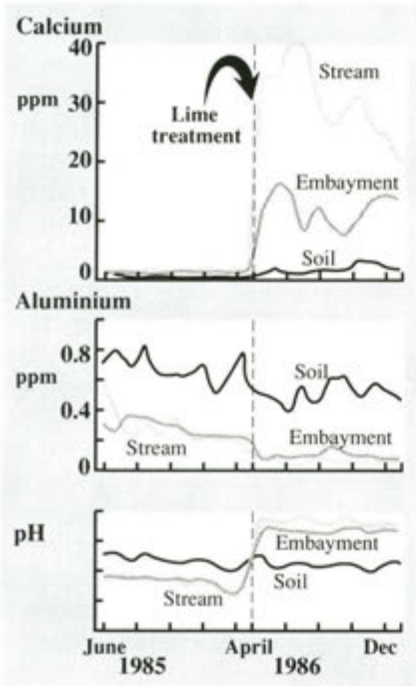


Figure 5. The effects of liming on pH, aluminium and calcium in the Loch Fleet catchment.

which took place in April 1986 in three sectors of the catchment.

As anticipated there were immediate changes in the chemical properties of the topsoil horizons (5-10 cm) sampled before and after lime treatment, notably increases in pH, exchangeable calcium and percent base saturation along with decreases in exchangeable hydrogen. However, there was little evidence that liming had any effect on sub-surface soils. Particular attention was paid to the composition of soil seepage waters which were sampled at 30 cm depth at the interface between organic and mineral soils around the perimeter of the loch. These soil waters were not affected at all by the lime treatment although, in contrast, the effect on embayment and stream waters was dramatic (Figure 5); here there was a ten-fold increase in Ca content and an increase in pH from 4 to 7. Another notable difference is that aluminium is generally highest in soil waters and that liming induces a further drop in aluminium in both embayments and stream waters.

The results indicate that soil seepage waters do not play a significant role in the determination on the chemistry of the loch waters and that surface run-off must be all important.

Contact name: **Basil Smith**

Devise practical methods to remove pollutants from agricultural and industrial wastes

Wastes from the whisky industry are reprocessed for use in agriculture or disposed of directly on to the land. These wastes contain appreciable amounts of copper and it is now necessary to devise simple, efficient, cost-effective techniques to lower their copper contents to meet the requirements of a recent CEC directive on the disposal of heavy metals in agriculture.

Two major waste components are produced in the manufacture of malt whisky. The first, pot ale, remains in the still after the removal of "low wines" by distillation of the fermented mash. Distillation of the "low wines" produces whisky, leaving behind the second waste component, spent lees. These components contain a total of about 20 Mg (tonnes) of copper per annum.

Every year about 350 million litres of spent lees are discharged into the environment. This waste is low in organic matter (0.05%) and the copper (about 40 ug/ml) is mainly ionic. This form of copper can be removed easily by adsorption on to coniferous bark (5g Cu / kg dry bark) or more efficiently (Figure 6) using an ion exchange resin (45 g / kg resin). Composting the bark results in a 3-fold increase in its capacity to absorb copper, but once absorbed the metal is not released. In contrast, the resin (1 kg will treat > 1,000 litres of spent lees), can be regenerated with a dilute acid and re-used.

A more difficult problem is presented by the pot ale which contains about 8.7 tonnes of copper per year. The pot ale which contains 7 - 10 ug/ml copper, is reprocessed into animal feedstuffs in a pelleted form but is unsuitable for sheep because of their susceptibility to copper toxicity. About 99% of the copper is bound to the substantial organic content which comprises up to 4.5% of the pot ale. Much of this bound copper (50-60%) can be removed by absorption onto coniferous bark but this also removes large amounts of the valuable organic components used in animal feedstuffs.

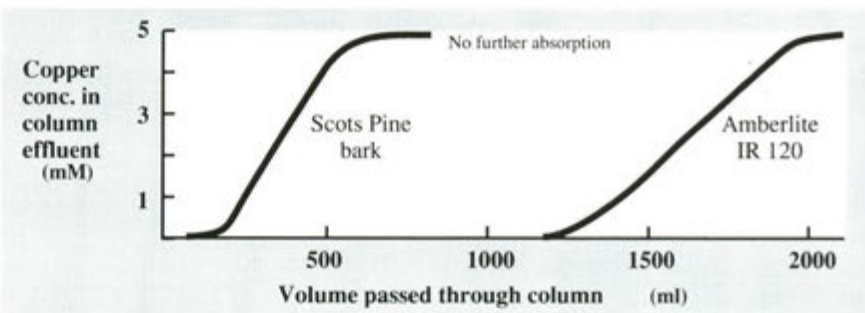


Figure 6. Removal of ionic copper from solution using 1g of dry Scots pine bark and Amberlite IR 120 resin.

A more practical approach is to identify the organically-bound forms of copper and to convert these to an ionic form for subsequent removal as for the spent lees. Studies on molecular size have shown that most of the copper is bound to constituents of size similar to amino acids, sugars and small polypeptide molecules. Spectroscopic analysis suggests that at least some of

the copper is bound to peptides. The data indicate that the treatment of pot ale with suitable protein degrading enzymes could provide a suitable method of releasing bound copper into the ionic form.
Contact name: **Derek Vaughan**

PLANT NUTRIENT SUPPLY FROM SOILS

Organic matter composition

The chemical and biopolymer composition of environmentally evolved organic matter, as found in soils, peats and kerogens, is highly complex and differs markedly depending on its development and the prevailing source materials. This composition, however, is of prime importance in the cycling and control of C, N, and plant nutrient elements. Methods developed at this Institute based on mass spectrometry and analytical pyrolysis have been used to determine the main organic types in temperate soil horizons (Bracewell and Robertson, 1984; 1987a; 1987b) and in diagenetically altered kerogens in shales and chalks (Bracewell *et al.*, 1987; Bracewell and Robertson, 1987c). The "pyrogram" or pattern of pyrolytic decomposition products is interpreted by multivariate statistical methods which present it in a readily understandable form. Two main evolutionary pathways could be used to explain the variations found by these new techniques.

The first pathway, characterised by moderately fast cycling of organic matter as in most temperate soils, leads to the build up of secondary polymers which display their own characteristics in the pyrogram as well as those of the biopolymers with which they readily combine such as polysaccharide, polypeptide and lignin. Their degree of reduction, which results from anaerobiosis can be observed. The second pathway, characterised by partially arrested biodegradation as in peats or other cold/wet environments, gives abundant evidence of original plant biopolymers, notably lignins and polysaccharides. These evolve through very slow anaerobic processes into polymeric structures which resemble coal, shale and chalk kerogens, a process which can readily be followed by these new techniques.

Many soil properties which are significant for land management depend critically on the amount, but more importantly on the type of organic matter present. These include water retention, porosity and good structure, as well as the provision of source material and storage capacity for nutrient cycling. The composition of soil organic matter is being related to specific physical soil properties. The aggregate stability, in a sequence of soils on the same series, correlates well, with the total amount of organic matter but also with aspects of composition mostly related to polysaccharides. There was also a weak correlation with lignins of primary plant origin, interpreted as binding of the soil particles by roots. A more powerful relationship was seen in terms of polysaccharide chemistry. A similar relationship between polysaccharide and erosion resistance was found in other experiments on a group of otherwise similar soils. The two experiments were thus in agreement since erosion resistance depends on soil aggregate stability.

New methods of examining organic composition have therefore provided a readily applied diagnostic criterion for the qualitative status of soil organic matter, have shown characteristic differences not formerly known and have indicated the pathways of organic matter development. Further they have shown how soil properties of significance depend not so much on total quantity but on quite specific aspects of organic composition.
Contact name: **Michael Bracewell**

Polysaccharide effects on soil physical properties

The presence of organic matter in soil is the result of dynamic processes involving a balance between the organic carbon added, mostly as decaying plant tissue, and that lost through oxidative metabolism. The amounts of organic matter present are therefore highly dependent on the rate of decomposition.

In soil, one part of the organic material decomposes more rapidly than others, even where the parts only differ slightly chemically.

Changes occurring at the surface of plant tissue, which are often masked by the gross analysis of soil and plant

	Initial Activity Bq/g soil	Incubation Period: 6 months without worms %	6 months with worms %	12 months without worms %	12 months with worms %
Rhamnose	70	160	146	181	109
Arabinose	1560	41	27	29	18
Xylose	3200	54**	49	55**	26
Mannose	206	187**	106	118**	82
Galactose	1150	57*	35	36*	22
Glucose	13300	30***	19	20***	12

***, **, * value significantly ($P \leq 0.001, 0.01, 0.05$ respectively) greater than with worms.

Table 1. Effect of earthworms on the persistence of grass residues during incubation in soil. Percentage of 14 C remaining in grass.

mixtures, may be discerned using multiple internal reflectance infrared spectroscopy. The change in the absorbance of a fast-decaying component such as carbohydrate has been measured in relation to the comparatively stable lignin.

By this means it has been shown that a significant decay of wheat (cv. Timor) carbohydrate, 67%, occurs at the inner surface after 21 days incubation in soil, whereas the corresponding decay in barley straw (cv. Golden Promise) was only about a third of that of the wheat. Lignin and acetyl groups became concentrated in the inner surface layers and it may be postulated that both progressively affect the rate of breakdown of the remaining carbohydrate. The outer straw surface, in contrast, is much more stable and this is presumably because of the cuticle layer.

A direct comparison may be made with degradation in the sheep rumen which shows a similar pattern over a much shorter period. This indicates that soil factors have a minimal effect on the pattern of decomposition in the early stages of decay although they have a considerable effect on the rate. Allowing for temperature differences the decomposition rate of straw in soil is about ten times slower than in the rumen.

Experiments have been conducted to determine the influence of three different types of invertebrate on the rate of decomposition of plant leaf tissue in soil. Laboratory experiments and many field studies usually exclude soil invertebrates because the soil sample is too small or the substrate needs to be physically contained, to a nylon bag for example, to allow recovery. The experiments show that earthworms (*Allolobophera caliginosa* and *Lumbricus rubellus* Table 1), cranefly larvae (*Tipula paludosa*) and woodlice (*Porcellio scaber*) species cause an increase in the rate of decomposition of the order of 10-20% over periods of 1 to 12 months. As well as digestion processes in the gut (Griffiths and Cheshire, 1987) the effect may be partly accounted for by the comminution and mixing of the plant material leading to an enhanced microbial activity.

Contact names: **Martin Cheshire, James Russell**

Nutrient immobilisation, mineralisation and availability in highly organic soils

Nitrogen transformations have been studied since 1985 in peat from an area of poorly drained reseeded blanket peat in the north of Scotland that had shown poor responses to early applications of NH_4NO_3 (112.5 kg Nha^{-1}) in April. Potential denitrification rates (PDR) in intact cores were high in March and April (approx. 7 kg N ha^{-1} day^{-1}), but zero rates in summer could not be attributed to improvements in aeration.

Each spring ammonium levels in the surface peat (0 to 10 cm depth) reached 15 to 30 kg N ha^{-1} in plots not receiving fertiliser-N (Figure 1), but amounts recovered in the grass were less, suggesting that available N is immobilised in the peat. Incubation of intact cores of peat with the grass removed *in situ* confirmed that net mineralisation occurred during the winter months and immobilisation predominated during the period April to June. This immobilisation could also compete with uptake by plants for available N and reduce the efficiency of fertiliser N.

Comparisons of potential denitrification, mineralisation and estimates of microbial N on adjacent areas of reseeded blanket peat having different fertiliser and cropping histories over a period of 2 years indicated that microbial N and readily mineralised N accumulated in uncropped, unfertilised reseeded peat. On sites cropped by grazing or cutting, readily mineralised N was greater on N treated than unfertilised areas. Potential denitrification was not recorded in natural peat, but nitrous oxide production increased with increasing pH and fertilisation. Poor recovery of nitrate accompanied by increasing nitrous oxide production suggested that nitrate transformations occurred by pathways other than denitrification.

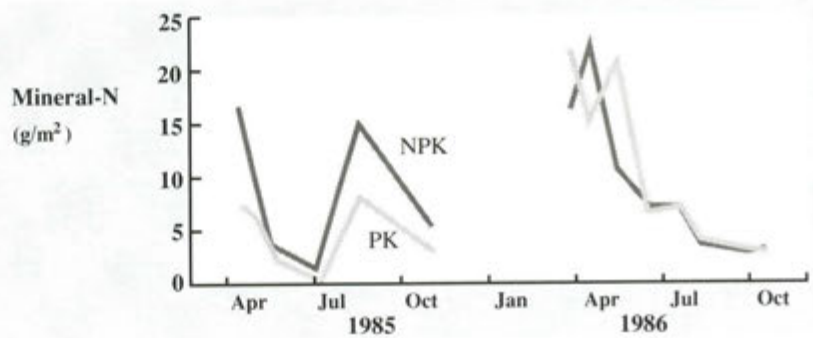


Figure 1. Mineral nitrogen levels in the upper 10cm layer of reseeded blanket peat at Slethill, Forsinard.

In spring 1987, NH_4NO_3 was replaced by urea and the amounts of P and K applied increased to 60 kg ha^{-1} of each element to take account of the high potential for denitrification and the low concentrations of K in the grass and peat. These changes were accompanied by an increased yield of dry matter in both PK and NPK treated plots.

Contact name: **Berwyn Williams**

Determine the nature, distribution and metabolic activity of protozoa in soils

The environmental conditions in soil limiting the activity of the smallest microscopic animals, the protozoa, were investigated. It was found that the largest protozoa, the ciliates, were relatively immobile, consumed little food and excreted little ammonium nitrogen at temperatures below 10°C, but the smallest protozoa, the flagellates, were active at temperatures as low as 5°C. Preliminary attempts have been made to simulate the fluctuations in existing data of field populations of soil protozoa assuming that soil temperature and moisture are the major environmental factors controlling protozoan growth and using data for growth rates and yields derived from laboratory investigations.

Physical barriers exist in the soil that prevent protozoa from eating and eliminating all the bacteria and fungi in the soil. Preliminary results suggest that ciliate protozoa do not inhabit the inside of soil aggregates of even as large as 1 to 2 mm diameter, although many bacteria and fungi survive in this region. Many of the smallest protozoa, the flagellates, can ingest small particles of soil organic matter and may act as important primary decomposers of organic matter in soil independent of bacteria and fungi.

Contact name: **John Darbyshire**

Inter-relationships between soil actinomycetes, bacteria, protozoa and plant roots

Microorganisms within the soil environment form a complex relationship with higher plants and, most directly, with the root system. The major, though not the only, effect is on the supply of nutrients. Besides the breakdown of organic matter to release inorganic ions, microorganisms are also involved in inorganic reactions such as the oxidation of elemental sulphur applied to soil as a fertiliser. Plant deficiencies in sulphur have been observed in Scotland and, more recently, in other parts of the UK. Where soils are low in sulphate, plants are dependent on the mineralisation of organic matter, atmospheric inputs or on fertiliser treatments for their sulphur supply.

Organic sulphur mineralisation in an S-deficient soil (Boyndie Association) was estimated to be at most 2.4 mg S / kg / year as indicated by uptake into continuously cut ryegrass. Under clover it was higher at 5.9 mg S / kg / year. Nevertheless, this was insufficient for plant growth and limited both grass and clover production. In a separate experiment it was shown that ryegrass which becomes sulphur-stressed can derive part of its sulphur from the atmosphere.

'Thiovit' (elemental sulphur in a micronized form) is used on grass and other crops where sulphur deficiency occurs. This form is oxidized readily by the soil microflora to plant-available sulphate, even at the low temperatures of a Scottish spring, and should be able to meet plant demand for sulphur. Though Thiobaccilli capable of oxidising elemental sulphur were present in most of the Scottish soils surveyed, heterotrophic organisms, which are present in much greater numbers, are thought to be responsible for this oxidation.

Contact name: **Stephen Chapman**

Microbial transformations of soil organic matter

Soil organic matter contains combined forms of nitrogen and sulphur both of which are important to the maintenance of soil fertility. It has been shown that the population of microorganisms within a soil, in itself forms a particularly readily available pool of N and S as well as mediating the opposing processes of mineralisation and immobilisation. An appraisal of nutrient cycling within the soil-plant ecosystem requires quantification of these two processes and of the nutrient pool bound up in the microbial biomass.

The addition of organic matter low in sulphur to sulphur-deficient soils causes immobilisation of soil sulphate. Immobilisation occurred where the C:S ratio of the organic matter was greater than 450 whereas mineralisation occurred below this value. Soil sulphur status is routinely assessed by the level of extractable soil sulphate. However this neglects the organic sulphur, part of which could be potentially mineralisable. The above immobilisation effect, measured by soil respiration enhancement upon sulphate addition, was used as a 'biological' soil test for sulphur deficiency. The test related to soil sulphur status when applied to fresh soils but when used with air-dried samples, the correlation with extractable soil sulphate was low.

The mineralisation of sulphur in microbial tissue added to soil was estimated by using radio-labelled cells. Much of the S from two bacteria (high in S) was released over the 18 day incubation period though less was released from a fungus (low in S). Microbial biomass nitrogen at an agroforestry site was estimated to be about 140 kg N/ha but was reduced where herbicide treatment had removed herbage from around the trees.

Contact name: **Stephen Chapman**

Mechanism of intake of foliar applications of elemental sulphur

Foliar applications of elemental sulphur in formulations such as Thiovit are effective in alleviating sulphur deficiency. While some of the foliar material certainly enters the plant via the roots after being washed

from the leaves it is clear that some enters via the leaves.The mechanism of this process is not known but information of this type is needed to improve the efficacy of formulations. The main possibilities are oxidation to a gaseous form and entry via the stomata or movement through the cuticle. These possibilities have been tested using a "model" system based on *Pisum sativum* cv Argentium. Elemental sulphur ^{35}S was spotted on to either the upper or lower surface of *P. savitum* leaves. At times after application, treated leaves were removed and sulphur measured in a water wash to remove unbound elemental S, a methanol wash which removed material in the cuticle and surface waxes (Figure 2), epidermis and the remainder of the leaf. In this cultivar it is especially easy to remove the epidermis without damaging the underlying cells. This makes it a good model system for studies of this type. Results from this study (shown in Figure 3 on the next page) indicated that where applications were made to the upper surface, material was found in the epidermis after two days. After two weeks over a third of the applied material was within the leaf although half still remained on the surface. Where the application was made to the lower surface, uptake by the epidermis was more rapid with 40% of the application being found here two days after application. After two weeks a similar amount of material was found within the leaf to the upper surface treatment. More of the applied material was removed from the lower surface compared to the upper. The large amounts found in the epidermis following application to the lower surface which had the light concentration of stomates suggests that gaseous entry via the stomates is unlikely to be the major pathway of entry.

Contact names:

Harry Shepherd,
David Atkinson

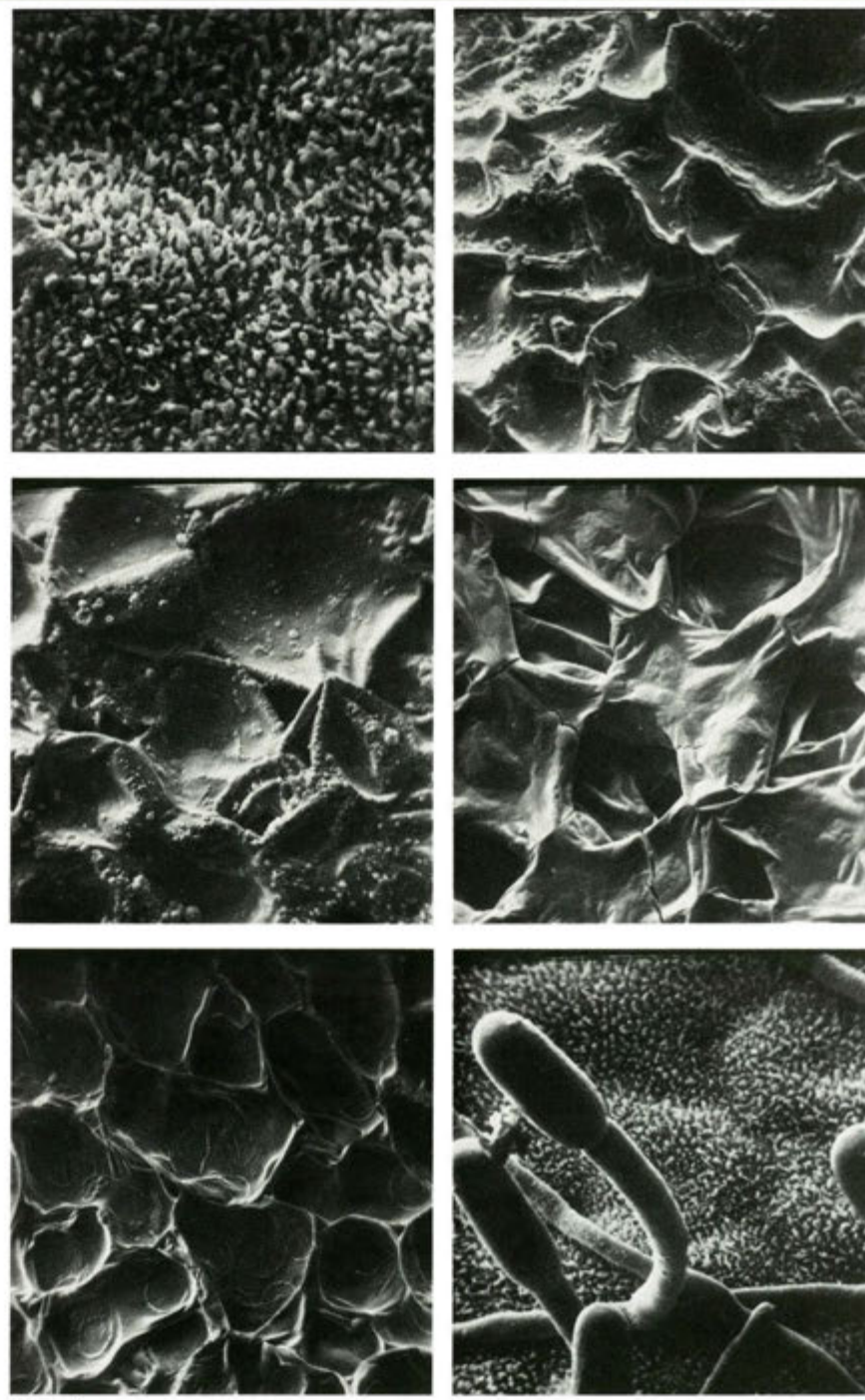


Figure 2.
Top left. The upper external surface of pea leaf showing the waxy material removed by methanol wash.
Top right. Inner surface of upper epidermis of pea leaf indicating the clean separation of epidermis from the remainder of the leaf by the stripping method
Middle left. Inner and upper surface of palisade following epidermal stripping. Damage is very limited.
Middle right. Inner surface of spongy mesophyll following removal of lower epidermis
Bottom left. Inner surface of lower epidermis
Bottom right. External surface of lower epidermis

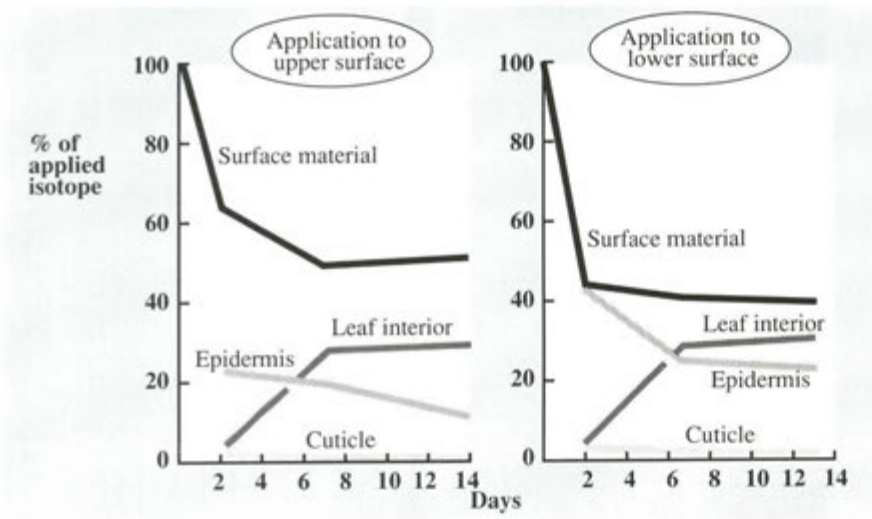


Figure 3. Distribution of applied isotope in the leaf.

Inductively coupled plasma emission spectrometry for solutions

The provision of high grade, cost-effective analyses is essential. During the past decade, the continuing development of inductively-coupled plasma atomic emission spectrometry has provided a powerful tool for

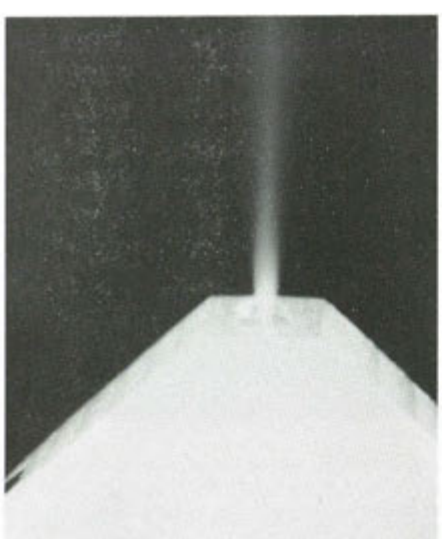


Figure 4. Cone spray nebuliser.

elemental analysis at major, minor and trace levels. The most unsatisfactory component in the current generation of commercial equipment is the sample introduction system which converts liquid samples into an aerosol for injection into the plasma. This is usually based on a pneumatic nebuliser and spray chamber combination which has a poor efficiency (*ca* 2%) and causes a number of operational problems. Because these devices have hitherto been poorly understood, a plethora of designs have been proposed and manufacturers often market several types to satisfy different applications.

A study of the mechanism of operation and design of these devices has indicated that a universal design is possible that combines good efficiency and the ability to perform well in a variety of applications (Sharp, 1988). The principles of such a design were experimentally tested and patented in 1986 (Sharp, 1986). Subsequently a contract was awarded by the British Technology Group for the development of commercial prototypes (figure 4). Under this contract, the design has been refined and an appropriate manufacturing technology delineated. Initial tests have shown that the device does indeed combine efficiency and robust sample handling characteristics and a batch of evaluation systems will be made available to manufacturers during 1988.

Contact name: **Barry Sharp**

Develop and apply thermal ionisation mass spectrometry for the precise determination of elemental isotopic composition

The isotopic composition of certain elements can be used to characterise the source of that element and to follow the element through a chemical or biochemical system and consequently to derive fundamental information about the process at work within that system. The thermal ionisation mass spectrometer (TIMS) measures the isotopic composition of elements with a very high precision, for example the ratio of ^{87}Sr to ^{86}Sr can be measured as 0.710116 + 0.000021, so that very small changes in ratio can be measured with confidence allowing systems to be studied in detail. Methods have been developed for the isotopic analysis of zinc, copper, iron, strontium, lead and potassium which can be considered in two groups.

Strontium and lead have variable isotopic compositions in nature which depend on the origin and history of the sample. The strontium isotopic compositions of precipitation and rocks differ so it is possible to quantify the relative proportion of strontium from precipitation or deposition and rocks appearing in run-off waters. This gives information on the degree and rate of weathering of the rocks. Problems of contamination of the food chain by industrial or other lead can be studied using the isotopic composition of lead to characterise it.

Other elements, such as zinc, copper, iron and potassium, have an invariant natural isotopic composition so we can add an enriched isotope to the input of a system and follow the element through the system. These are known as stable isotope tracers and can be used in cases where radioactive tracers would be unacceptable. Enriched ^{70}Zn has been added to the diet of human subjects and enriched ^{68}Zn introduced intravenously. By analysing faecal and plasma samples it

was possible to measure the amount of zinc absorbed into the body pool through the gastrointestinal tract and also the amount secreted back from the pool into the faeces. With the high precision available, small amounts (1 µg) could be identified in a large total amount of zinc (12 mg) and it is possible to detect the very slow secretion (<0.1% of enriched zinc per day) from the body tissues over a period of many months.
Contact name: **Jeff Bacon**

Organic matter and the amelioration of trace element problems in soil

Humified organic matter has the ability to complex metal ions in soil as well as being able to bring about changes in valency.

A study of the possible precursors of a salt marsh mud humic acid in humic-like substances extractable from the plant *Spartina alterniflora* in both fresh and dead state has been combined with one on the distribution and forms of metallic elements.

The humic substances from the plants obtained by extraction with alkaline pyrophosphate, showed an overall similarity to mud humic acid in terms of their infrared and UV visible spectra, though the plant derived material contained a higher proportion of aliphatic groups. The mud humic acid had the lowest carbon content, 40% compared with 46 and 52% for the fresh and dead plant humic substances respectively. The metal content of the humic substances for Al, Fe, Ti, V, Cr, Co, Cd, Sn and Pb was in the order mud > dead plant > fresh plant and could be related to the metal content of the whole materials. Electron paramagnetic resonance spectroscopy showed that the forms of iron were similar in all three materials but those of vanadium and copper showed differences.

Previous studies using electron paramagnetic resonance spectroscopy have demonstrated the ability of humic acid from a Countesswells soil to reduce Fe^{III} - Fe^{II}, V^{v} - V^{iv} and Mo^{vi} - Mo^{v} - Mo^{III}. The reduction of Fe has been the subject of further study using Mossbauer spectroscopy and the work has now been extended to a fulvic acid from the same source.

The reduction of Fe^{III} to Fe^{II} in fulvic acid solution has been shown to increase with increasing acidity over the pH range 5 to 1. Electron spin resonance spectroscopy used in conjunction with Mossbauer spectroscopy has shown that complex formation of mononuclear Fe^{III} species increases with decreasing Fe : fulvic acid ratios. There appears to be a competition between the reducing and complexing reactions.

Some Fe^{III} is reduced by fulvic acid solutions with pH as high as 5 indicating that the reaction may be of widespread occurrence in soils.
Contact names: **Martin Cheshire, Bernard Goodman**

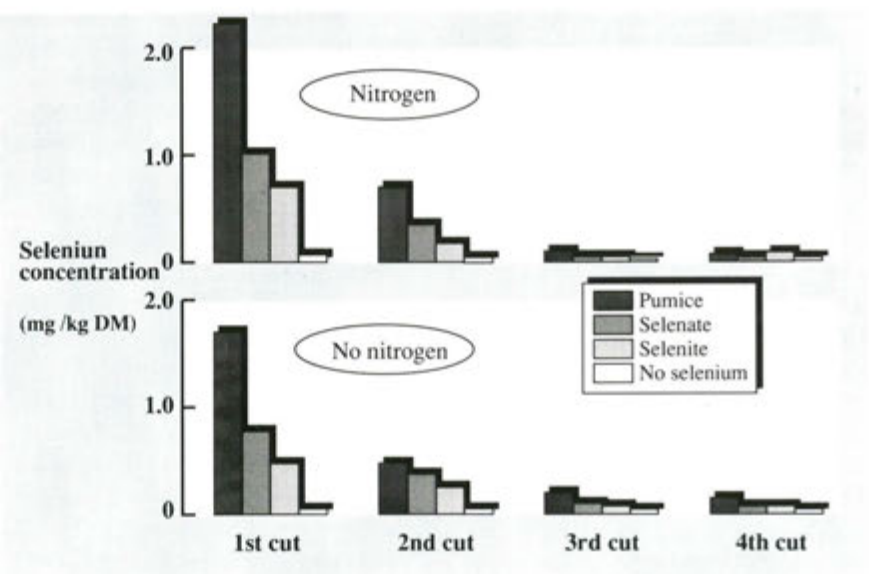
Selenium supply to herbage

Selenium is an essential nutrient in the diet of sheep and cattle. Many areas of Scotland produce fodder crops which tend to be deficient in this element. There is a need therefore to study the processes which control the uptake of selenium from the soil to the plant. Apparatus for the determination of this element in plant material has been constructed and methodology capable of determining low levels developed (Figure 5). Up to 200 samples per week can be analysed. The lower limit of determination is 0.010 mg per kg of dry plant material. This apparatus is being used in field studies involving soil applications of selenium.

Levels of Se in herbage in N. Scotland are often below those needed to prevent Se deficiency in livestock (@50mg/kg). Materials which could be used as "fertilisers" to increase and sustain the concentration of Se in the fodder all have drawbacks, ie selenates leach rapidly while selenites rapidly become immobilised and hence unavailable. There is a need for a slow release form of selenium. A possible material of this type, selenate immobilised on pumice granules is currently under evaluation.

Initial experimentation (MISR Annual Report, 1986, p.169) indicated that the "pumice formulation" could be effective in supplying Se to herbage in

Figure 5. Selenium concentrations in foliage.



the year of application and that concentrations varied substantially between the different components of a sward, eg concentrations in grass are 50% higher than those in clover (45 compared to 30mg Se/kg). A subsequent series of trials has aimed to assess the effect of soil type on selenium supply and to compare the pumice formulations with more rapidly available forms, ie sodium selenate and sodium selenite. High and low (90 and 20 kg N/ha) N treatments, initially and following each cut, were used to assess nitrogen effects and especially those mediated via pasture floristic composition. Results (Figure 5) indicate that, regardless of the N treatment, initially the selenate gave high concentrations in the forage but that concentrations then decreased and were similar to control levels at the end of the season. The pumice and selenite provided adequate concentrations throughout the 1985 season. The result for the selenite is unusual and is being assessed against the results from the other two sites. In the early cuts the higher N treatment increased the concentration of selenium. The contribution of changes in floristic composition to this is being assessed.
Contact names: **Grace Coutts, David Atkinson**

Effects of soil conditions on plant trace element uptake and distribution of trace elements in plant parts and species

Although a good general understanding of the relationships between the trace element content of Scottish soils and the crops grown on them has been built up, these relationships are mainly qualitative. In order to create effective models for trace element fluxes in grazing systems, quantitative relationships are needed. With this objective in mind, recent work has sought to quantify relationships between the trace element contents of ryegrass and clover, two important plant species in sown swards.

The type of information being obtained is illustrated in Figure 6 which shows how the cobalt contents of ryegrass and clover were related in a large group of samples from 14 farm sites in north-east Scotland. These farms were located on a wide range of soil types so that any findings should have a general validity. The data used for Figure 6 may be summarised by

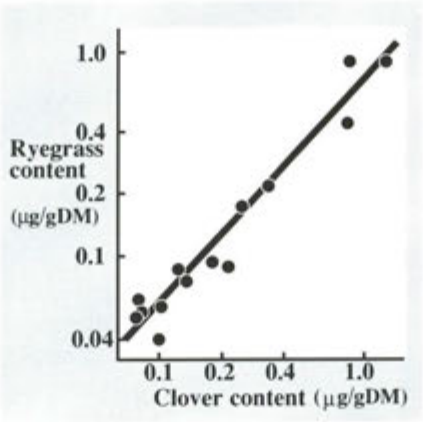


Figure 6. The relation between the cobalt contents of ryegrass and clover at 14 sites. Mean of 3 cuts in 3 successive years.

the statement that on average, clover can be expected to contain 60% more cobalt in its dry matter than does ryegrass growing in the same sward. Finer details, such as the way this relationship varies with the time of year or with soil type are being evaluated. Comparable data for other elements, e.g; molybdenum and zinc have been collected.

The total amount of a trace element in a plant is a useful indicator of the amount available to grazing animals. However, only a small fraction of the total is in fact utilised by their digestive systems. Research into the forms in which trace elements occur in plants is therefore in progress. One aspect of this has been a study of the effect of treating barley straw with ammonia, to increase its digestibility, on the binding and release of copper during digestion in the rumen. Initial work using a laboratory technique suggests that the ammonia treatment may inhibit the release of copper from sraw, but more work is needed before the implications for animal nutrition can be assessed.
Contact name: **John Burridge**

Elemental content of soils and vegetation on a range of improved and unimproved soil and vegetation types in the Outer Hebrides

The Scottish crofting counties benefit from a range of different agricultural grants some of which directly or indirectly aim to improve the quality of agricultural production and maintain soil fertility. The effects of some of these improvements on the nutrient status of soils and vegetation have been assessed. Soils were analysed for total and SO_4-S, exchangeable bases, Cu, Mn and Zn. Vegetation was assessed for ash and base content, N, Se, Cu, Mo, Fe and total and SO_4-S. Sequential soil extraction with silver thiourea and EDTA was used in the estimation of soil Cu, Mn and Zn. This new method reduced anion interference and was especially useful on highly organic soils.

Results from the study are being analysed using a "Generalised linear interactive modelling" programme and suggest that there are significant spatially scattered but persistent incidences of Se and Cu deficiency. In some herbage samples sulphur concentrations are very high. It is clear however that plans for the improvement of crofting land must take account of the environmental conditions in the year when the improvement programme is initiated and that given the potential for annual climatic variation in the western isles sustainability of yield with time must be an integral part of the improvement process.
Contact name: **David Atkinson**

Establish geochemical and environmental origins, distribution and mobility of trace elements in Scottish soils

Total and extractable trace elements have been determined in some 1000 soil profiles representing all the soil associations mapped throughout Scotland. These data, which have been built up over a period of some 35 years, can now be presented in the form of trace element maps.

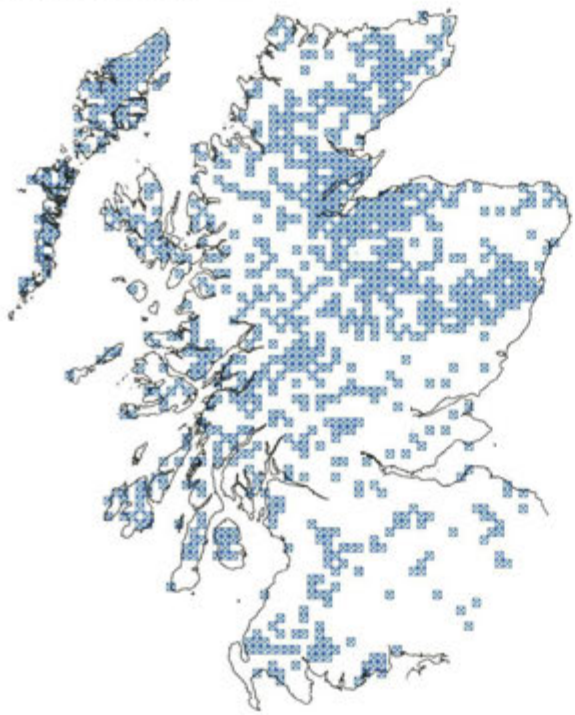


Figure 7. Areas of cobalt concentration less than 5µg/g.

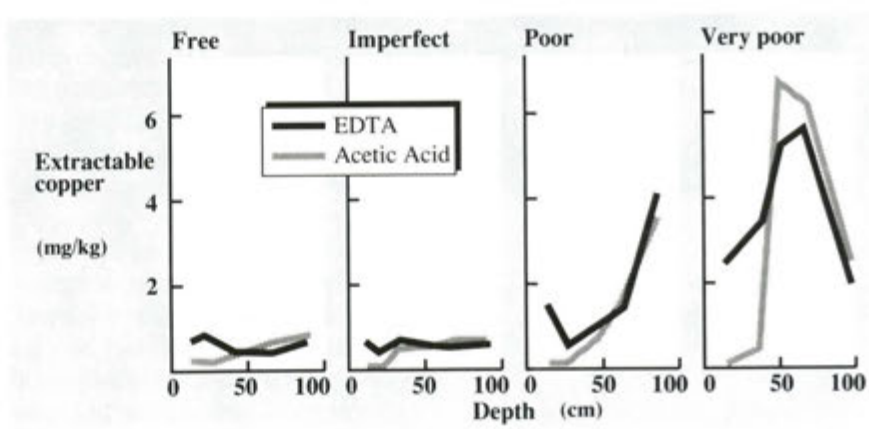
Because soil total trace element contents are closely related to the geological nature of their parent materials, trace element maps on a 1:2.5 M scale, have initially been prepared based on total contents in profile B-horizons. Such a map illustrating soils which contain less than 5 µg/g total cobalt is shown. (Figure 7). Areas where cobalt deficiency is prevalent such as Black Isle/Easter Ross, Morayshire, Aberdeenshire, the Hebrides and the Solway are highlighted but also several other areas. Such maps provide useful preliminary indications of risks of deficiencies or excesses of trace elements and may be useful in agricultural, environmental, geochemical or epidemiological research. A further objective is to produce maps based on extractable contents in topsoils related to soil series for selected areas on a larger scale.

Poor pedological drainage conditions lead to hydrologic weathering in the gleyed subsoils of soil profiles. This effect is illustrated in a hydrologic sequence of four profiles developed on mica schist, all on one farm in Angus, (Figure 8). Total copper contents in the subsoils of all four profiles are similar so the striking mobilisation of copper is due to impeded drainage conditions. This effect which has important implications for the uptake of trace elements by herbage is being further investigated by studies of distribution in particle size separates.

The fate of heavy metals applied to soils has been investigated in three different situations:
a) In 52 field experiment plots where copper and/or cobalt have been applied to soils deficient in these elements.
b) In 10 soil profiles near Aberdeen where sewage sludge has been applied.
c) At two long-term field experiment sites where sewage sludges heavily contaminated by metals were applied in 1968. These latter investigations have been carried out in collaboration with ADAS. The results overall indicate that heavy metals are firmly fixed in topsoils and are largely held in the upper 0 to 25 cm horizon. Where heavy applications of Cd, Ni or Zn in sewage sludge have been made there is evidence of some loss of these elements from the 0 to 15 cm horizon possibly due to leaching.

Contact name: **Mike Berrow**

Figure 8. The effect of soil drainage on extractable copper.



Manganese oxide minerals in Scottish soils

Accessory minerals, such as the hydrous oxides of iron (Fe), aluminium (Al) and manganese (Mn), play an important role in the sorption, fixation and release of nutrients in soils. Considerable data are now

Figure 9. Two views of a manganese pan exposed by erosion at the surface of a soil developed on raised beach deposits near Mull of Kintyre.

available on the influence of Fe and Al oxides and, indeed, on their formation and stability in the soil environment (Farmer *et al.*, 1987) but this is not the case with the manganese oxides. Much of the data on their properties and stability are based on statistical correlation rather than direct observation. In order to understand and hence predict the behaviour of Mn in soils detailed mineralogical data would be of considerable value. The present study was undertaken to provide such basic data on the Mn oxide minerals found in Scottish soils.

Mn staining is a common feature in imperfectly drained Scottish soils but the components responsible are difficult to isolate and characterise. However, Mn oxides also occur in the form of Mn-pans (Figure 9) where it is easier to obtain the Mn minerals free from adhering impurities.

The investigation of hand-picked separates from a number of deposits has been carried out using a range of analytical equipment, including electron microscopy and X-ray diffraction. The results show clearly that the deposits are not monomineralic. For example, in the Mn-pan at Toll of Birness, near Aberdeen, where birnessite was first identified as a distinct mineral, two distinct nodule types were found in close proximity. One of these was virtually pure cryptomelane, a potassium containing manganate, and the other contained a complex mixture of minerals, including hollandite, a barium containing manganate, vernadite, a poorly crystallised species and a third material thought to be birnessite. Electron microprobe analysis showed that the nodules from Birness contained significant amounts of the trace elements, Ni, Cu and Zn but the amounts varied in each nodule type according to the predominant mineral present. The phyllomanganates, birnessite and lithiophorite, have a higher content of trace metals than the tectomanganates, hollandite and cryptomelane. This observation may go some way towards explaining the observation made by Berrow and Mitchell (1980) that the statistical relationship between Mn content and other trace metals was different in Scottish soils compared to that reported from other parts of the world.

It is clear from this study that structural factors and mineral type play a significant role in the accumulation of trace metals by manganese oxides. In view of the metastability of these oxides in the soil environment, particularly their susceptibility to acid attack, and the known plant toxicity of some of the elements concentrated in them, as well as manganese itself, soil manganese oxides must be considered a potential hazard in soil acidification.

Contact name: **Ed Paterson**

Determine mechanisms involved in ochre formation and devise methods of minimising its production

Iron ochre deposition is a serious agricultural problem resulting in the costly blockage of field drains and often polluting streams and rivers (Figure 10). The problem is most accute on peaty soils or on acid soils close to peat deposits such as those often encountered in upland and marginal land areas.

Ochre formation occurs when the water-soluble ferrous iron Fe(II) is oxidised to the insoluble ferric Fe(III) form. To ameliorate the problem it has been necessary to ascertain the actual and potential amount of Fe(II) in the system and the precise mechanisms by which ochre is formed. The removal of all the Fe(II) before oxidation would provide an ideal solution to the problem, but this has proved difficult in practice. Laboratory experiments have shown that coniferous tree bark absorbed appreciable amounts of ferrous iron (33.8 mg/g dry Scots pine bark). Once absorbed the Fe(II) was not released back into the solution. The absorption capacity of the bark was increased 3-fold on composting.

Figure 10. Field ditch, heavily polluted with ochre at Cairnrobin Farm, Aberdeen.

The suitability of using coniferous tree bark to ease the ochre problem

was investigated by studying, for 5 years, the case histories of 2 farms near Campbeltown, each having an ochre problem of a different type. On one farm, Kilmichael, the Fe(II) concentrations in the drainage waters varied from 0.1 - 5.0 µgFe/ml, according to the drainage line, and this concentration dropped by about 60% in

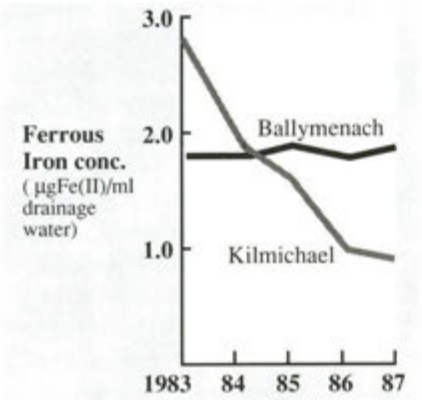


Figure 11. Ferrous iron concentrations in the waters of drainage line No. 4 at Kilmichael Farm and line No 13 at Ballymenach Farm, both near Campbeltown, Kintyre.

4 years (Figure 11). This farm may be regarded as having a temporary ochre problem. As a result of this case study, a nearby farm with a probable temporary ochre problem was treated with Scots pine bark 2 years ago. The bark, in pieces about 25 mm diameter, was mixed with an equal volume of gravel and used as an infill surrounding the newly installed drainage lines at a rate of 20 kg dry bark/m. After 2 years there has been no blockage of the system by ochre and the bark now contains only 4-6 mg Fe/g, well below its theoretical laboratory capacity of 35 mg Fe/g. No microbial decomposition of the bark was observed on this farm, or on another farm given a similar treatment near Elgin.

The second case study, at Ballymenach farm near Campbeltown, showed that although the Fe(II) concentration in the drainage lines varied between 0.1 - 3.4 µg Fe/ml, this value remained constant over 5 years of monitoring (Figure 11). This is regarded as a permanent ochre problem and the Fe(II) enters this basin site in the groundwater from the surrounding hills. On this farm renewable sources of bark were supplied in loose weave, polypropylene sacks inserted into specially constructed plastic chambers (0.5 m diameter) intersecting the drainage lines at 50 m intervals. Each chamber contained 20 kg bark. During the entire monitoring period the bark, changed annually, contained 8.0 - 12.4 mg Fe/g depending on its position along the drainage line.

Our experience suggests that on permanent ochre sites, the most practical solution is the design of the system to allow for minimal blockage and easy cleaning. A predictive model to forecast the nature and extent of the problem would prove useful and preliminary work on this aspect has started with the frequent monitoring of a permanent, severe ochre site near Aberdeen.

Contact name: **Derek Vaughan**

The reactivity of Al carboxylate complexes in the formation of imogolite, with implications for podzolization

Growing vegetation often acidifies the soil in which it grows. For some plant species, for example, coniferous trees, heaths and heathers, the acidification becomes so pronounced as to modify the soil by promoting the leaching, of aluminium, silicon and iron from upper horizons, and their deposition in lower horizons as aluminium silicates (allophane). This soil process, known as podzolization, can be quite rapid and can have a damaging effect on the cultivation and crops because of nutrient deficiencies and toxicities. We already know how aluminium and silicon react and are translocated from the results of laboratory studies, but we need to know the role of plants, their roots and general litter decomposition products, in this reaction. Organic acids such as acetic, formic, oxalic, malic, citric, 4-hydroxy- and 3,4- dihydroxybenzoic acids are commonly found in soil solution, and we have investigated, again in laboratory studies, how these acids individually influence the reaction between aluminium and silicon. Two of the reaction products, allophane and imogolite, are similar but have different physical properties and this has been exploited to distinguish them by gel forming capacity, infrared spectra and electronmicroscopy.

It is relatively easy to understand how, in the soil, organic acids from decomposing plant remains can chemically attack soil minerals dissolving aluminium, silicon and iron and thereby mobilising these elements. Some of the organic acids, for example, oxalic and citric, form very strong complexes with aluminium, but contrary to expectations, it has been shown even this complexed form of aluminium can react with silicic acid to form proto- imogolite allophane, a highly mobile form of aluminium in acid soils. The eventual crystallization of proto-imogolite allophane to fibrous imogolite has been shown to be strongly influenced by the type and amount of complexing organic acid present, and we have demonstrated for 3,4-di-hydroxybenzoic acid, a major aromatic acid associated with microbial degradation of plants in soil, that the complexed aluminium produces a wide range of imogolite morphologies which may ultimately influence such properties as ion exchange, gel formation, and soil structure. The specific influence of particular plant species in this regard is not yet known with any certainty.

Contact name: **James Russell**

Mineral weathering in relation to soil and freshwater acidification

The composition of waters entering a surface drainage system depends not only on the hydrological pathway, but also on the chemical, mineralogical and biological nature of the materials through which the waters percolate. Waters which percolate slowly through soils react and equilibrate with the constituent minerals and may assume a composition derived from these minerals. To understand the processes whereby soils and freshwater become acidified, therefore, it is necessary to establish the mineral weathering processes operating in soils, as these processes are responsible for release of base cations, for the formation of fine-grained, highly reactive phases which dominate exchange and adsorption in mineral soils, and for the release of soluble aluminium. Mineral weathering is the principal mechanism whereby the acid neutralising capacity of soilds is replenished.

Mineralogical and chemical analyses of soils from the four SWAP catchments have been carried out to establish the processes and products of weathering and to determine weathering rates. Two of these catchments (near Loch Ard) are heavily-acidified, one is moderately-acidified (in the Cairngorms) and the fourth (in Norway) is pristine.

The main mineral weathering processes identified are as follows,

a) Decomposition of chlorite, with no identifiable weathering product, thereby releasing iron, magnesium, silicon and aluminium.

b) Transformation of mica to vermiculite by loss of interlayer potassium.

c) Formation of non-exchangeable hydroxy-aluminium species in the interlayer region of vermiculite, particularly in B horizons.

d) Precipitation of imogolitic/allophanic material thereby immobilising aluminium.

e) Corrosion of feldspars and resultant release of base cations, silicon and aluminium.

f) Crystallization of gibbsite in montane alpine podzols in the Cairngorms catchment.

To predict future changes in soil/water acidification, it is necessary to determine rates of base losses on a catchment scale Long-term (historical) rates have been calculated for the moderately-acidified catchment in the Cairngorms by comparing the chemical composition of soil horizons with that of the parent material. Potassium and sodium have apparently been lost at rates of 2.6 to 4.0 kg/ha/a from individual horizons (11.5 and 9.2 kg/ha/a. respectively, from the whole soil) whereas calcium and magnesium are depleted at rates of 0.3 to 0.7 kg/ha/a from horizons, and 1.6 and 1.1 kg/ha/a, respectively, from the soils. An assumption in the calculations is that the loss rates have been constant since post-glacial time and this is likely to be incorrect. However, by studying a sequence of dated soils (chronosequence) at the nearby Glen Feshie, it should be possible to determine changes in weathering rate with time.

Contact name: **Jeff Wilson**

Acid transfer through vegetation and soils

The degree to which rainfall acidity is changed is strongly dependent on the time taken by percolating waters during their passage to streams or lochs. In general, the shorter the transit time the more likely will rainfall acidity transfer to surface waters. The factors mediating the transfer of acidity through vegetation and soils at two specific, partly forested sites with an existing or potential surface water acidification problem were quantified. The sites chosen were at Loch Fleet in Galloway, which has been acidified to such an extent (pH <4.4) that it can no longer sustain a fish population, and at Fetteresso in the Grampian Region where there is a small upland catchment with an acidification problem that has been identified by the River Purification Board. The two sites enabled comparison of different pollution loading regimes characteristic of the very wet west coast and dry east coast of Scotland. The study was divided into two parts

(a) an above ground study aimed at monitoring changes in rainwater chemistry through the forest canopy and forest floor and at modifying those changes by application of urea or base cations (K, Ca and Mg) and

(b) a below ground study aimed at the examination of patterns of water flow over and through soils in forested and moorland sites and the monitoring of changes in water chemistry.

The study revealed a number of interesting contrasts between the two catchments and elucidated the nature of current acidification processes. At Loch Fleet, the predominantly saturated condition of the peaty soils resulted in the majority of slope drainage being routed through the surface vegetation, root/litter mat of the soil so that rainfall-vegetation interactions largely controlled drainage water chemistry. Both forest and moorland vegetation further acidified the already acid bulk deposition throughout the year reflecting the nutrient poor states of the catchment soils. In the summer, an important source of acidification was the uptake of NH_4 ions from incoming precipitation by the vegetation canopy and surface root mat with a corresponding reverse flux of H ions. This process resulted in a marked increase in throughfall acidity from the tree canopies of N-deficient Lodgepole pine and Sitka spruce stands, which in the latter case could be reversed by the application of urea to the forest floor. Application of base cations caused no significant reduction of throughfall acidity. The acidifying effects of vegetation during the winter months

were attributed to greater interception of acid mists and fog at this time. Throughout the year, the continual inflows of acid waters from moorland and forested slopes explained the acid, low base status of the loch and its outflow.

At Fetteresso, surface throughflow pathways were again predominant on steep moorland slopes, the large flux of incoming rainfall acidity being further increased on passage through the surface vegetation. However, the forest cover exerted a major effect on both hydrology and drainage water chemistry. Thus, the marked seasonality of rainfall - Lodgepole pine canopy interactions resulted in a net acidification of rainfall during winter, and in a neutralization during summer. The latter was attributed to base exchange and leaching processes in the canopy, resulting in a marked reduction of acid flux to the forest floor. These processes were unaltered by the application of either base cations or urea. The high evapotranspiration rates in the forested area markedly dried out the soil and reduced the volume of soil drainage water, which was restricted by an impermeable layer to the upper soil horizons. Thus, stream flow and water chemistry in the catchment were determined largely by hydrological pathways and interactions on the moorland slopes.

Contact names:
Anne Leech, Tom Nisbet.

The release and sorption of nutrient elements

The availability of trace elements in Scottish soils varies with drainage status and a study of soils with different drainage developed on a range of parent materials has been carried out to try and locate the sites of the trace elements, and to obtain a better understanding of the pedogenic factors involved. The mineralogy and trace element contents have been determined on whole soil and particle size fractions. Accumulation of Co, Cu, Ni, Pb and Zn in the silt and clay fractions has been found in soils of all drainage categories derived from granite, basic igneous rocks, mica-schist, flagstones, shales and greywackes. The concentration of these elements in every particle size fraction increases with depth in the profile and these accumulation effects are most marked in soils with poor drainage, particularly those developed on igneous and metamorphic rocks, due to their higher content of primary ferromagnesian minerals. Levels of trace elements extractable by EDTA and acetic acid are also higher in profiles with poor drainage.

All these effects were examined in detail in a hydrologic sequence of four profiles developed on mica-schist on an upland farm in Angus and found to be similar for Cu, Co, Ni, Pb and Zn. Copper, for example, increases in the clays from 19 to 21 to 27 to 31% with increasing drainage impedance whereas the corresponding figures for the coarse sand are 26, 28, 13 and 16, respectively. This suggests that hydrologic weathering results in a loss of Cu from the sand and enrichment in the associated clay.

The mineralogy of the clay fractions of all four profiles is dominated by dioctahedral mica with lesser amounts of kaolinite, chlorite, vermiculite, hydrobiotite, feldspar and quartz. There is some evidence that Cu may be associated with vermiculite and hydrobiotite formed by biotite weathering, the nature of which is dependent on drainage conditions.A series of sequential extractions with water, ammonium acetate, acetic acid and EDTA indicated that most of the extractable Cu in the two most poorly-drained soils was associated with the exchange complex whereas most of the extractable Cu in the freely-drained profiles is more strongly bound. Thus trace elements are concentrated in the clays and where the drainage is poor, most of the extractable component is held in a readily exchangeable form.

Contact: **Derek Bain**

PLANTS - NUTRIENT UPTAKE, GROWTH AND PRODUCTION

Interactions at the root/soil interface

Processes taking place at the soil/root interface influence water supply, mineral nutrition and the susceptibility to pathogens in plants. There is also some evidence for intensified weathering and structural modification of soil materials in the zone immediately adjacent to the plant root. The *in situ* study of this interface region is being pursued by electron microscopy. However many technical problems need to be overcome, particularly in specimen preparation, before its potential can be fully exploited. For the examination of morphology we are using low temperature scanning electron microscopy where the specimen is examined in the frozen hydrated state at temperatures of -140°C or less, thus avoiding the chemical fixation and critical point drying procedures which can lead to shrinkage and the formation of artefacts. Studies to date have been aimed at optimising specimen preparation, recognising specific features, documenting the physical adherence of the soil material to the root surface and the changes which occur in roots as they age. The roots chosen for study were those of barley grown in a sandy soil which when removed from their growing medium always have a cylinder of soil firmly attached to the root surface. Root hairs, fungal hyphae and mucilagInous exudates all contribute to this adhesion process, the latter being particularly interesting since it can be involved in the cementing of adjacent sand grains situated some way from the root surface. Particle size analysis of an attached cylinder of Boyndie series soil and of the bulk soil in which the plants had grown indicated that the rhizosphere soil (Figure 1) had relatively less large (0.5-2 mm) diameter particles and relatively more small (1-20 µm) diameter particles. As the finer soil particles have major effects upon soil hydrology this "root effect" may have a significant influence on the roots' water supply. For microanalytical studies, segments of root with their adhering soil have been freeze dried and resin embedded and a polished cross section surface prepared. In Figure 1, an SEM micrograph of the boundary between a root and soil is accompanied by a Si X-ray distribution image of the same area.

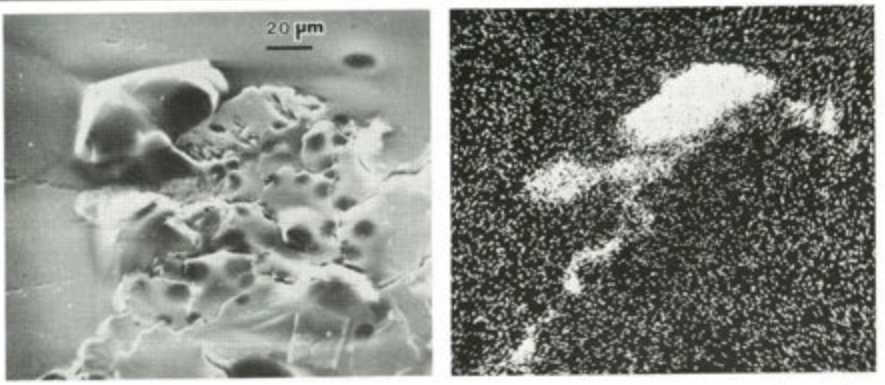


Figure 1. An SEM micrograph of the boundary between a root and soil, (left) and a Si X-ray distribution image of the same area, (right). The occurrence of a thin (<10µm) Si rich band along the root boundary is interpreted to mean that clay material may be concentrated at the root surface.

Observations on the changes (with age) which occur in the roots of a deciduous tree, using M26 apple roots as a model system, have been made using the scanning electron microscope (Figure 2). The root tip has little soil material tightly bound to it and the cells are around 40µm diameter with a high water content. Cell walls are thin. An obvious partly water filled apoplast is visible (top left). The mature root has a well-attached covering of soil which is held to the root surface by mucilaginous material. Although the outline of the root is essentially circular it is slightly irregular (top centre and top right). The cortical cells are similar to those of the root tip

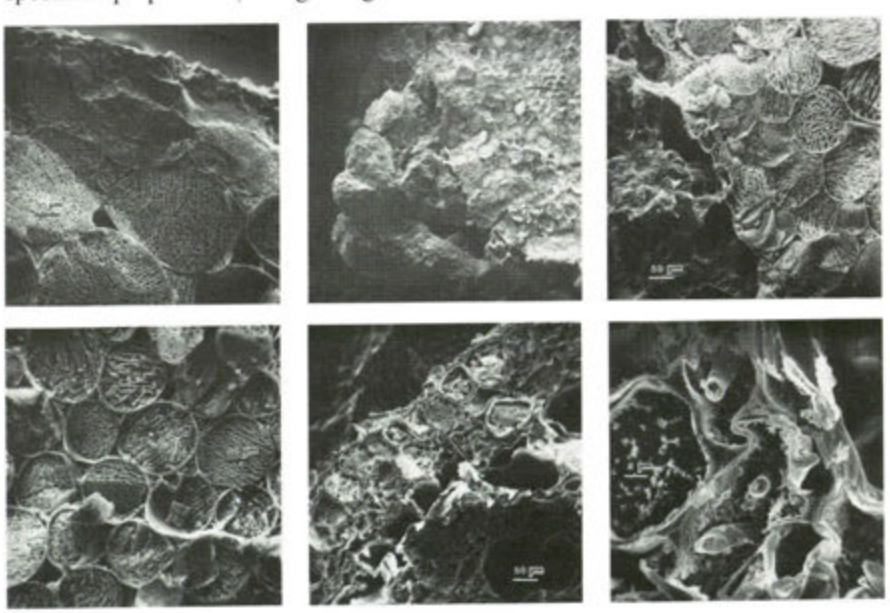


Figure 2. A series of six scanning electron micrographs illustrating some morphological aspects of apple roots in contact with soil. Full details appear in the text.

although in the outer cortex the intra-cellular spaces are less well developed (Figure 2 top right and bottom left). Decomposition appears to begin not at the root surface but within the inner cortex. Cell contents and radial walls seem generally to be lost earlier than tangential walls (Figure 2 bottom centre). Subsequently pieces of cortex are shed into the soil and these can contain some relatively intact cells some containing hyphae of what seem to be vesicular arbuscular mycorrhizas (bottom right). The state of these cells suggests that this represents a substantial loss of nutrients from root to soil.
Contact name: **Bill McHardy**

Inter-relationships between fungi and plant roots

Research on the interactions between fungi and plant roots encompasses studies on saprophytic, and parasitic and mycorrhizal fungi. The ecology and physiology of soil fungi, from the root regions of plants, involved in the degradation of phytotoxic phenolic acids which are found in varying amounts in the soil solution have been assessed. Other studies have been involved in elucidating the processes leading to the microbiological weathering of minerals in soils, leading to the release of important plant nutrient species and the antagonism of soil fungi to other species which are either saprophytic or parasitic on plant roots. The latter studies have resulted in the discovery of two known, and one unknown, secondary metabolites in Penicillium echinulatum, which could prove potentially useful in combating certain fungi which are damaging to roots of various plants of economic importance. A related research line by Swedish workers has revealed two antibiotics, Mycorrhizin A and Chloromycorrhizin B, from a mycorrhizal fungus which are inhibitory to the root rot fungus *Fomes annosus* which causes large economic losses in Swedish forest trees.

Current interest in on-farm forestry, makes important the isolation and

Figure 3. A mycorrhizal fungus from a Scots pine forest.

selection of mycorrhizal and rhizosphere fungi which are capable of releasing phosphate from inorganic rock phosphates. A mycorrhizal fungus (Figure.3) from a Scots pine forest which shows great potential in this respect is now in culture. It should be feasible to inoculate tree seedlings with a combination of this fungus with the rock phosphate substrate to stimulate tree growth.
Contact name: **David Jones**

Root growth in relation to the soil physical environment

The soil physical environment can affect many aspects of root physiology, root penetration to depth, root density and diameter, branching habits, elongation rates and nutrient uptake rates.

The methodology used to study root system dynamics is important. A new method, the rhizotron camera system, is being used in the study of crop root systems in the field. The equipment consists of a black and white television camera attached to a video control unit and a monitor. The system is portable and can be operated from the back of a vehicle using a petrol driven generator in the field (Figure 4). The system has

Figure 4. A petrol driven generator in the field.

limitations in its use for quantifying root number and root length, and is not suitable for use in the upper 0.1 m of soil but has great potential for studying turnover rates, branching habits and elongation rates.

In other experiments the soil coring method of root extraction has been compared with the profile wall method. The profile wall method has advantages when studying a

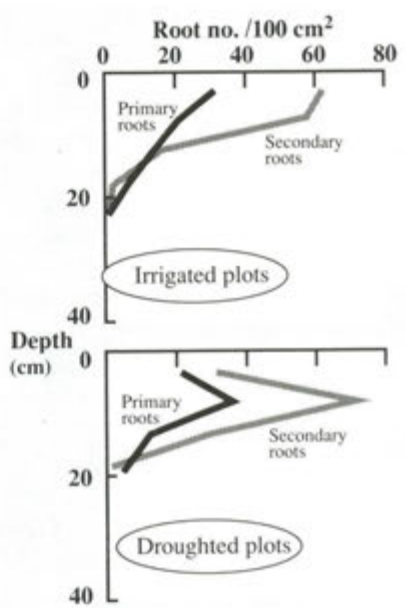


Figure 5. The number of primary and secondary potato roots on irrigated and droughted plots.

heterogeneous spatially distributed root system such as the potato. In the initial stages of development of the potato crop, most roots are within 0.1 m of the mother tuber. Later in the

season, the roots spread laterally outwards, although avoiding the area directly beneath the furrow. Management can also affect root distribution. Irrigation of the potato crop led to more roots being located in the surface 0.05 m of soil, and at depth in the profile (Figure 5). This led to a higher uptake of water and nutrients, and a higher yield of tubers at harvest.

Cultivation affected early root distribution in winter barley. Here there were consistently more roots penetrating below 0.2 m depth where the soil had been ploughed, compared to where the soil had been rotaspiked or disced. Later on in the season in the two later treatments, the root system was able to compensate for poor early growth by increasing the uptake of nutrients and, leading to there being no differences in final yield at the end of the season. Roots have a great ability to adapt and continually change in response to their surrounding environment.

Contact name: **Lorna Dawson**

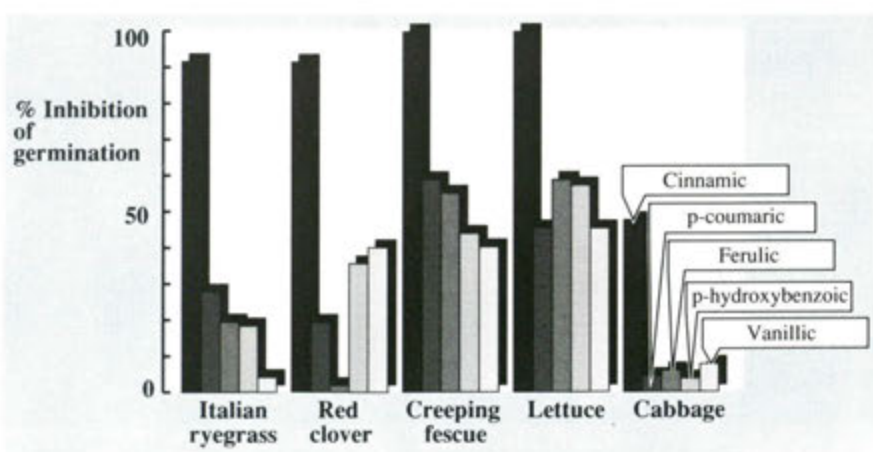
The effect of organic constituents from soils on plant and microbial metabolism

Soil organic matter can have a direct effect on plant growth. Usually more than 60% of this organic material is composed of humic substances which are unlikely to make a major contribution to the direct growth response. In contrast, phenolic acids, which comprise < 0.01% of the organic matter, are biologically active secondary metabolites and appear to be implicated in allelopathy, the means by which one plant species can influence the germination, growth and development of a different and often competitor species.

The most common phenolic acids found in the soil solution are p-hydroxybenzoic, ferulic, p-coumaric and vanillic acids with some syringic acid. Experiments carried out under axenic conditions show that these phenolic acids inhibit the germination and growth of ryegrass, creeping fescue, clover, lettuce, peas and cabbage. The magnitude of these effects depends on the phenolic acid and the plant species under investigation (Figure 6). Creeping fescue and lettuce are the most sensitive species whereas crucifers such as cabbage and mustard are virtually unaffected by the usual soil phenolic acids.

Plant roots rapidly take up ^{14}C-labelled phenolic acids by a process dependent on metabolism. Once inside the root the acids influence cell elongation and division and have a considerable effect on root morphology, for example, in the presence of syringic acid, peas produce short, stubby roots with few laterals, contrasting with long, thin roots formed in the presence of ferulic acid or darkened roots in caffeic acid.

Figure 6. The effect of 500µM concentrations of different acids on germination.



In all cases where root growth is reduced, protein synthesis, measured in terms of ^{14}C-proline incorporation, is inhibited, with p-hydroxybenzoic and vanillic acids being more effective than ferulic acid. The uptakes of ^{22}Na, ^{36}Cl and ^{45}Ca are also reduced.

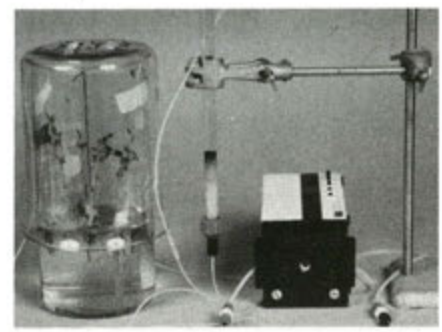


Figure 7. Apparatus for measuring the phenolic acids produced in root exudates.

A sterile technique has been developed to measure the phenolic acids produced in root exudates and to assess the contribution made by the exudates of different plant species to the soil phenolic acid pool. Using an enclosed system, a growth solution is circulated continuously between the plant vessel and a resin column which will trap phenolic acids (Figure 7). The use of a solution culture technique is essential as soil can selectively adsorb phenolic acids. For a Countesswells series soil the order of sorption was ferulic = vanillic > p-coumaric > p-hydroxybenzoic acid.

A modification of this system is being developed to model the complex interactions between phenolic acids, or other toxic organic substances, nutrient supply and microbial activity in relation to plant growth and yield. Toxic concentrations of phenolic acids are added to nutrient media, and the resin is replaced by soil fungi which can metabolise the phenolic acid under investigation. Preliminary work suggests that these fungi can ameliorate phenolic acid toxicity towards higher plants.

Contact name : **Derek Vaughan**

The efficiency of uptake and transport of ammonium and nitrate ions

Experiments on nitrogen fluxes mark the end of a long series of ion transport studies using onion roots. The thick, straight, unbranched roots (Figure 8) are ideal for cutting easily managed segments.

Nitrate reductase activity was absent from onion roots, so that uptake, measured with the stable isotope tracer ^{15}N, from 2mM $^{15}NO^-_3$ in a complete nutrient solution, could be taken to represent unassimilated nitrate within the root segments. This made the onion root tissue amenable to compartmental analysis for nitrate, from which fluxes across the membranes bounding the cell cytoplasm and vacuole could be estimated. Similar experiments performed with ^{15}N-labelled ammonium salts were difficult to interpret because of the activity of

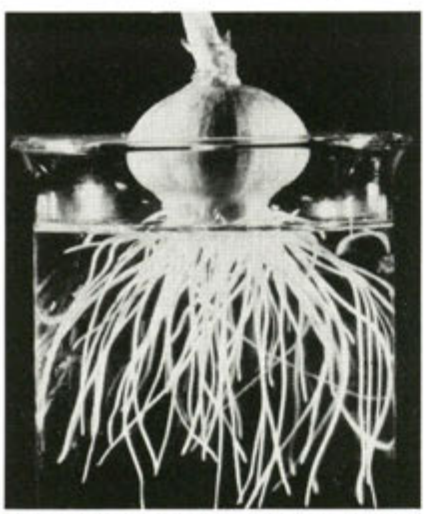


Figure 8. Thick, straight, unbranched onion roots are ideal for cutting easily managed segments.

glutamine synthetase leading to rapid assimilation of $^{15}NH^+_4$ into amino acids and proteins.

Net NO^-_3 uptake was relatively slow (Figure 9), although influx was rapid enough for vacuolar exchange to approach completion in 30 hours. In contrast, when NH^+_4 was the sole N source, no change in the content of free NH^+_4 occurred, but $^{15}NH^+_4$ uptake gave a ^{15}N content six times the background level of NH_4-N after 24 h (Figure 9). This resulted from the continual removal of absorbed NH^+_4 from the ion transport milieu by assimilation. Competition was evident between NH^+_4 and NO^-_3 when provided together in the nutrient solution. Compared with uptake from single N sources, uptake of nitrate over 24 h was reduced by 70 per cent in the presence of NH^+_4, whereas 24 hours

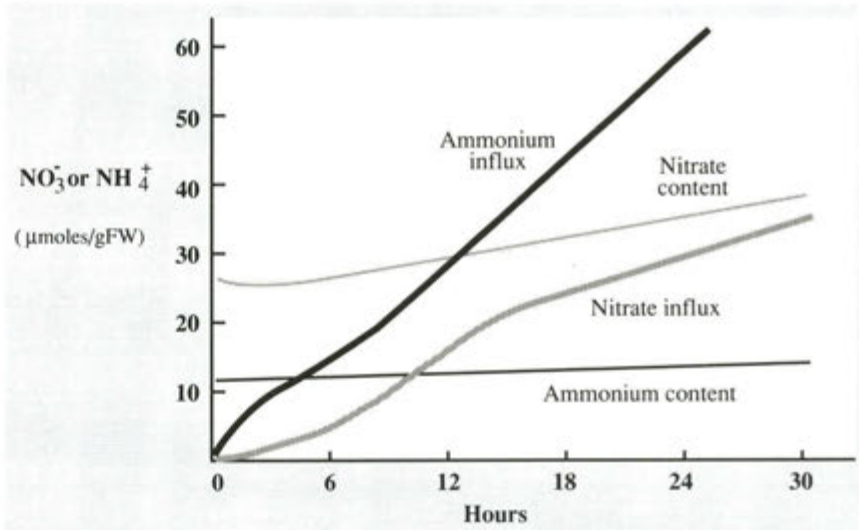


Figure 9. The course of ammonium and nitrate influx and content. Nitrogen was supplied to the nutrient solution either as 2mM $(NH_4)_2SO_4$, or as 2mM$NaNO_3$.

uptake of NH^+_4 was reduced by only 25 per cent in the presence of nitrate.

The flux analysis revealed compartments identified with the vacuole, cytoplasm and free space in root cortical cells. Further calculations indicated that nitrate is actively pumped into the cytoplasm from the outside solution, but enters the vacuole by passive diffusion.

The experience gained from these studies will be used to pursue a new programme of work on competition between ammonium and nitrate for uptake, transport and exchange in species comprising upland pasture, in particular ryegrass. This will be part of a study aimed at improving N fertiliser efficiency.

Contact name: **Alan Macklon**

Trace element uptake by roots

Problems of Co and Cu deficiency in grazing animals led to the study of the physiological factors limiting herbage content of these micronutrients. In ryegrass, the root content of Co and Cu was found to be high, relative to the levels found in the shoots. Experiments with seedling plants (12 days old) in sterile solution culture (Figure 10) showed considerable differences in the way that Cu was held in the root, compared with Co. Most of the Cu was absorbed by the root cell walls which initially dominated total uptake, and which was still a large persistent contributor after 50 hours. During this time adsorption changed from sites more ionic, less Cu specific in character (and filled during the first 10 hours of exposure to radio-Cu) to sites more covalent, and

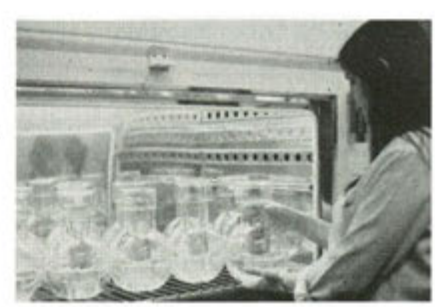


Figure 10. Experimenting with 12 days old seedling plants.

more Cu specific in character. These conclusions were reached by comparison of uptake and loss of Cu in living and dead roots, cell wall extracts and pure cellulose. The dominance of cell wall Cu exchange over exchange within living cells limited the examination of the latter, although a small uptake into the symplast was detectable.

The cell wall exchange of Co in ryegrass roots was much simpler than for Cu, having a half-time of the order of 10 minutes, allowing a full compartmental analysis of the root cells. This revealed that the major part of the root Co was contained not in the cell walls but in the vacuoles, where it was actively accumulated after passive entry into the cytoplasm. It was also found that Co uptake increased with alkalinity of the nutrient solution, counterbalancing the favourable feature of acid soil, in which solublisation of Co, and hence "availability" for uptake, increases.

Transport of Co to the shoot is limited compared with root accumulation, reaching only 10 percent of total uptake after 72 hours. Further observations have led to the working hypothesis that Cu and Co are transported as complexes with amino acids or larger molecules, and transport is limited by supply of suitable ligands.

Contact name: **Alan Macklon**

Root growth in relation to nitrogen supply

In 1987 an experiment was set up at Craigiebuckler to investigate root growth, nitrogen uptake and inflow rates in the potato crop. Plants were supplied with either 20 kg N /ha at planting, or no N fertiliser at all. Eight replicates of each treatment in randomised blocks were divided into 3 areas to give growth analysis subplots, root coring subplots and subplots for neutron probe measurements. Ten plants adjacent to the soil cores were divided into tubers, stems and leaves and the nitrate and total N content of these tissues were measured. Two sets of cores and one set of soil blocks were taken for root length, biomass and diameter measurements.

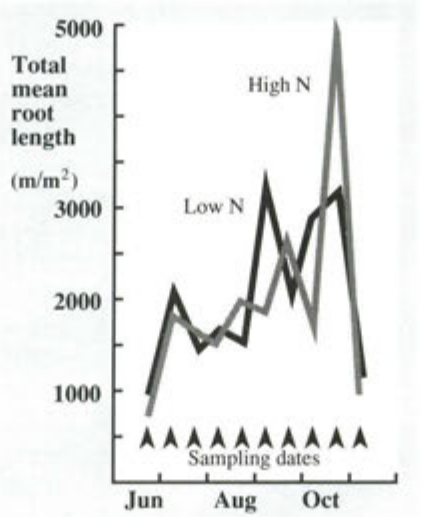


Figure 11. Seasonal pattern of potato root growth with low and high levels of N.

In a similar experiment in 1986 where root growth was quantified at fortnightly intervals, seasonal trends in root growth were evident (Figure 11). No great differences in root growth in response to N fertilisation were observed until September, except during the initial weeks growth in June and early July. Early in the growth of the potato plant (before full canopy cover), there were more roots growing to depth (20-25 cm) where fertiliser N had not been applied. The root system of both treatments decreased after the end of September, although the roots of the plants from the treatment receiving no fertiliser N persisted longer in the soil.

Since differences in root populations between the two treatments were greatest at the start of the season, more effort was directed in 1987 into the collection of samples in the early stages of the plants' development. Root cores (surface area of 38.5 cm^2) were collected along the row to the maximum depth of rooting at weekly intervals. Most of the N uptake by the potato crop had occurred by August, although the roots retain a considerable physiological capacity to absorb N during the second half of the growing season (Robinson and Millard, 1987) and the root system continues to develop until October. It appears to be the soil, not the plant that is the main limitation to further N uptake.

Contact name: **Lorna Dawson**

Organic nitrogen compounds in soil

A potato crop had ^{15}N-labelled fertiliser applied and the gradual immobilisation of the nitrogen into soil organic matter was followed over an entire growing season. There was a very rapid translocation of ^{15}N down the soil profile, probably as nitrate which was then taken up into organic matter. The major component, humic acid, gradually accumulated almost 50% of the label present in the soil, while there appeared to be a residual pool of label resident in the hydrophilic acid fraction, generally associated with biomass. Losses of nitrogen in the procedure used in the potato experiment has led to new methods being applied to a similar grass experiment, whose results are being evaluated.

Contact name: **Hamish Anderson**

The effects of spaced conifers on herbage production

An experiment has been set up in which Sitka spruce trees at three heights (3 m, 5 m and 8 m tall) have been re-spaced to three spacings (4 m, 6 m and 8 m) equivalent to 625, 278 and 156 stems per hectare. The tallest trees have had the lowest four whorls of branches removed.

Sward boxes sown with ryegrass have been distributed in a stratified pattern beneath the nine tree-canopy structures created. Herbage growth is measured directly from the sward

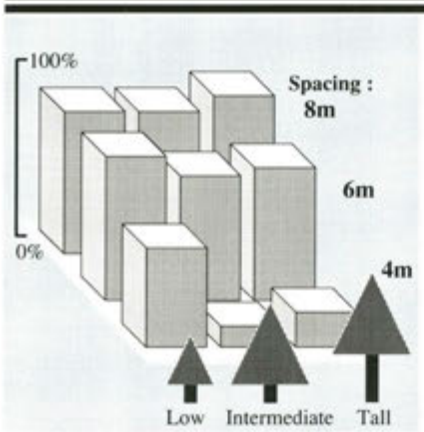


Figure 12. The percentage of open herbage growth.

boxes. In addition a limited number of boxes are being monitored for a range of micro-climate parameters.

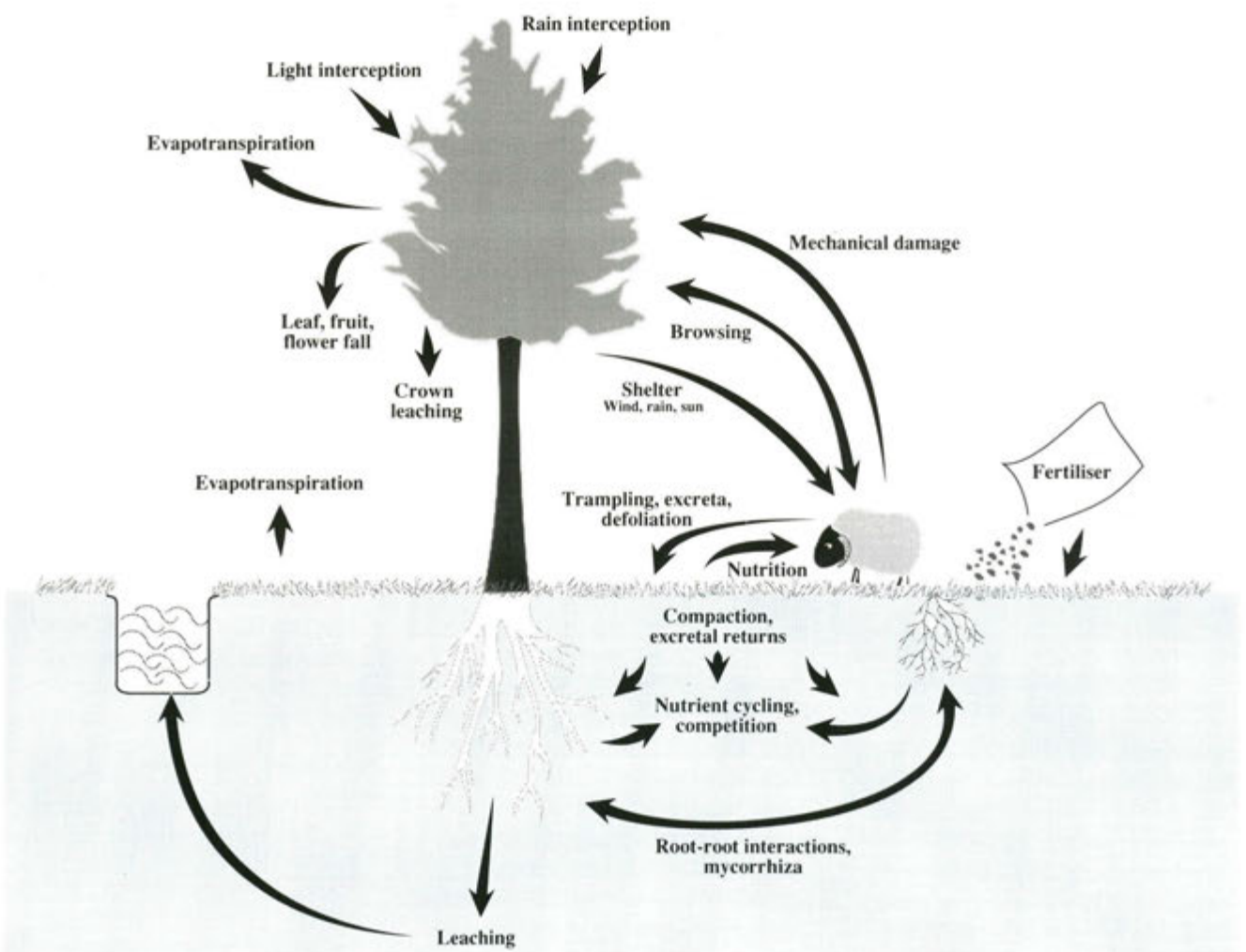
During the establishment year of 1986, when the swards were one year old, they adapted to their new environment. Boxes in very shaded conditions (60-65% reduction in light) showed reduced tiller numbers (30% of unshaded swards) and etiolated leaves.

During 1987 there was a reduction of 85% in the growth rate of grass growing below the most dense canopy (5 m height and 4 m spacing). Swards below the taller trees, at the same spacing, showed a slightly smaller reduction of 79%. The shortest trees at 4 m spacing reduced herbage growth by 42% (see also Figure 12).

Reductions in herbage growth measured below the trees at the wider spacings were rather less. They were in the order of 18-28% for the 6 m spaced trees and 10-20% for the 8 m spacing. The tallest trees at the widest spacing reduced the mean annual growth rate by only 10%.

An investigation of the data collected from the sward boxes equipped with micro-climate monitors indicated that 80% of the variation in mean annual herbage growth rate was accounted for by level of light received. There was no evidence of an effect during 1987 of soil moisture level even though precipitation was reduced by 25% in some cases.

Figure 13. The interaction of silvopasturalism.



There is some slight evidence that light is not the main limiting factor at all stages of the growing season. Further analysis of the 1987 data will be carried out to investigate effects within the growing season.

The experiment will continue in its present form for at least one more year.

Contact name : **Alan Sibbald**

The nitrogen and water relations of grass and trees on establishing a silvopastoral system

The integration of forestry and grazing systems, silvopastoralism, involves complex biological interactions of trees, grass and animals (Figure 13). The differing nutritional requirements of trees and grass raises important questions about the use of fertilisers to maximise the efficient production of both components; the use of fertiliser at a normal level for grass may be detrimental to tree form. It is necessary therefore to evaluate the growth and nutrition of trees under typical grass management systems and to consider alternative methods and levels of fertiliser application.

A field experiment with grazed plots receiving four fertiliser

Figure 14. Wild cherry planted at 4 x 4m spacing.

treatments has been set up with Wild Cherry (*Prunus avium* L.) planted at 625 stems/ha (4 x 4 m spacing) on a permanent pasture (Figure 14). Each tree was protected by a treeshelter (1.2 m high) and by two stakes to prevent twisting and breaking of the treeshelter by the grazing sheep (Figure 15). The

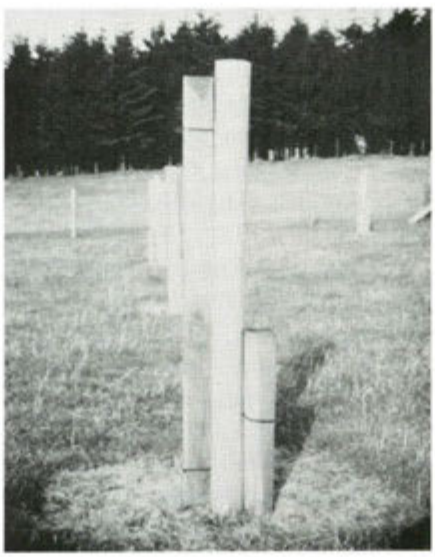


Figure 15. The method used as protection from grazing sheep.

treatments are designed to study the response of trees and grass to levels of fertiliser normally applied to both when grown independently of each other and also investigates the more efficient use of fertiliser by the more frequent applications of low amounts of fertiliser tailored to predicted plant demand. The low levels of fertiliser N to be applied in some of the nitrogen treatments meant that a granular fertiliser could not be applied with accuracy and so liquid fertiliser

Figure 16. Liquid fertiliser being applied with a crop sprayer.

(Ammonium nitrate) was sprayed on with a crop sprayer on board an ATV bike (Figure 16).

Laboratory experiments are also being used to study the nutrition and growth of trees and grass under closely controlled conditions to determine the optimum nutrient mixtures and has relevance for the formulation and application of fertilisers.

Contact name: **Colin Campbell**

Mixtures of tree species enhance nitrogen availability

A leaching column experiment was set up to test the hypothesis that interactions occur in mixed litters which increase microbial activity and N mineralisation. Litters taken from beneath stands of Sitka spruce (*Picea abies* (Bong.) Carr) and Scots pine (*Pinus sylvestris* L.) were leached with water for 21 weeks at 20°C either singly or in a 1:1 mixture. Microbial respiration, N mineralisation and nitrification were greater in spruce than in pine litter and the mixed litters had higher rates for these processes than values calculated for a 1:1 mixture. The greatest interaction occurred in the numbers of enchytraeid worms introduced in the spruce litter that proliferated when mixed with pine needles.

A second experiment to test the effects of the enchytraeids was carried out using pure spruce litter, uninoculated or inoculated with worms. After 16 weeks leaching at 20°C with distilled water the enchytraeids had significantly increased mineral-N and nitrification. Concentrations of phosphate in the leachates were accompanied by decreases in the estimates of microbial N and P and the effects of the worms were attributed to a grazing effect that replaced fungal with bacterial biomass and diminished the amounts of N and P immobilised.

Contact name: **Berwyn Williams**

Nutritional requirements of Sitka spruce

Nutritional demands by young trees relate to the rate of formation and the eventual size of the green canopy, while the maintainance demand, once the canopy has formed and closed, is a

function of the amount of foliage replaced each year.

Studies have shown that the total weight of foliage in spruce is around 15-20 Mg ha^{-1} compared to 7-15 Mg ha^{-1} for most pine species. These differences are due to the amount of foliage formed in the current year rather than to the amount of foliage retained by the trees (Table 1). Older foliage may act primarily as a reservoir of nutrients and stored energy; older spruce foliage (> 2 yr old) may contain 25-45% of major nutrients but older pine foliage may only contribute 5-20% (Table 2).

The losses of foliage as litter are also much less for spruce (about 10% yr^{-1}) compared to pines (about 30% yr^{-1}) and the losses of nutrients by litterfall are correspondingly lower for spruce (about 5% yr^{-1}) compared to pine (about 15% yr^{-1}).

This results in nutrient demands on the soil being very much greater by spruce than pine during canopy formation. However once spruce has established its larger crown at canopy closure, the demands on the soil by the two species will not be significantly different.

Contact name: **John Miller**

Simulation modelling of tree nutrition

Work has continued on the development and use of a computer simulation model (FENDS) designed to investigate growth and nitrogen dynamics in managed stands of Corsican pine. FENDS attempts to represent ecosystem processes in a simplified fashion so as to minimise data requirements of the model user. Forestry Commission yield tables and detailed empirical data from a fertiliser experiment on Corsican pine have been used to develop the model which has been tested against a wider range of published yield tables. Options available to the users of the model include the simulation of weeding, fertilisation and thinning operations with harvest intensities ranging from conventional removal of stems only to complete tree harvesting in which stumps and all above-ground material is removed from the site.

The development of the model has highlighted a number of areas in which information was lacking or contradictory. These included effects of site factors and management operations on partitioning of growth within trees and competing ground vegetation, the processes controlling internal nutrient cycling and the long-term dynamics of recalcitrant soil organic matter within forest ecosystems.

FENDS has been used to simulate a range of management scenarios and results suggest, for example, that care should be taken when interpreting short-term growth responses to weeding on sites of low fertility because elevated leaching losses may result in exacerbated nutrient deficiencies later in the rotation.

Contact name: **Mike Proe**

Nutrient cycling in birch

Assessment plots were laid out in a range of age classes of birchwoods at two sites, one, Silpho, showing no changes in soil properties, the other, Craggan, having pronounced changes, particularly in soil pH, exchangeable calcium and total phosphorus. At each site the assessment of the above ground biomass and nutrient contents were determined along with the amounts and concentrations in litterfall. Examples of regression data used to produce component and crop weights is given in Figure 17, showing the similarity between both sites, Craggan and Silpho.

	N	P	K	Ca	Mg
Silpho					
leaves	2.4-2.5	0.25-0.27	0.65-0.75	0.35-0.40	0.15-0.20
leaf litter	1.0-1.1	0.13-0.15	0.30-0.35	0.55-0.65	0.22-0.28
Craggan					
leaves	2.3-2.4	0.22-0.27	0.80-0.90	0.30-0.35	0.20-0.25
leaf litter	1.2-1.5	0.10-0.15	0.20-0.30	0.55-0.75	0.15-0.20

Table 1. Mean nutrient concentration (%) in leaves and leaf litter at Silpho and Craggen.

Preliminary assessment of the chemical data has shown that the nutrient concentrations and amounts in the tree components are again similar at both sites, there appears to be a larger weight of leaf litter at the site showing no changes in soil properties (Silpho) than at Craggan. Preliminary data for foliage and leaf litter analysis are given in Table 1.

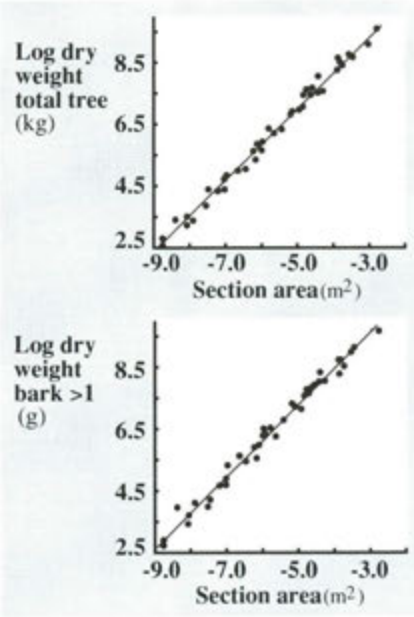


Figure 17. Examples of regression data in birch.

Contact name: **John Miller**

P and N cycling in established grass/clover swards and the effects of soil acidity

The seasonal dynamics of N and P cycling between soil and plant have

Treatment NPK	Acetic Acid P (mg/kg) Oct 1986	Soil ** status	Herbage yield* 1986	Mg/ha (OD) 19 year mean
000	21.2	Low	3.3	4.6
001	23.8	Low	5.2	6.4
101	18.3	Low	5.9	8.0
201	19.3	Low	6.6	8.4
011	76.0	Moderate	7.9	7.9
111	69.5	Moderate	10.6	10.6
211	50.6	Moderate	10.4	11.7

* means of duplicated plots
**Advisory soil status (Low 10-35 mg P/l and Moderate 36-90 mg P/l)

Table 2. Acetic acid extractable phosphorus and herbage yields for experimental plots (65/32).

been investigated for established grass/clover swards. The study considers soil nutrient availability, plant root growth and nutrient uptake and the partitioning of nutrients within both grass and clover. An overall aim is to understand nutrient cycling within the swards, possible fertiliser interactions and the effect of soil nutrient status on plant development and productivity.

The experiment was established in 1965 at the Institute's Craigiebuckler site, on a soil of the Countesswells Association and received a range of N, P, K additions which have remained constant since initiation. Fertiliser treatments studied included three rates of N (0, 220 and 440 kg/ha) with and without P (50 kg/ha). All plots received K (280 kg/ha) except for one which has received no fertiliser since 1965. The resulting differences in nutritional status between plots are substantial, as is herbage production (Table 2). Seven of the twelve replicated treatments were intensively sampled during the 1987 growing season. Data collected has included estimates of soil nutrient availability, root density and distribution, herbage production and composition. In addition, soil moisture content (neutron probe) and water potential (tensiometers), water-table level (dipwells), soil solution (suction lysimeters), precipitation and soil/air temperatures have been monitored.

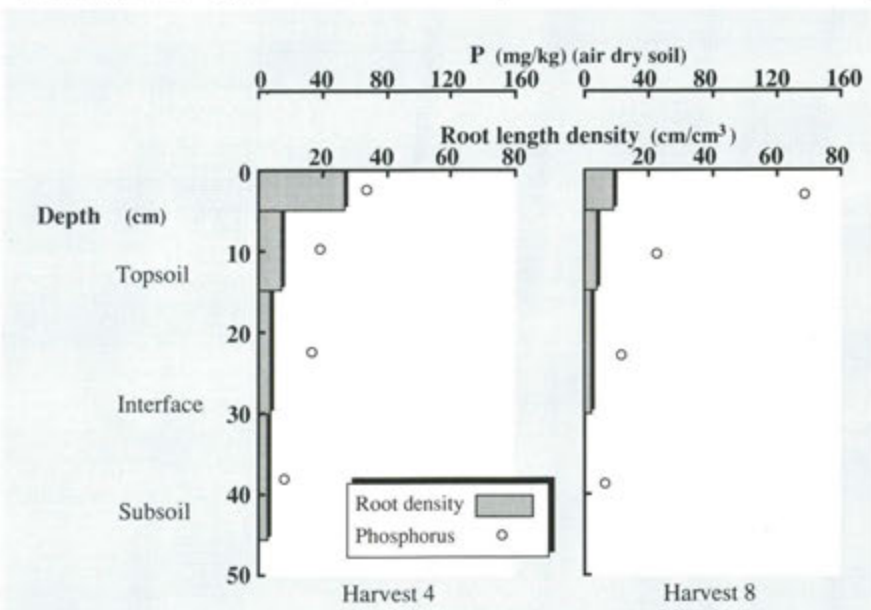


Figure 18. Phosphorus content and root density.

Isotopes were applied in order to quantify the uptake of the current year's fertiliser and investigate the dynamics of the nutrients in the soil . ^{32}P and/or ^{15}N were added to subplots at rates equivalent to the relevant annual rates on the rest of the plot. A total of 22.5 mCi of ^{32}P was applied to each of the six subplots (1.75 m^2) receiving phosphorus, while ^{15}N was applied as double-labelled ammonium nitrate (5.0 atom %).

The volume of soil exploited by roots is a particularly important factor when considering nutrients with low soil availabilities such as phosphorus. The seasonal patterns in root system development and turnover rates collected in association with information on nutrient availability are therefore particularly important. Soil cores were collected on each sampling date and subdivided according to depth (0-5 cm, 5-15 cm, 15-subsoil boundary and subsoil). Soil from one core was used for chemical analysis while the roots were removed from the replicate cores and used to calculate root densities for each sampling depth.

An example of the data obtained is shown in Figure 18 where two sampling times are plotted. The most noticeable factor is the sharp decline in root density with depth. Comparison of the two sampling dates suggests that root decay was greater than the rate of root growth for the last (No. 8) harvest, resulting in a marked reduction of roots. The available phosphorus content is also shown for each soil core and a similar decline in amount occurs with soil depth. It is important to notice however that both the highest P concentrations and root densities coincide. The results also suggest that as plant demand decreases towards the end of the season the available phosphorus levels appear to recover.

Contact names: **Anthony Edwards, Lorna Dawson**

The biogeochemical cycling of elements in upland ecosystems

A fertiliser experiment laid out in 1964 within pole-stage stands of Corsican pine forms the basis of studies into the cycling of nutrients during the establishment of newly planted second rotation plantations. In the original trial ammonium sulphate was used to supply nitrogen at rates of 0, 252, 504, 1008 and 1512 kgN/ha. Fertiliser was applied over three years with split applications being used for the two highest rates.

In March 1986 (20 years after fertilisation had ceased) destructive sampling was carried out within each of the five treatments. Basal area, volume and above-ground standing biomass increased with increasing rate of fertiliser application.

Detailed investigations are now being carried out on the control and heaviest fertilised treatments to quantify the nutrient requirements of newly planted trees and to measure the supply of nutrients within different parts of each system. Rates of decomposition are being determined for foliage twig and branch residues remaining after harvest operations. Mineralisation at different depths within the soil profile together with uptake by plants and losses through leaching are being estimated using a sequential coring technique (Raison *et al.*, 1987) supplemented by field lysimeters. In addition, rainfall reaching the forest floor is being measured using a network of permanently sited through fall gauges which will enable changes to be monitored as the tree canopies develop.

Early results suggest that weight loss of residues is more rapid in the fertilised plots compared to controls and that foliage and twigs decompose more readily than branch material.
Contact name: **Mike Proe**

The role of organic nitrogen for grass growth in grazed swards

The amount of nitrogen in soil organic matter is about 150 times that added as fertiliser but as it is only slowly broken down to forms that can be used by plants, it usually supplies only 25 to 50% of the N requirements of a good grass crop. Nevertheless soil organic nitrogen is a central component of the N cycle and determines the long term sustainability of grassland systems. We need to know how much nitrogen is made available to grass from soil organic nitrogen and what factors affect this process in order to make more efficient use of this large resource.

Using a tiller tissue turnover technique to measure the accumulation of nitrogen by grass (Thomas et al. 1988), and animals fitted with collection bags to prevent the return of excreta to pasture, the flux of nitrogen from soil organic nitrogen to herbage was determined in continuously grazed swards maintained at a steady state height of 5 cm and given no N fertiliser. Over two seasons the average rate of net N accumulation was 0.5 kg N/ha/day on a non-calcareous gley soil (approximately equal to 100 kg N/ha/yr).

Fertiliser N is often applied to supplement the supply of nitrogen from soil organic nitrogen and a study has been conducted to 1), determine the efficiency of different forms of fertiliser when applied to limed and unlimed soils of differing organic matter content and 2), assess the effects of fertiliser application on the mineralisation of organic nitrogen.

A non-calcareous gley soil (11% OM) was compared with a peat (76% OM) in a pot experiment in growth chambers with the following treatments: no lime or lime added to raise pH to 5.5, no ryegrass or 40 seeds per pot, no N or the equivalent of 50 kg N/ha (10% ^{15}N enriched) of urea, ammonium chloride or potassium nitrate. Plants recovered more of the added fertiliser nitrogen when grown in the peat compared with the gley. The recovery of different forms of fertiliser decreased in the order nitrate > ammonium > urea for both soil types. Liming the peat (from pH 3.9 to 4.9) significantly increased herbage yield but had little effect on yield from the gley (from pH 4.9 to 5.5). There was no effect of lime on the recovery of added fertiliser nitrogen. Greatest amounts of mineralisation of organic nitrogen occurred in the presence of plants but in the absence of added fertiliser nitrogen (Figure 19). Different forms of fertiliser nitrogen did not result in large differences in

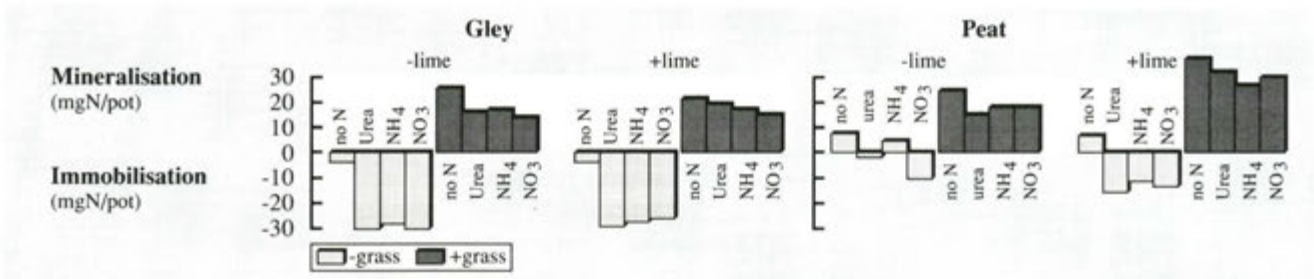


Figure 19. The effect of form of nitrogen fertiliser and lime application on soil organic mineralisation or immobilisation.

the amounts of soil organic nitrogen mineralised. Liming had little or no effect on the mineralisation of the organic nitrogen in the gley soil with or without added fertiliser but increased mineralisation of the peat by 50-100% in the presence or absence of fertiliser. The results indicate that liming high OM soils to ca. pH 5 has a greater impact on the mineralisation of organic nitrogen than the addition of different forms of N fertiliser.
Contact name: **Richard Thomas**

The effect of grazing management and fertiliser N on nitrogen fixation

For successful management of grass/clover swards and to obtain the maximum input of fixed atmospheric nitrogen from clover we need to understand the N economy of grazed swards. This requires information on both the quantity and the seasonal pattern of nitrogen fixing activity of clover in swards subjected to different fertiliser N and grazing management regimes.

The nitrogen fixing activity (acetylene reduction) of clover in continuously stocked swards, maintained at a surface height of 3.5 cm without N and with N (20 kg N/ha) every 3 weeks), was monitored for 3 successive seasons. In all 3 seasons and in both fertilised and unfertilised swards, peak activity was measured in May and June (Figure 20), concurrently with maximum growth. The reduction in nitrogen fixing activity in fertilised swards was largely explained by differences in clover leaf dry weight (Figure 20). Nitrogen fixing activity in grazed swards was positively correlated with the amount of clover leaf material present (HFRO Biennial Report 1984/85, p5). However, the extent to which it was affected by sward height history, i.e. whether swards were grazed down to or growing to reach target height, was not clear. Four sward treatments were established in which the effect of sward height manipulation on nitrogen fixing activity was determined: swards maintained at 3 or 5 cm, or grazed down from 5 to 3 cm, or allowed to grow from 3 to 5 cm. There was no significant difference in nitrogen fixing activity per g clover leaf dry weight between sward treatments, and the greatest activity was found in the treatment with the greatest amount of clover leaf tissue i.e. 3 cm growing to 5 cm. Differences in excretal return may be implicated in causing the observed differences in clover content since sward height was confounded with stocking rate.

The acetylene reduction technique is useful for comparing nitrogen fixing activity in different sward treatments, but provides only semi-quantitative estimates of the amount of nitrogen fixed. The possibility of combining tissue turnover techniques with ^{15}N dilution methodology to quantify nitrogen fixation in continuously stocked swards is now under investigation but the success of this approach cannot yet be judged.

The amount of clover present in the sward is clearly a major factor determining the input of fixed N. Although light and competition for space are important factors in determining clover content of the sward, they are insufficient to explain fully the differences in clover both within a single sward and between different sward treatments, especially in N fertilised swards. An experiment was conducted to identify soil, plant and animal factors determining spatial heterogeneity of clover within swards maintained at 3.5 cm with and without N . In both sward treatments several clover parameters (including meristem number, leaf and stolon dry weight, and nodule number) were negatively correlated with the population of Poa species, the dominant weed grass in the sward. In N fertilised swards only, the number of clover nodules was negatively correlated with soil total nitrogen concentration. Work to identify major factors determining the spatial heterogeneity of clover in grazed swards continues.
Contact name: **Carol Marriott**

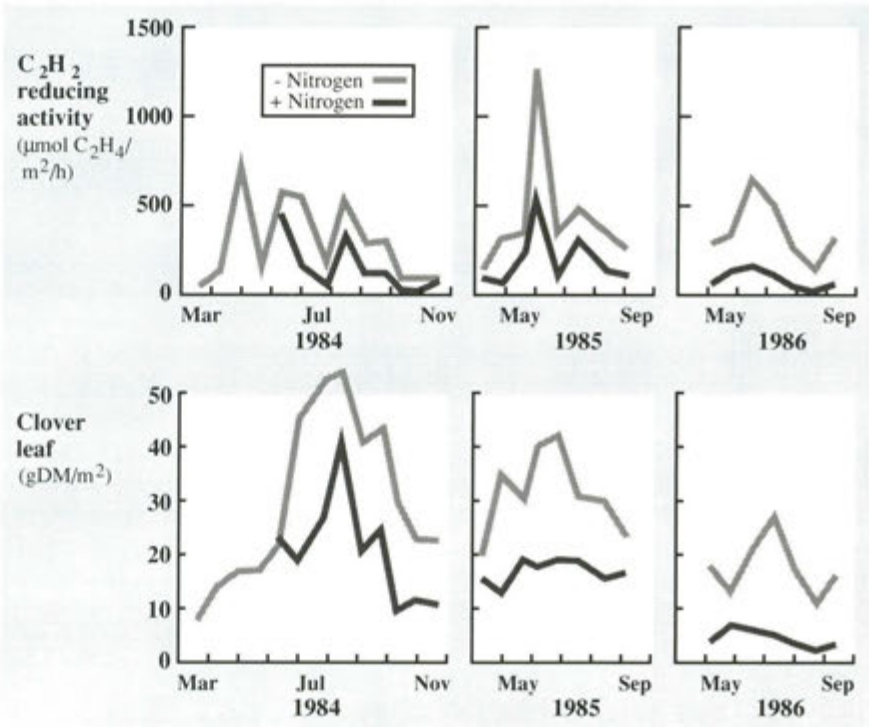


Figure 20. C_2H_2 reducing activity and clover leaf dry weight in 3.5cm swards which are N fertilised or receive no N.

The transfer of fixed N from clover to grass

White clover, through the fixation of atmospheric N, can make a valuable input of N to hill and upland pasture systems. Clover N is recycled through the soil-plant-animal system via several pathways, e.g. animal consumption and excretal return, and via herbage, root and nodule senescence and decomposition. The relative importance of each pathway is determined by the quantity of N

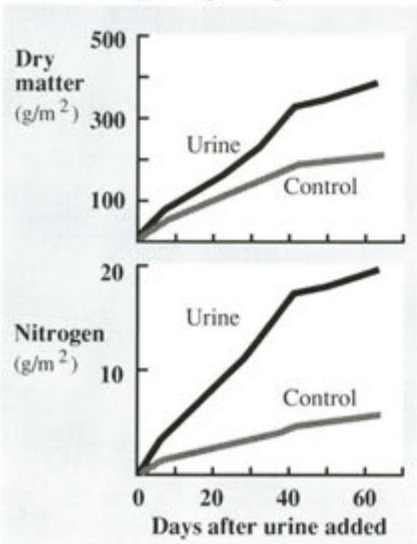


Figure 21. 1986 urine experiment. Cumulative DM in urine treated and control areas and cumulative N from strip cuts.

cycling and the rates and timescale of recovery of N by plants. This may be strongly influenced by management factors, including grazing and N fertiliser strategies. Knowledge of the cycling of clover N is required so that full advantage of the input of fixed N can be taken and strategies to minimise the use of fertiliser N can be developed. Urine return and herbage senescence two important pathways for the transfer of fixed N in grazed swards have been studied. Urine (1l/m^2, equivalent to the rate of urine deposition by grazing sheep) was applied in spring 1986 to areas of a sward maintained at 3.5 cm, which were either grazed or protected from grazing, (control areas received an equal volume of water). Urine addition almost doubled total herbage dry matter accumulation, and N accumulation was over three times that in control plots (Figure 21). N was rapidly recycled via the urine pathway, although this is a relatively inefficient route as only about 25% of urine N applied was recovered in herbage. Although urine increased total dry matter accumulation, clover growth was reduced; meristem numbers by 80% for up to 17 weeks following urine application. In addition leaf appearance and stolon branching were reduced and stolon death was increased Thus urine adversely affects the future performance of clover, and may in response to patchy deposition generate large-scale heterogeneity in both clover content and the cycling of fixed N.

Field and box experiments to assess the quantity of clover petiole and stolon N returned to the soil via herbage senescence, and the pattern of addition of senescent material during the year are currently in progress. Preliminary results suggest that very little stolon tissue survives for longer than one growing season and that stolon senescence accelerates during August-October. More petiole tissue also senesced later in the season that in early summer. The quantitites of N cycling via petiole senescence have yet to be calculated, but early results suggest that the amount of dry matter senescing is similar in swards maintained at 3.5 and 5.0 cm. A growth room experiment will provide information on the rate and timescale of recovery of legume residue N by ryegrass plants. The data from these experiments will be used to model the transfer of fixed N from clover to grass and to assess the relative importance of urine and herbage senescence in cycling clover N in swards subjected to different management regimes.

Contact Name: **Carol Marriott**

The transfer of N from ingested herbage to the soil N pool

Animals grazing herbage excrete more than 75% of the nitrogen they ingest, mainly via urine. The amount of nitrogen returned to pasture via the animal is often equal to the amount added as fertiliser. Although large amounts of excreted nitrogen are lost by leaching, volatilisation or denitrification, some is recovered by herbage. (Figure 22). In order to identify inefficiencies in the overall

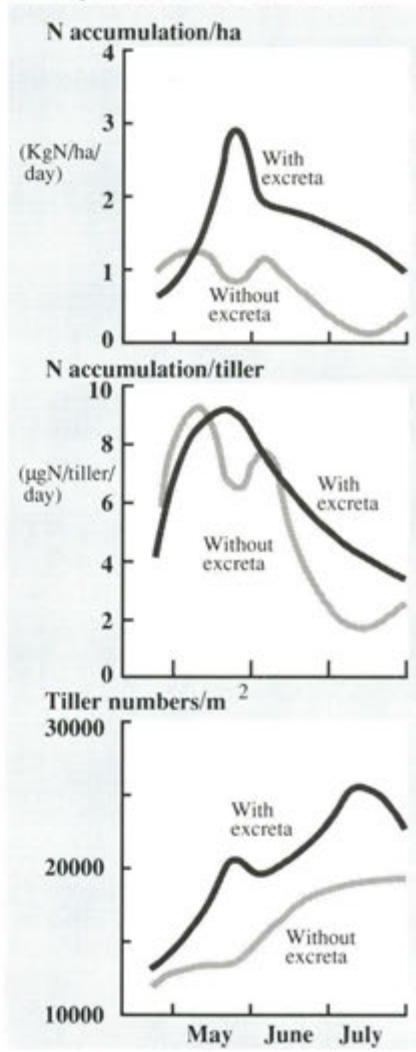


Figure 22. The effect of excreta on rates of N accumulation and tiller numbers.

flow of nitrogen through the soil-plant-animal continuum we need to know the fate of excretal nitrogen in hill and upland pastures. This

information can then be used to improve the efficiency of nitrogen use on grasslands.

Measurements of nitrogen accumulation by herbage from ungrazed swards cannot be accurately extrapolated to the grazed sward because of the absence of excretal returns, trampling and selective defoliation. These factors result in important differences between grazed and cut swards in both sward structure and physiology. To assess the effects of excreta from grazing animals on the accumulation of nitrogen by herbage, a technique has been developed which measures changes in the total amounts of nitrogen in grass tillers. The technique allows an assessment to be made of the components of nitrogen accumulation including the remobilisation of nitrogen from senescing leaves and rates of senescence.

The effect of excretal returns was studied during May to October in 1985 and 1986 by comparing two 0.15 ha plots grazed by Blackface ewes, fitted with collection bags to prevent excretal returns, with two plots similarly grazed but with normal returns. In 1985 normal excretal returns doubled the rate of accumulation of nitrogen by herbage on grass-only swards given no nitrogen fertiliser, and maintained at a height of 5 cm throughout the season by adjusting sheep numbers. Similar results were obtained in 1986. The main factor responsible for the increased accumulation rates was a greater number of tillers in the plots receiving excreta compared with those not receiving excreta, while there was little or no difference in the rates of nitrogen accumulation, remobilisation from leaves or in rates of senescence expressed on a per tiller basis.

The same technique has been extended to include the cycling of phosphorus and potassium in swards receiving 156 kg N/ha during 1987. Normal excretal returns increased the rates of accumulation of nitrogen by 89%, phosphorus by 73% and potassium by 72% compared with plots receiving no excreta. Both uptake per tiller and increased tiller numbers were responsible for these increases.

The data from these experiments, in conjunction with information on the distribution and duration of dung and urine patches, will be used to model the effects of grazing animals on the cycling of nutrients through the soil-plant-animal system.
Contact name: **Richard Thomas**

Genetic variation in the barley root system and its consequences

The root systems of different plant species and of genotypes within a species can vary in a number of ways. Using spring barley as a model system the extent of variation in major characters such as distribution with depth has been assessed. In addition, to assist in the use of root assessments in genotype selection by plant breeders, a number of sampling systems have been tested.

Barley plants, of 25 varieties, were grown in a Boyndie series soil in 1 m glass tubes or perspex faced observation cells in a glasshouse. Root growth was assessed using an intersection method. Root length density as indicated by the intersection of roots with a single 1 cm square in a 10 cm depth increment significantly related to intersections in the whole section. This suggests that for this species a small sample could be representative of the whole. Measurements of root length density for plants 26 days post emergence were correlated with records at 12 days. This suggests that genotypes with particular root system vigour could be predicted at an early date. In addition comparisons of the length of root at a given date with that at the same or a deeper depth on a later date were correlated, ie length at 75 cm depth on day 26 was correlated with that at 25 cm on day 19.

Among the genotypes studied variation has been detected in root length density, distribution with depth and root diameter. Varieties with similar total production but different root systems were compared in respect of their ability to grow with a bottom water supply or under conditions of a restricted supply of mineral nutrients (Figure 23). In a study of this type the variety Keria which has a relatively shallow root system grew less well than average, especially with a restricted nutrient supply while the variety Heriot which had a relatively deep root system seemed to do better than average. The variety Ayr which had good root hair development did relatively well with a restricted nutrient supply.
Contact name: **David Atkinson**

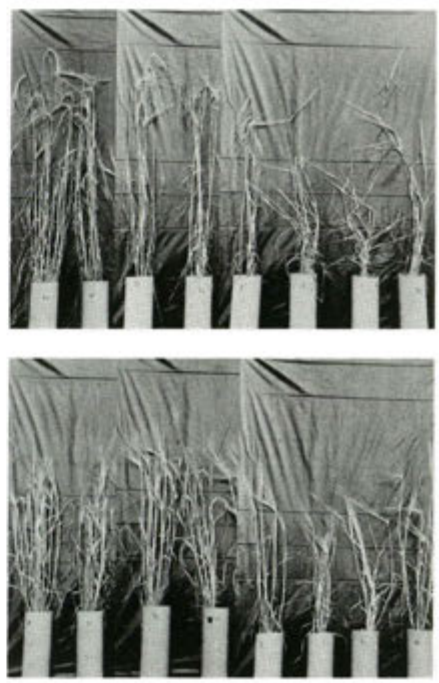


Figure 23. (Top) barley variety Keria, left watered with full nutrients, centre watered with 1/10 nutrients. Both sub-optimal regimes resulted in restricted growth. (Bottom) the barley variety Ayr arranged as above. A restricted nutrient supply had little effect on growth and bottom watering less effect than in Keria.

Internal rust spot, a physiological disorder in potato tubers.

Internal rust spot (IRS) is a physiological disorder of the potato plant, in which externally healthy-looking tubers contain discrete rust-coloured lesions in the medullary tissue of the flesh. This necrotic tissue has now been subjected to a detailed investigation by electron spin resonance (ESR) spectroscopy with the objective of identifying chemical changes that occur as a result of the disorder.

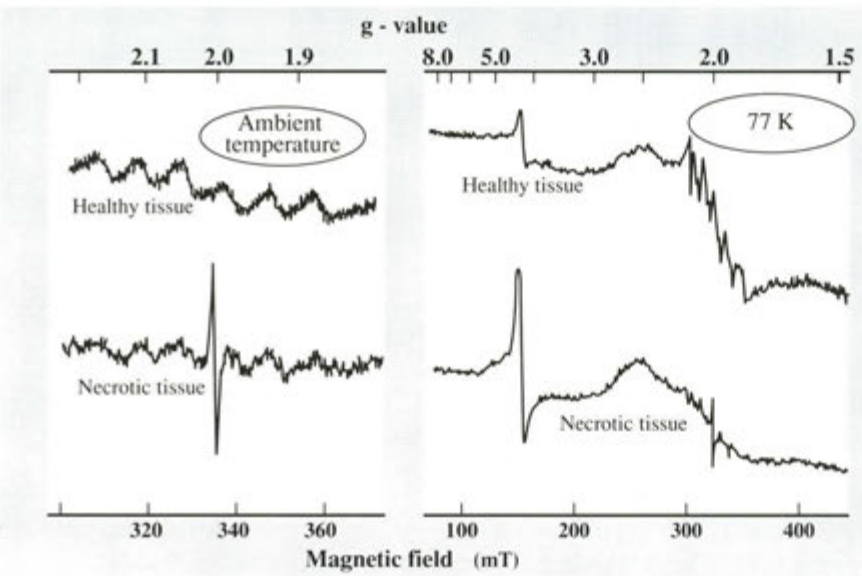


Figure 24. ESR spectra of tissue from potato (SCRI clone 10337 de 40). Important features are sextets from uncomplexed Mn(II), narrow single peak free radical components with g≈2 (necrotic tissue), Fe(III) complexes with g≈4.3 and other Fe(III) species, seen as the broad peak with g≈2 (at 77K).

The ESR results (Figure 24) clearly show that production of free radicals and oxidation of metal ions such as Fe (II) and Mn(II) occur when the necrotic tissue is formed. Major amounts of Fe(III) are produced. However, although much smaller quantities of free radicals are detected, large scale free radical production cannot be discounted because of the likely mutual annhilation of free radicals during polymerization processes.

There is other circumstantial evidence implicating inadequate supplies of calcium in the production of IRS. Since calcium has an important function in the preservation of membrane structure, low calcium stress could result in disruption of cellular organisation by loss of membrane integrity. This would then allow the antioxidant systems in the cell membrane to be by-passed by natural oxidizing agents leading to rapid oxidation of cell components. Both metals and organic molecules within the cell would be affected, cell senescence occurring very rapidly with the production of coloured materials which represent the IRS.

Contact names: **Bernard Goodman, Donald McPhail**

The effect of age on the organic and inorganic constituent of crops

For many annual plants most of the nitrogen (N) used is taken up during vegetative growth. Reproductive growth can, therefore, rely upon redistribution of some or all of the required N from vegetative tissues. Potato plants store N in their leaves to augment soil N taken up during the tuber growth, so as to provide sufficient N for tuber bulking at the end of the season. Although N can be stored in leaves as nitrate, most is stored as protein, particularly in plants grown with a low N supply. The chloroplastic enzyme ribulose 1,5-*bis*phosphate carboxylase/oxygenase (RUBISCO) is responsible for carbon fixation and can constitute up to 80% of the soluble leaf protein in plants. In addition to its catalytic activities, RUBISCO has the properties needed for a storage protein and is quantitatively the most important leaf protein from which N is remobilised during leaf senescence.

Fertilisation of potatoes with N changes the seasonal pattern of N uptake by the crop, distribution of N within the canopy and the pattern of canopy senescence. To optimise fertiliser use we need to understand how N supply effects partitioning of N within the plant and remobilisation of vegetative N for reproductive (tuber) growth. The ability of the potato plant to accumulate and remobilise N from both nitrate and RUBISCO has been studied in plants grown with or without N fertiliser, using an immunosorbtion technique developed to measure RUBISCO.

Nitrogen fertilisation caused N to accumulate in the lowermost leaves of the canopy as nitrate and as protein in higher leaves, but had no effect upon the proportion of the total protein accounted for by RUBISCO. During tuber growth leaves began to senesce and become net exporters of N. Remobilisation of N from nitrate was only significant for tuber growth in well fertilised plants. In contrast, degradation of RUBISCO contributed a large proportion of the protein-N lost from leaves during tuber bulking, contributing between 11% and 15% of the total N found in the tubers, regardless of the N supply to the plants. Fertilised plants continued to grow leaves at the top of the canopy, throughout tuber bulking, while those at the base of the canopy senesce. The use of isotopic N (^{15}N) supplied to the plant at different phases of crop

growth has shown that fertilised plants use current uptake of N at the end of the season to augment the canopy N and drive the continued leaf growth. In contrast, transfer of N from the canopy to the tubers was associated predominantly with remobilisation of protein (RUBISCO) N from leaves during senescence. Late applications of fertiliser N to the crop by, for example, foliar sprays of urea, are unlikely to directly increase the N supply to the growing tubers, but will maintain leaf growth at the end of the season and so be a benefit for ware crops.

Contact name: **Peter Millard**

Crop rotations and the use of fertilisers

In the majority of agricultural systems, fertiliser supplements are a necessary requirement for the maintenance of both crop yields and soil nutrient status although a variable but often relatively small proportion of the fertiliser applied in a particular year is recovered in the final harvested crop. Under some situations this results in excessive nutrient losses (particularly nitrogen and phosphorus) via drainage waters which may cause environmental linked problems. There is therefore an urgent need to improve overall agricultural 'efficiency' by practices geared not just to crop yields but which deliberately also maximise the proportion of applied fertiliser actually removed in the final product.

A long-term experiment, established in 1984 at Cross of Jackston on a Foudland soil (MISR Annual Report, 1986, pp. 159-163) was designed to provide information on both crop responses and fertiliser strategies. The experimental design had time as an essential component. A four-crop rotation sequence comprising winter wheat, potatoes, spring barley and a grass/clover ley was planted on four individual treatment blocks. Fertiliser treatments (partly factorial) include two levels of nitrogen and sulphur and three rates of phosphate and potassium. Two of the plots also receive farmyard manure (FYM) either with or without additional N. The actual quantities of fertiliser added is adjusted to suit each crop type. A first full rotational cycle has now been completed (4 years) and considerable treatment differences are apparent. The greatest total dry matter production (over the four years) was associated with the high nitrogen input treatments (Figure 1). The plots receiving only FYM gave the poorest yield returns, however additional inorganic nitrogen increased yields substantially. For the three remaining major plant nutrients, phosphorus has the greatest individual influence on crop yield.

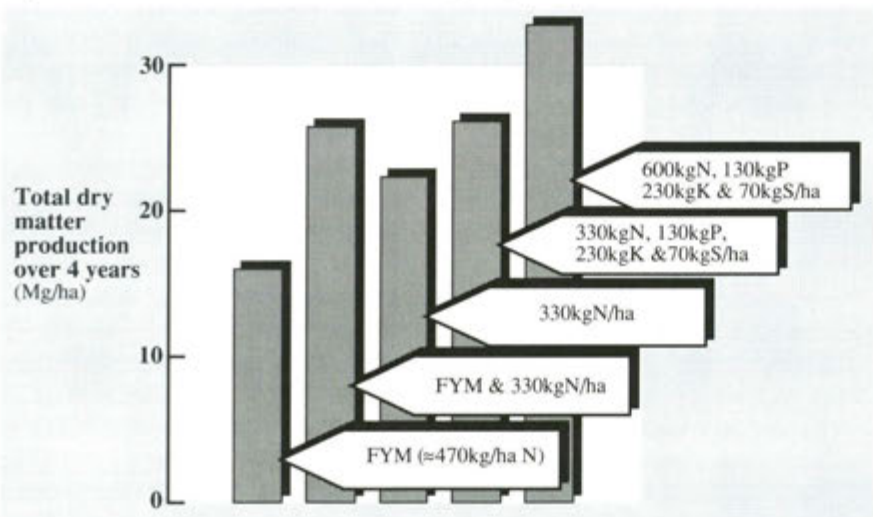


Figure 25. Crop yields under different fertiliser strategies.

As the major interest in this trial is not maximum crop yield with the highest rates of fertiliser inputs but rather more with crop 'efficiency', ie; the proportion of fertiliser added which is actually removed in harvested material (Table 3). Increasing nitrogen levels increased total yields but the relative amounts of N removed in plant material tended to drop. In this study approximately 116 and 350 kg/ha N remained unused and potentially available for leaching with the low N and high N treatment respectively.

Fertiliser input (kg/ha N or P)			% efficiency		Yield (mg/ha)
N	P		N	P	4 years (OD)
330	0	**	65	-	24.3
660		*	42	-	28.3
330	130	***	65.8	43	26.2
	260	**	81	23.5	27.9
660	130	****	51	52	32.2
	260	**	44	31	30.4

*,**,***,**** means values of 1,2,4 and 5 respectively.

Table 3. Relationship between various combinations and amounts of fertilizer inputs and crop yield over 1 full rotation (4 years).

Interactions between individual fertiliser elements can improve overall uptake rates. This certainly happened between N and P (Table 3). Additions of either 130 or 260 kg/ha of phosphorus slightly improved yields but greatly decreased the amounts of soil residual N (104 and 63 kg/ha for low N or 294 and 336 kg/ha for the high N).

Initial results from this experiment are encouraging. The range of applications the data can be used for will increase greatly as time proceeds, seasonal/climatic factors being an obvious possibility.

Contact name: **Anthony Edwards**

Study the growth, development, nutrient accumulation and yield of field crops

The internal cycling of nitrogen (N) allows trees to optimise their efficiency of nutrient use, and achieve relatively high productivity. Deciduous trees remobilise N from their senescing leaves in the autumn, for storage in perennial woody tissues over the winter. Such winter storage of N is important since bud break can occur before mineralisation of soil organic N provides sufficient N for growth. Mobilisation of stored N may, therefore, provide much of the N used for canopy growth in the spring. In order to optimise tree nutrition and growth, particularly that of seedlings where nutrient cycling can be crucial for survival, we need to understand the mechanisms of nutrient cycling within the plant and the influence nutrient supply has upon cycling.

Measurements of the contribution remobilised N made to the growth of leaves, stem extension wood and roots have been made on one-year-old apple rootstocks grown in sand. Increasing the supply of N to the plants increased the growth of new tissues (Figure 26), from 8.1 g/plant when no N was supplied, to 15.4 g/plant with a luxurious N supply. In each treatment there was an initial rapid growth of leaves, lasting for about six weeks. Thereafter, plants not supplied with N ceased to grow leaves and produced root material, while plants grown with luxurious N maintained leaf production. In consequence, although N supply had only a very small effect on the total amount of N remobilised from stems for new growth - 62 mg/plant when no fertiliser N was supplied, compared with 73 mg/plant for trees grown with a luxurious N supply - the distribution of remobilised N within the plant was altered. Nitrogen-deficient trees cycled remobilised N from leaves to roots, thereby maintaining the same amount of root growth as the well-fertilised plants. In contrast, well-fertilised plants remobilised N for leaf growth and at the same time accumulated N from fertiliser in their leaves so that the proportion of their total N content recovered in the leaves was much higher than for the N-deficient plants. It appears, therefore, that plants did not respond to N-deficiency by remobilising more stored reserves, but by recycling the remobilised N from leaves to roots in order to maintain root growth at the expense of the leaves. The effect of N withdrawal from leaves prior to their senescence on N storage and remobilisation the following spring is currently under study.

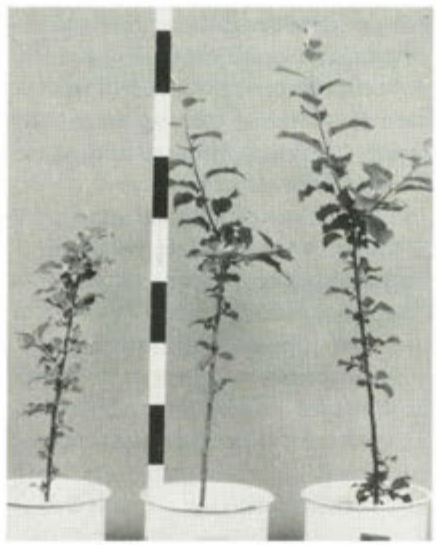


Figure 26. Nitrogen supply increases the growth of apple trees. The tree on the left received no fertiliser N, so that growth of leaves and roots depended entirely upon the remobilisation of stored reserves from the stem. The other two trees received a low, (central tree) or high, (tree on right), supply of N and so their growth was increased accordingly, producing dark green leaves.

Contact name: **Peter Millard**

Develop portable radiometers for monitoring crop cover, biomass and stress parameters

Crop photography and crop radiance measurements have been used to monitor the crop growth and performance of both potatoes and winter barley. These experiments used a simple two band hand-held radiometer providing reflectance measurements at the red (0.595-0.635 µm) and infrared (0.880-0.930 µm) wavelengths. These wavelengths have been found to be the most sensitive to changes in vegetation cover over bare soil surfaces and are extensively used for the remote sensing of vegetation. The principal being exploited is that, at red wavelengths, green vegetation has lower reflectance relative to soil, due to chlorophyll absorption and at near-infrared wavelengths this relationship is reversed. The high reflectance of vegetation in the near-infrared is due to scattering effects within the leaf mesophyll. In spectral terms therefore, the development of a canopy over bare soil through to leaf extension and senescence, will be marked by a decreasing red reflectance and increasing infrared reflectance, low red and high infrared with a final increasing red reflectance and decreasing infrared. By comparing radiometric measurements with actual ground measurements it is possible to show that these spectral changes are highly correlated with ground cover and/or final yield.

Daily measurements of canopy radiance at red and near-infrared wavelengths were made on potato crops receiving either no nitrogen fertiliser of 20 g nitrogen/m2 and compared with ground cover measurements made by aerial photography. The reflectance measurements were used to calculate cumulative values of IR/R (EIR/R), and cumulative light interception values were calculated using ground cover measurements and daily solar radiation data. There was a curvi-linear relationship between cumulative light interception and cumulative radiance values. With high N the linear component was found after 30 days after emergence (DAE), and 27 DAE for low N treatment. Since cumulative solar radiation

values increased in an approximately linear fashion throughout the season, there was a similar relationship between cumulative ground cover and cumulative radiance values.

The differences between these two treatments were due to changes in leaf chlorophyll concentration caused by nitrogen application. This was demonstrated by plotting the product of cumulative ground cover and chlorophyll concentration against cumulative NIR/R values. For both Nitrogen treatments this gave a single line with a linear correlation coefficient of 0.99. When analysed separately there was no significant difference between slopes and intercepts for each treatment.

It appears, therefore, that NIR/R correlates well with ground cover and provides a measure of the effectiveness of light interception. The NIR/R measurement also responds to the chlorophyll status of the leaves and allows for radiation scattering and reflection from the canopy, to give a measure of light absorption and efficiency of light use.

In collaboration with the North of Scotland College of Agriculture the NIR and R reflectance measurements were used to monitor the growth and performance of winter barley. The experimental trial consisted of over 320 plots with 4 different sowing dates, 2 levels of autumn nitrogen, 2 levels of growth regulator and 5 rates of spring fertiliser application. The crop reflectance measurements were made over a whole growing season (25 sample dates) and produced in excess of 10,000 reflectance readings.

Statistical analysis of the autumn data produced good correlations with leaf area and dry matter production. This enabled identification of winter senescence (decrease NIR, rise in R value) before it was apparent by visual inspection of the crop. It could also be shown that for the earliest sown plots receiving autumn nitrogen, excessive 'soft' growth resulted in a greater loss of green leaf matter during winter compared to those sown three weeks later. These plots did however have the ability to recover fully in the spring.

For the spring and summer reflectance values a vegetation index (NIR-R) (NIR+R) was correlated against final dry yield. Using this vegetation index (VI) a stepwise regression was performed on all sample data from spring regrowth to harvest. The highest correlation with final yield was found using an integrated VI from stem extension to authesis (correlation coefficient 0.90, $p < 0.001$). The integrated sum (Σ VI) of reflectance values for the average of all sowing dates and spring fertiliser treatments was then used to produce a regression equation for final dry yield,

Dry Yield = - 2.93 + 1.22 (Σ VI)

This regression equation gave predicted yield figures between 87 and 110 percent of the actual yields. One of the original aims of the experiment was to assess the use of this non-destructive remote sensing technique in assessing the treatment performance sequence (ie is A > B < C). The predicted yield rating produced results only 20 percent of treatments in a correct sequence, 60 percent ± 1 position and 80 percent ± 2 positions. The dry yield values for some treatments were very close and so sequence could easily be 1 or 2 positions out without altering the overall impression of the treatments. The worst errors occurred on the early sown, high nitrogen plots which suffered wind damage and consequent yield loss, so that the final dry yield may not have been consistent with the through season reflectance values.

By being so sensitive to ground cover and leaf chlorophyll status during the period of plant growth and senescence, radiometry offers a non-destructuve means of assessing relative performance of crops. This may be used to determine variation between treatments, remedial fertiliser applications or to detect crop stress affecting leaf chlorophyll concentrations.

Contact name: **Richard Birnie**

VEGETATION DYNAMICS AND ECOLOGY OF GRAZING SYSTEMS

Manipulation of the floristic composition and nutritive value of hill swards by grazing ruminants

a) Studies on *Nardus* grassland
Long-term grazing experiments are investigating the potential of controlled grazing by sheep, cattle, or goats as a means of altering the floristic composition and improving the nutritive value of *Nardus* dominant grassland. Plots grazed by sheep or cattle at one site, and by sheep or goats at another site, are managed in relation to maintaining a given sward surface height on the preferred between-tussock grassy areas.

Where sward surface height has been maintained at 4.5 cm by either grazing cattle or goats, high proportions of *Nardus* leaves were closely grazed so that the swards soon lost their tussocky appearance. By contrast sheep grazed many fewer Nardus leaves less closely; even where sward height was reduced to 3.5 cm, the increase in *Nardus* utilisation failed to match that of cattle or goats at the taller height. The severity of defoliation achieved by cattle and goats was adequate to reduce the vigour of *Nardus* growth. On the cattle plot, where *Nardus* was originally dominant and broad-leaved grasses had modest cover, the cover due to broad-leaved grasses has increased. In contrast, over the same period *Nardus* cover has increased on the sheep-grazed plots.

The cattle intake and liveweight data (Figure 1) indicate that not only has the sward improvement to date been achieved apparently without serious nutritional cost to the cattle, but also that the cattle are improving in performance with successive years. The animals, however, were dry cattle and further work is planned to see whether the higher nutrient demands of suckler cows can be met in regimes designed to reduce *Nardus* cover.

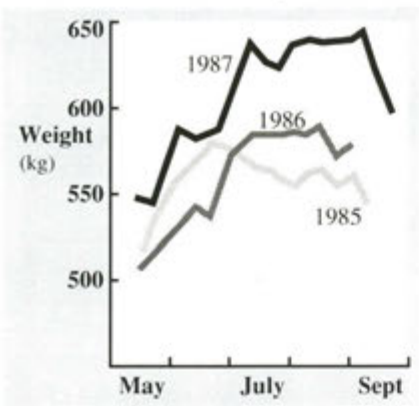


Figure 1. Cattle live weights in successive years.

b) Studies on *Molinia* grassland
The potential of *Molinia* grassland for the summering of hill cattle is being investigated in two long-term grazing experiments, begun in 1985, at Riccarton, Roxburghshire and Cleish, Fife. The aim of the work includes the identification of the proportion of current growth of *Molinia* that can be utilised if *Molinia* dominance is to be sustained. Supportive cutting experiments in which the more detailed responses of *Molinia* to variation in timing, level and frequency of defoliation are being studied are also in progress.

The grazed plots are continuously stocked with dry cows during the growing season of *Molinia* (June-early August). Two treatments are provided by adjusting animal numbers twice weekly as necessary to maintain target *Molinia* leaf lengths corresponding to removal of one third or two thirds of the annual production.

Measurements of *Molinia* leaf growth (mm/tiller/day) on the grazed plots have shown that not only were the leaf extension rates reduced on the heavier compared with the lighter grazed plots, but that the extent of the reduction was increased by successive years of grazing (Figure 2). The between-year variation in vigour of growth of many species was such that no clear trends in floristic composition are yet evident.

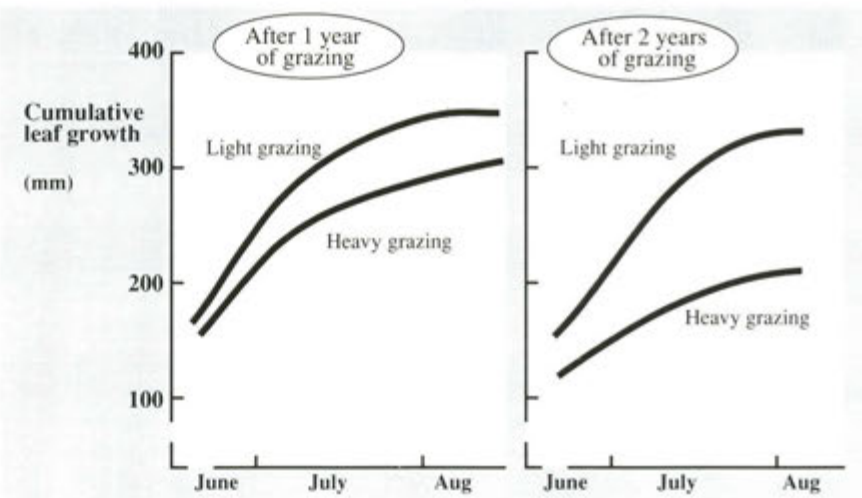


Figure 2. Cumulative length of leaf grown per tiller as influenced by previous grazing.

The amounts of herbage utilised ranged between 600-800 kg DM/ha on the lightly grazed plot and 1100-1200 kg DM/ha on the more heavily grazed plot at the Riccarton site. About six weeks grazing only was afforded. Diet digestibilities were generally around 0.69-0.72 though slightly lower values sometimes occurred in late June - early July on the lightly grazed plot (due to grass flowers) and late July - early August on the more heavily grazed plot. Slightly low levels of vegetation cover and pasture growth resulted in modest intake levels and liveweight gains. The gains were 2 g/kg

liveweight/day on the taller, more lightly grazed plot and 1 g/kg liveweight/day on the shorter, more heavily grazed plot.

The cutting studies have shown that *Molinia* is very sensitive to defoliation; as little as 33% leaf removal led to reduced early season leaf extension the following year. Work is continuing to assess the relative importance of recycled energy and nutrients as limiting factors in sustaining *Molinia* production and to identify amounts, if any, of annual leaf removal which would not depress the productive capacity of the plant.
Contact name: **Sheila Grant**

Establish the amount, type of supplements and feeding method to give ewes in mid-pregnancy grazing different vegetation

Supplementation of ewes grazing a heather hill in mid-pregnancy has been shown to increase lamb birth weights by 10%. One method of giving the daily supplement of approximately 150 g is by means of feedblocks. In a previous experiment it was observed that the siting of feedblocks influenced the grazing behaviour of sheep. A knowledge of the diet composition of ewes in relation to the siting of feedblocks in a mosaic of plant communities could allow the control of the winter grazing of plant communities, particularly those known to be susceptible to grazing or treading at this time.

The siting of feedblocks on either heather or *Agrostis/Festuca* plant communities was compared in mid-pregnancy using a site on Birnie Hill, Glensaugh Research Station. Fifty Scottish Blackface ewes grazed two 25 ha plots containing 20% *Agrostis/Festuca* spp:80% heather by area from January to March. The *Agrostis/Festuca* area was at the lower end of each plot. On one plot the feedblocks were placed for 4 weeks (Period 1) on the *Agrostis/Festuca* area followed by 3 weeks (Period 2) on the heather area and the sequence was reversed on the other plot.
Daily supplement intakes were measured on 10 ewes per plot by measuring daily faecal output and the concentration of Chromium (Cr) in the faeces for one week on each vegetation type. A known amount of Cr was incorporated in the feedblock. The n-alkane method for estimating dietary composition from the n-alkane concentrations in the feed and faeces was used to estimate dietary composition.

Placement site :	*Agrostis/Festuca*		Heather		
	Period 1	Period 2	Period 1	Period 2	SE
Ruminal NH_3 concentration (mM)	3.14	2.89	2.25	1.78	0.377
Proportion of heather in diet	0.271	0.296	0.693	0.534	-

Table 1. The effect of the placement site of feed blocks on ruminal NH_3 concentration and proportion of heather in diet.

The intakes of supplement were similar when feedblocks were placed on heather (167 g DM/day) or on *Agrostis/Festuca* (154 g DM/day). Ruminal ammonia (NH_3) concentrations were significantly ($P<0.05$) higher when the feedblocks were placed on the *Agrostis/Festuca* than on the heather areas (Table 1).

Placing the blocks on heather rather than on *Agrostis/Festuca* resulted in a considerably higher proportion of heather in the diet. The lower ruminal NH_3 concentrations when the block was placed on heather reflect the lower nitrogen (N) content in heather and its low availability in the rumen. These results confirm the effect that block placement can have on dietary composition of sheep and illustrate how the n-alkane method can be successfully used to measure the dietary composition of free-grazing ruminants.

Feedblocks are a possible means of regulating where sheep graze in the winter and have potential as a tool in the management of hill vegetation.
Contact names:
John Milne, Margaret Merchant

Heather regeneration from seed

The amount of heather moorland has declined in the British uplands significantly in the last 20 years. There may be several reasons for this decline, but one factor is the burning of stands of heather which are too old.

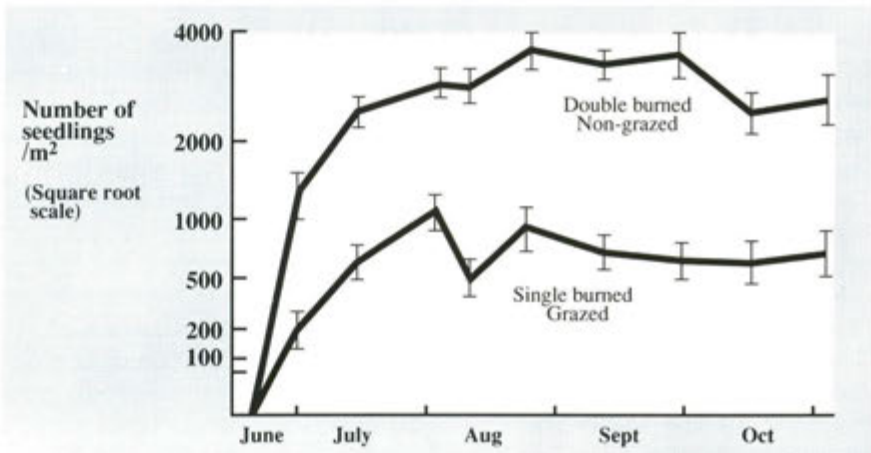


Figure 3. The effect of Calluna seedling regeneration of burning regime and sheep access on a degenerating Callunetum.

Investigations have been carried out on how to encourage regeneration when managing old heather, and facilitate the return of heather once it has been lost and replaced by purple moor-grass.

At Glensaugh Research Station, an area of old heather, burned twice in consecutive years, produced a larger crop of seedlings than one burned once, leaving charred stems. Also seedling numbers were higher where sheep were denied access. Any surface disturbance reduced seedling numbers (Figure 3 on previous page). In Roxburgh District, where purple moor-grass had replaced heather, regeneration was best where turf had been removed, or completely disturbed, and in these treatments, the application of herbicide decreased seedling numbers. If the surface was disturbed only in shallow channels, 2 cm or 7 cm wide, herbicide application improved regeneration. A third area, in Lanark District, where former heather cover had been replaced by purple moor-grass, had low regeneration independent of treatment, but seedling numbers were highest at the edge of treatments where turf had been removed. Narrow channels produced better regeneration than other treatments, early in the year. although later improved results were achieved in plots which had been treated with a mulch. Thus, shallow channels about 15 cm wide and 5 m long are now being investigated.

The results indicate that to maximise heather regeneration from seed it is necessary to expose areas of peat. However, this peat requires protection from instability caused by sheep trampling, the cultivation method, and wind and rain. Large scale trials using machinery are being set up to investigate the practical applications.

This work is funded by the Joseph Nickerson Heather Improvement Foundation.

Contact name: **Eurig Scandrett**

Grazing in upland broadleaf woods

The shelter and grazing provided by upland broadleaf woods can play an important role in upland agriculture. However, these woods are also prime sites for nature conservation and overgrazing by large herbivores is normally blamed for the lack of natural tree regeneration. The current conservation response to this is the total exclusion of large herbivores by fencing. A reduction in grazing rather than its cessation may, in terms of the environment, be a better course of action and would allow some continued use of the woods by stock.

The aim is to assess the impact of controlled variations in intensity and seasonality of grazing on tree regeneration and on the ground vegetation in upland broadleaf woodland on a site in Cumbria. The site covers 36 ha of a NW-NE facing slope (250-400 m OD). Oak and ash woodland grades into open birch wood with rising altitude. Swaledale x Herdwick yearling wethers are grazed at three different stocking densities designed to remove nominally 20%, 40% and 60% of annual herbage accumulation in fenced plots. Each plot runs upslope to cover the full altitudinal range and thus contains the major variations in vegetation. To make up for the lack of saplings in the wood, 65 young trees of oak, ash, birch and holly have been planted in each plot. Plots at each utilisation level are grazed either from April to October or from October to April in order to assess the effect of seasonality of grazing. The experimental treatments were initiated in May 1986, prior to this the wood was uniformally grazed by free-ranging sheep. Preliminary data from the first two of the four years of the study indicate that there are significant differences between the incidence, and effects, of browsing during the summer and winter periods within both the seedling and sapling populations. To put the experimental data in a wider context, a survey of other woods in Cumbria, North Wales and Argyll is being conducted to investigate their regenerative status under varying grazing conditions. This work is funded by Nature Conservancy Council.

Contact name: **Fraser Mitchell**

The grazing preferences of cattle, sheep and goats for swards of differing height

Cattle, sheep and goats are considered to have different reactions to grazing swards. For example sheep, and to a lesser extent cattle, are noted for grazing patches of short sward and avoidance of long and more mature herbage, whilst goats appear to graze less deeply into the sward canopy. However there is little evidence for species differences where comparisons are unconfounded by differences in pasture morphology or the influence of excreta. Similarly the effect of size of a species on their preference for swards of different height has not been studied.

Height comparison	Factor of difference	Cattle	Sheep	Goats
2 v 8cm	4	0.98	0.91	0.99
4 v 16cm		0.92	0.77	0.86
8 v 32cm		0.76	0.93	0.97
2 v 4cm	2	0.93	0.81	0.96
4 v 8cm		0.75	0.47	0.96
8 v 16cm		0.77	0.61	0.73
16 v 32cm		0.46	0.72	0.76

Table 2. The proportion of time spent grazing the taller sward in paired sward height comparisons for cattle, sheep and goats.

Experiments were conducted in which cattle, sheep and goats and ewes of different size were offered a choice of pairs of swards of different height and their preference observed by

noting their position whilst they were grazing; measurements were also made of rate of intake. The comparisons were made with swards that differed by factors of 1, 2 and 4 over a range of height of 2 to 32 cm for the 3 species and 2 to 8 cm in the size of ewe comparison.

All 3 species showed a preference for grazing the taller swards (Table 2) with the goats showing the greatest preference for taller swards followed by the cattle with sheep showing little preference between swards of almost similar height. The results suggest that there is a relationship between preference and the difference between the intake rate of pairs of swards, since there was a linear increase in preference as intake rate differences increased. However the results can only partially be explained in terms of an optimal foraging theory which states that animals will forage in such a way as to maximise nutrient intake and minimise energy expenditure in foraging. Given constraints on grazing time that are known to exist, total nutrient intake is likely to have been sub-optimal with the sward preferences exerted.

Both breeds of ewes (Scottish Halfbred, 72 kg liveweight; Welsh Mountain, 36 kg liveweight) preferred taller swards but the larger ewe was more sensitive to small height differences. Taking into account the biting rates observed in this experiment and the grazing times observed in other experiments at the same sward heights, it is concluded that the performance of the larger ewe would be reduced on shorter swards to a greater extent than that of the smaller ewe.

The results of these experiments indicate that our understanding of the grazing of swards which are heterogeneous in height is as yet incomplete and that the interaction between ewe size and sward height may have important practical implications.

Contact name: **John Milne**

Investigate the manipulation of clover content in grazed swards and the effects on herbage production

The effects of different sward heights and two fertiliser nitrogen levels on clover performance and content of grass/clover swards continuously stocked by sheep have been examined in a long term experiment at Hartwood Research Station. The causes of variability in clover performance between and within seasons were also studied. The swards, sown with perennial ryegrass (cv Perma) and white clover (cv Huia), have been maintained with mean surface heights of 2.5, 3.5 and 5.0 cm during each growing season. The fertiliser treatments are zero fertiliser nitrogen (NO) and 120-140 kg N/ha/year applied in 20 kg/ha dressings evenly throughout the growing season (NI).

Clover growing point population densities declined steadily in the N1 treatments (Figure 4). This contrasts with the NO treatments where the end of season population densities remained constant until 1986, but declined thereafter. There was no measurable difference in clover content between treatment plots maintained at the different mean sward surface heights. Within plots in the NO treatment, however, the population densities were greatest in the shorter patches of sward. The rate at which clover growing points were produced was greatest before mid-summer, greatest in the NO treatments, and greatest at the beginning of the year in the shorter patches of sward.

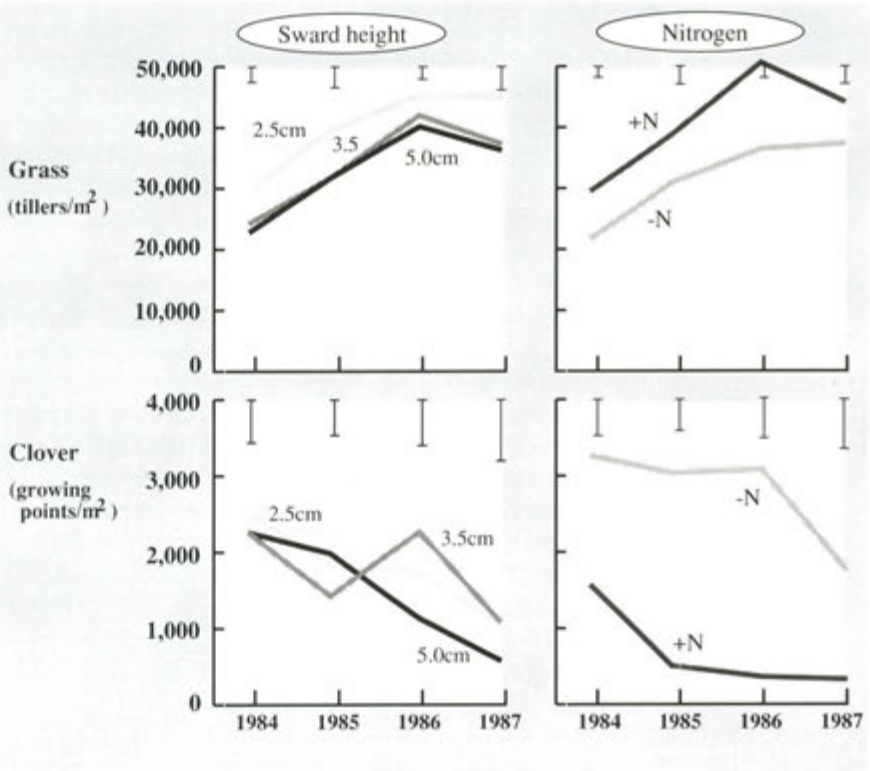


Figure 4. The effects of treatments on grass tiller and clover growing point population densities in September of each year.

Investigations into seasonal differences in clover growing point population densities and production rates continue. Some of the differences observed appear to be due to climatic effects which both act directly on the clover and indirectly through their effects on rate processes; for example rate of tillering, which affects the rate at which the canopy closes up each spring and summer. Ryegrass accounted for 68% of the

total grass tiller population in the first year. By September 1986 ryegrass accounted for only 35% of tillers in the NO and 30% in the NI swards, with the reduction being greater on the sward maintained at 2.5 cm than on the taller swards. These were the swards which had the highest stocking densities. The most likely reasons for the sward deterioration are soil compaction and poaching on the heavy soil during the wet autumn of 1985 and the wet summer of 1986. By September 1987 ryegrass accounted for 42% of tillers in the NO treatment but still only 30% in NI.

The evidence confirms the adverse effects of fertiliser nitrogen on clover and suggests that to obtain high clover contents swards should be closely grazed early in the season. Strategies aimed at improving and maintaining clover content of continuously stocked perennial ryegrass/white clover swards based on these findings are being investigated.

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

Practical Grazing Control

A surface height range within which sown sward continuously grazed by ewes need to be maintained at different times of the year has been advocated but the method of determining the adjustment in the stocking rate necessary to obtain the correct sward height remains in doubt.

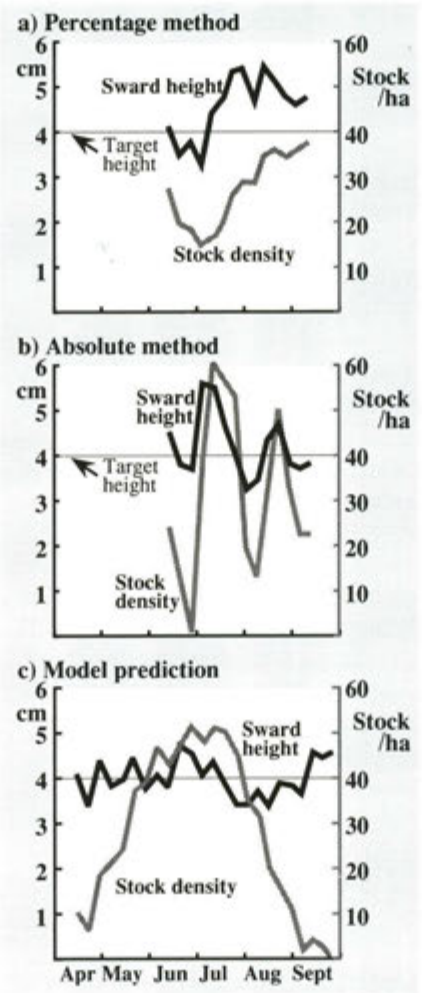


Figure 5. Sward height control methods.

One method of controlling sward surface height is by adding or removing a percentage of the current stock in response to a deviation above or below the desired target surface height. This 'Percentage' method was tested using lactating Greyface ewes on two 0.33 ha paddocks at Hartwood Research Station during 1987. Sward surface heights were measured weekly and the stocking density was adjusted weekly to achieve a target surface height of 4.0 cm. The method did not adequately control sward height (Figure 5a), confirming previous experience.

An alternative method of grazing control is by adjusting the absolute number of animals to correct a deviation from target sward height. This 'Absolute' method was tested under the same conditions as described above. However, this too proved inadequate (Figure 5b). A subsequent analysis of previous grazing experiments suggested that incorrect factor values were chosen in the calculation of stock numbers. The Percentage and Absolute methods of grazing control were also tested by computer modelling, using a variety of factor values. The Absolute method was found to be more effective than the Percentage method under all conditions. However, when adjustments were made weekly, there were still significant deviations from target height when the growth rate was changing rapidly. This could be largely overcome by more frequent sampling of sward surface height and stocking rate adjustment or by anticipating changes in the growth rate (Figure 5c).

Contact name: **Nick Hutchings**

NUTRITION OF GRAZING RUMINANTS

Factors affecting carcase composition of Scottish Blackface lambs at different stages of maturity

To predict a desired carcase composition in lambs of a single breed requires a knowledge of the relationship between live weight at slaughter and carcase composition. This relationship is considered to be dependent upon potential mature size but may also be influenced by rate of growth in the pre- and post-weaning period and the composition of the diet.

The effect of two weaning liveweights (24 and 29 kg) and two diets with differing protein:energy ratio (12 and 18 g CP: MJ ME) were compared with 104 Scottish Blackface lambs slaughtered at a range of live weights up to mature live weight, which was similar across all treatments.

Live-weight gain was higher in the lambs given the high protein diet up to a live weight of 43 kg (148 v 118 g/day). There was no major effect of diet on carcase composition, although the increase in fat per kg live weight over the whole range of live weight was greater on the low protein diet. Although there was no difference in the proportion of fat and of protein in the carcase at the two initial weaning weights, and all lambs had the same liveweight gains, there was more subcutaneous and total fat and a lower proportion of muscle in the lambs (slaughtered at 33 kg) and weaned at the lower weaning weight of 24 kg. These differences in carcase composition at the same live weight between animals with different weaning weights are most probably related to the amount of live weight that had to be gained in the post-weaning phase. The results highlight the difficulty of predicting carcase composition from live weight without a knowledge as to how that live weight has been achieved.

Contact Name: **John Milne**

Substitution rate of herbage by supplements offered to ewes over the mating period

In the autumn nutrient supply from herbage declines, principally as sward height declines. Supplementation with cereals or other supplements is one means whereby nutrient supply can be increased. The advent of the long-chain n-alkane technique, developed at MLURI, allows for the first time the opportunity of accurately measuring herbage intake when supplements are given. The effect of supplements on herbage intake is conventionally described as a substitution rate, i.e. the rate at which herbage intake declines per unit increase in suppplement intake. In consequence low substitution rates are desirable. The more precise prediction of nutrient supply in the autumn will enable desired lambing rates to be more readily achieved.

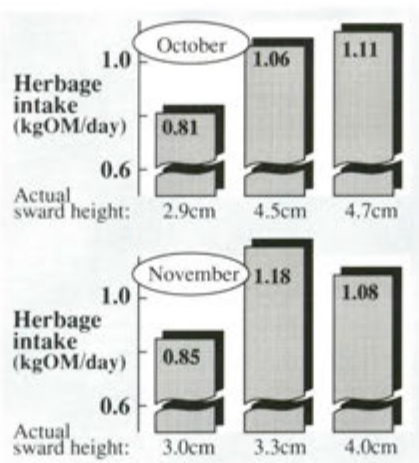


Figure 1. Herbage intake recorded at different sward heights.

In an experiment with 216 Greyface ewes the herbage intake of ewes in three degrees of fatness, grazing three sward heights - 3, 4 and 5 cm, and when given a range of intake of two supplements, 0-500 g DM/day of either pelleted rolled barley or dried molassed sugar beet pulp, was compared on two occasions in September and October.

As can be seen from Figure 1, herbage intake declined with sward height in both September and October. There was a significant decline in intake as ewe body condition increased. The rate of decrease in herbage intake (g DM) per unit increase in supplement intake (g DM) was different for the two supplements, being 0.48 for the dried molassed sugar beet pulp and 0.68 for the barley supplement. A statistical model which included sward height, supplement type and level of intake, body condition and date of grazing in the autumn and interaction terms explained only about 50% of the variation in supplement intake.

The results highlight the importance of the relationship between sward height and herbage intake, the potential significance of the type of supplement in influencing substitution rate and the low amount of variation in herbage intake that can be explained by the variables studied.

Contact name: John Milne

The effect of ewe genotype on utilisation of pasture maintained at different sward heights

Ewe genotypes differ in size and lactation potential, among other characters. These characters are likely to interact with sward management and effect the efficiency with which an area of land is utilised for lamb production. Four genotypes, Scottish Halfbred, Greyface, East Friesland x Scottish Blackface and North Country Cheviot x Shetland (NCCxSh), were compared when the same sward management - sward height maintained between 4-4.5 cm - was applied to ewes and lambs between lambing and weaning. The design of the experiment was replicated three times and all the ewes had been mated

to the Suffolk ram and reared twin lambs.

The breeds differed in live weight with the Scottish Halfbred the heaviest and the NCCxSh the lightest (see Table 1). Live-weight gain of lambs

	Ewe genotype			
	Scottish Halfbred	Greyface	East Friesland x Scott. Blackface	NC Cheviot x Shetland
Ewe weight (kg)	68	62	61	50
Lamb live-weight gain (g/day)	236	240	247	212
Lamb production/hectare (kg/ha)	567	555	546	526

Table 1. The effect of ewe genotype on lamb performance on an individual and an area basis.

was lowest with the NCC x Sh genotype but since the stocking rate of the NCCxSh genotype, necessary to maintain sward height within the desired range, was highest, there was no difference between the four genotypes in live-weight gain per hectare. At the most extreme ends of the sward height range there is evidence that ewe size differences interact with sward height to influence herbage intake and sward choice which may lead to greater differences between genotypes than those observed in this study.

Live-weight gain of lambs declined with time but fluctuated considerably. These fluctuations in lamb growth rate were reflected in the rate of herbage accumulation across both replicates and genotypes. The significance of this finding is currently being investigated.

Contact name: **John Milne**

Factors influencing the voluntary intake of forage brassicas by lambs

A major limitation to the predictable use of forage brassica crops by lambs is the low and variable intakes of such forages. Most of the variability appears to be associated with the intrinsic composition of the crops rather than with factors of animal origin or ingestive grazing behaviour. A series of experiments was conducted to examine the significance of some of the factors considered to be important.

It was found that the presence or absence of tactile stimuli in the rumen wall, associated with the amount of fibre in the diet, or the amount of foam in the rumen, attributed to the high levels of fermentable carbohydrate and the presence of possible foam-stabilising compounds, were not involved in regulating the voluntary intake of forage brassicas. Sulphur (S)-containing compounds are present in relatively large quantities in forage brassicas and have been implicated in the low and variable intakes. S-methyl cysteine sulphoxide (SMCO) has been found to depress intake at slightly higher than physiological levels and there have been suggestions that other S-containing compounds, such as glucosinolates, could be involved.

	Control	Isothio-cyanate	Nitrile	SE
Period 1	630	336	712	
2	517	508	307	71.3
3	554	475	436	

Table 2. Voluntary intake by lambs ingesting cabbage and offered glucosilinate breakdown products, (g OM/day).

Glucosinolates break down in the rumen to produce isothiocyanates, thiocyanate ions and nitriles. One of the commonly available glucosinolates, sinigrin, produces allyl isothiocyanate and allyl cyanide as breakdown products. These were infused into the rumen of lambs at physiological levels when lambs were fed non-forage brassica (dried grass pellets) and a forage brassica (cabbage) diets. Voluntary intakes of lambs infused with allyl isothiocyanate and allyl cyanide were more variable than those of control lambs, with significantly lower intakes for lambs infused with allyl isothiocyanate at the beginning and nitriles at the end of the experiment when cabbage was offered (Table 2). These results indicate that both isothiocyanates and nitriles may be involved in the low and variable intakes by lambs of forage brassicas.

Contact name: **John Milne**

The effect of selenium and vitamin E deficiences on paramagnetic centres and the spin trapping of free radicals in rat heart and liver

Tissue damage mediated by the formation of chemically reactive free radicals has been implicated as the cause of many diseases in man and animals. The effect of breakdown products of S-containing compounds in forage brassicas on lamb tissues is one example.

Natural metabolic processes involve the production of O_2- derived free radicals which are scavenged by antioxidants such as the vitamins C and E and the Se-containing enzyme glutathione peroxidase. In the present work electron spin resonance spectroscopy has been used to study the formation of free radicals in rats with Se and/or vitamin E deficiences. Stable species can be studied directly, but unstable free radicals can also be monitored by reacting them with a chemical "spin trap" which results in the formation of radicals with lifetimes long enough for detection.

Several stable paramagnetic centres of both free radical and transition metal origins were observed in intact tissue from a range of organs. There were, however, no significant differences in the effects of dietary history on the spectra from a particular type of organ.

Homogenates of heart, when incubated with the spin trap a-

(4-pyridyl-1-oxide)-N-tert-butyl nitrone (4-POBN) in the presence of $FeSO_4$, ADP and NADPH, gave spectra consistent with a free radical/4-POBN adduct. Spectra developed over a period of 1.5-2 hours with similar intensities for control and Se-deficient rats. Significantly greater spectral intensity was obtained with vitamin E deficient hearts and still greater intensity was seen with hearts from animals deficient in both Se and vitamin E.

With microsomal preparations of liver treated as above, there was an initial distinction between samples according to the vitamin E status of the animal, but after prolonged incubation radical levels in the Se-deficient animals rose to become comparable to the vitamin E deficient cases. Measurement of the thiobarbituric acid reactive substances showed that 4-POBN was able to only partially scavenge the radical that is responsible for peroxidation in the microsomes, the time course for development of the species not trapped by 4-POBN showing a clear distinction between samples on the basis of the vitamin E status of the animal..

Overall these results are consistent with the hypothesis that tissue damage in Se and/or vitamin E deficiency is initiated by free radicals and that the modes of operation of the two antioxidants are quite different.

Contact names: **Donald McPhail, Bernard Goodman**

Understand the soil and plant factors which influence the content of Cu, Mo and S in herbage from improved hill pastures

Animals which graze reseeded hill pastures may develop symptoms of copper deficiency including reduced weight gain in suckling lambs and increases in the incidence of Swayback. Although the copper content of the herbage may be normal the effects of liming and reseeding increase molybdenum and sulphur levels of herbage which when ingested may induce a copper deficiency by reducing copper absorption in grazing stock.

It is possible to predict copper absorbability and dietary copper absorption in grazing sheep from the concentrations of molybdenum, sulphur and copper in herbage. For the use of prediction methods, further information is needed on the seasonal variation of molybdenum, sulphur and copper in the herbage of reseeded hill pasture together with a better understanding of the plant, soil and environment factors which control the trace element content of hill herbages.

Herbages were sampled throughout the growing season from three reseeded pastures known to produce vegetation with elevated levels of molybdenum and sulphur. The experimental sites were grazed continuously and samples were cut from under animal exclusion cages at 3-4 week intervals. In 1985 molybdenum and sulphur concentrations were highest during autumn and, on some sites, high concentrations were measured in early spring in white clover. In contrast herbage copper levels were highest during summer and lowest in spring and autumn. The seasonal pattern of predicted copper absorbability and dietary copper absorption in grazing sheep reflected the molybdenum and sulphur herbage concentrations with higher values in late spring and early summer which then declined to very low levels by late autumn. For most of the year copper absorbability at less than 1% and dietary copper absorption at less than 0.06 µg/g were indicative of sub-optimal supplies of dietary copper.

Herbage growth rate influenced the levels of copper, sulphur and molybdenum and accounted for significant proportions of the variability of the concentrations of these elements. Both molybdenum (in white clover only) and sulphur concentrations were negatively correlated with growth rate which suggested a dilution effect when pasture growth rate was greatest. The influence of growth rate on herbage Cu was dependent upon the site, plant species and the quantity of available Cu in the soil. Predicted copper absorption in grazing sheep was similarly and directly influenced by pasture growth rate with a tendency for lower copper absorption to occur at times of slow pasture growth in early spring and particularly during the autumn.

	Grass			White Clover		
Facing:	North	South	South	North	South	South
Drainage:	Free	Free	Poor	Free	Free	Poor
Molybdenum (µg/g)	2.9	2.9	3.5	2.8	2.0	3.8
Sulphur (g/kg)	3.3	3.2	3.5	2.8	2.6	2.7
Copper (µg/g)	4.9	6.3	7.6	3.3	4.0	7.4
Copper Absorbability (%)	0.9	0.9	0.7	1.5	2.0	1.1
Dietery Copper Absorption (µg/g)	0.041	0.057	0.053	0.051	0.079	0.084

Table 3. The influence of aspect and soil drainage on the trace element content in grass and white clover, with predicted copper absorption in grazing sheep (annual means).

The influence of poor soil drainage, shown by the results in Table 3, was to significantly increase the concentrations of molybdenum, copper and sulphur in both the grass and white clover components of herbage. This gave an overall reduction in predicted copper absorption in grazing sheep. Herbages from pastures which faced north contained significantly higher levels of sulphur and molybdenum (white clover only) and substantially lower levels of copper than south facing pastures. The overall influence of a north-facing aspect was to reduce predicted copper absorption.

If confirmed by current experiments,

it would seem that the effect of enhanced molybdenum and sulphur in reducing absorbable dietary copper in grazed herbages is influenced by a number of important factors. It may be anticipated that these effects will be most noticeable in spring and autumn due, in significant part, to changes in pasture growth rates and will be exacerbated in soils of poor drainage status and in pastures with a north facing aspect.

Contact name: **Colin Evans**

Body composition changes during compensatory growth of cattle

It is well documented that following a period of feed restriction cattle exhibit compensatory growth, and growing cattle are often subjected to a 'store' period when level of feeding is deliberately restricted in winter to allow high levels of live-weight gain in summer when they are grazing. It has been shown by work in this Institute and elsewhere that during compensatory growth cattle show enhanced levels of feed intake. It is also likely that changes occur in the composition of the tissue gained during compensatory growth, and this could also explain, at least in part, some of the enhanced performance.

In previous experiments, compensatory growth has usually been studied during periods of restricted feed intake, so previous and current feed intake have been confounded. To overcome this problem an experiment was designed whereby Charolais-cross weaned, suckled steers were fed at one of two levels from a mean weight of 259 kg up to 350 kg. At 350 kg those steers from the lower level of feeding had their feed intake increased such that subsequent feed intakes were identical for the two groups at any given live weight. Representative cattle were slaughtered at the start and at 350 , 400 and 450 kg live weight so that changes in body composition could be estimated. The body composition data are not yet available, but between 350 and 400 kg the steers from the previous low level of feed intake gained significantly more weight although their feed intake was the same as those that were previously on the high level of feeding. In other words they showed compensatory growth without an increase in feed intake.

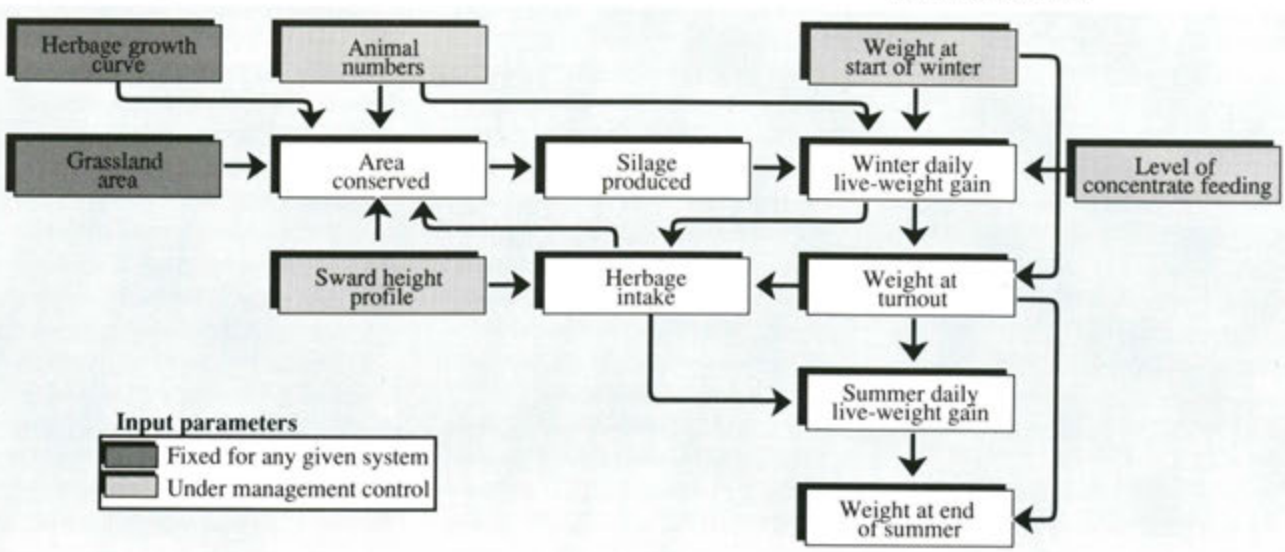
Modelling resource utilisation by weaned suckled calves

Currently the advice offered by the extension services in the UK on feeding levels for weaned suckled calves is based on the results of experiments which were concerned with individual animal performance. For example it is generally accepted that calves fed at lower levels during the post-weaning winter will show compensatory growth when turned out to pasture during the following grazing season. This has led to the general recommendation that weaned suckled calves should be fed to achieve growth rates of 0.4 to 0.6 kg/day depending on genotype and sex. However such recommendations do not recognise that decisions as to the optimum winter growth rate should be based on the profitability of the whole enterprise or indeed the whole farm business, and not merely on the basis of individual animal performance and margin.

To base decision making on an enterprise basis, information is needed on how that enterprise utilises resources, and what effect changing one set of inputs or resources has on the way in which others are used.

One way of tackling this problem is to model the enterprise. A model of resource utilisation by weaned suckled calves is currently being developed. To date a simple conceptual model has been developed (Figure 2). This is based on an enterprise which buys weaned suckled calves in autumn and feeds silage and concentrates over winter. Cattle are turned out to pasture

Figure 2. Simple model of resource used by weaned suckled calves.



in spring and sold at the end of summer. A sward height profile is maintained over summer by closing areas for conservation of silage which is fed the following winter. The relationships between winter and summer live-weight gains and the effect of sward height on animal intake and performance have been quantified in experiments carried out in the Institute over the past five years, and these relationships will be used in the model.

Ultimately it is intended to build a 'what if' model in which input parameters can be changed and different constraints imposed to simulate real farm conditions. Although initially the model will be biologically based it will be constructed in a way which will allow it to be developed into a full economic model.

Contact name: **Iain Wright**

The effect of winter feed level and summer sward height on the performance of autumn calving beef cows and their calves

To date most of the work on grazing management and on interactions between winter and summer nutrition has been carried out with spring calving cows. Little information is available for autumn calving cows, so an experiment was designed to examine the effect of sward height on cow and calf performance in cows turned out at two levels of body condition.

The experiment was of a 2 x 2 x 2 factorial design with two winter feeding levels, two sward heights from turn-out to weaning (mid May to early July) and two sward heights from weaning until the end of the experiment (1 October). Thirty-nine Hereford x Friesian cows and their autumn born Charolais-cross calves were used.

Level of winter feeding affected cow body condition score at turn-out (2.30 and 2.48 for the low and high levels of feeding respectively). The calves from the high level of feeding were also 30 kg heavier. After turnout, both winter feeding level and sward height affected cow performance. Cows from the low level of winter feeding gained more weight and condition at pasture. However winter feeding level had no effect on calf performance at pasture, and at weaning there was still a 25 kg difference in live weight as a consequence of the different winter feeding levels. The mean sward heights from turnout to weaning were 4.8 and 7.6 cm. The short sward reduced cow live weight gain by 0.89 kg/day and calf live-weight gain by 0.78 kg/day. From weaning to housing mean sward heights were 4.7 and 8.0 cm. Winter feeding level had no effect on cow performance, but sward height before weaning affected cow live-weight gain after weaning,

	Sward height	
	4.8 cm	7.6 cm
Cow live-weight gain	0.30	1.19
Cow milk yield	6.2	10.4
Calf live-weight gain	0.43	1.21

(All units kg/day)

Table 4. The effect of sward height between turn-out and weaning on performance of autumn weaning cows and their calves.

with the cows which had previously been on the short sward gaining more weight. The 4.7 cm sward resulted in a cow live-weight gain of 0.96 kg/day. Similarly the short sward reduced calf live-weight gain in the early part of the following lactation by 0.36 kg/day. There was no effect of any treatment on calf birth weight or calving difficulty.

The experiment confirms results with spring calving cows that sward height has a major effect on cow and calf performance and that winter feeding also affects cow live-weight gain during the grazing season. A sward height of 7-8 cm would seem to be appropriate between turnout and weaning and, when cows are turned out at a condition score similar to that in this experiment, there appears to be no need to reduce sward height after weaning in an attempt to decrease calving difficulty.

Contact name: **Iain Wright**

The role of prolactin in influencing appetite and reproductive performance of red deer in the autumn

Daylength has been shown to be one of the factors signalling seasonal changes in reproduction, intake and coat growth in red deer, through the secretion of melatonin from the pineal gland during periods of darkness. Daily oral administration of melatonin during normal daylight can advance the onset of the breeding season by artificially signalling short daylengths. Plasma prolactin levels also show seasonal fluctuations, with the lowest levels occurring during the winter months, and it has been shown that prolactin levels can be suppressed at other times of the year by melatonin treatment.

Two experiments were carried out to test the hypothesis that the photoperiodic control of seasonal cycles in red deer might be mediated through changes in circulating prolactin levels. The first experiment involved maintaining raised plasma prolactin levels in melatonin-treated hinds during the period when prolactin and intake normally show a seasonal decline prior to the start of oestrous activity. The second involved lowering plasma prolactin levels independently of melatonin over the same period, and in advance of the normal seasonal decline.

In the first experiment, 8 non-lactating red deer hinds were treated daily with melatonin from early July to early November, and 8 were also treated with domperidone, which is known to raise prolactin levels. These animals were compared with a group of untreated animals. Melatonin

advanced the onset of oestrous activity and the seasonal decline in intake by two to three weeks, and lowered plasma prolactin levels six weeks earlier than untreated animals. Domperidone was not effective in raising prolactin levels when dosed orally, and the replacement of dosing by intra-muscular injections after 10 weeks caused only a transitory rise in prolactin.

In the following autumn, 8 untreated non-lactating hinds were compared with 8 hinds treated with melatonin, and 8 with the dopamine agonist, bromocriptine, which reduces prolactin levels. Melatonin advanced the onset of oestrous activity and the decline in intake, again by two to three weeks, and prolactin values showed the same rapid fall as in the previous year. Treatment with bromocriptine also lowered prolactin values but the date of oestrus onset was not significantly different from that of control hinds. Voluntary intakes by the bromocriptine-treated hinds were 25% lower than control values but reached similar levels to control animals by the end of the experiment. However, immediately after the end of dosing, voluntary intakes by the bromocriptine-treated hinds rose to levels higher than would normally be found at that time of year. There were no concomitant changes in plasma prolactin, suggesting that bromocriptine has an independent effect on voluntary intake. Treatment with both melatonin and bromocriptine impaired normal winter coat growth, and differences in mean staple length of coat hairs were still apparent the following spring.

These experiments show that treatment with melatonin influences not only the advance in the date of onset of oestrus but also the seasonal cycles of intake and coat growth. However, the effects of the dopamine agonist, bromocriptine, on prolactin levels, intake and coat growth, though not on the start of the breeding season, suggest that these seasonal cycles are not necessarily all controlled by the same mechanism in red deer.

Contact names: **John Milne, Angela Sibbald**

Comparison of the seasonal cycles of the red deer and the Père David's deer

The red deer and Père David's deer are closely related species which differ in body size and in the timing of various seasonal cycles involved in growth and reproduction. A comparative study was set up to investigate the mechanisms controlling these seasonal changes, and to explore the possibility that the Père David's deer might have advantages over the red deer for farming purposes.

Six Père David's deer hind calves were compared with a group of red deer hind calves from birth to 18 months of age. Both sets of calves were hand-reared and housed in group pens during this period, with measurements being made of voluntary intake, live weight, and plamsa levels of prolactin, thyroxine (T3) and progesterone. The same protocols were adopted for similar numbers of adult red deer and Père David's deer. In the young animals the voluntary intake of the Pere David's deer declined slightly earlier than those of the red deer in the autumn. The Père David's deer calves reached puberty in August but only two of the red deer calves had reached puberty by the beginning of November. There were no significant differences in the timing of peak prolactin values between the two species, supporting the view that there is no fixed relationship between the timing of seasonal prolactin and other cycles in the young animal.

With the adult animals, there were quite different appetite, coat growth and reproductive cycles for the two species. Prolactin levels rose earlier in the year in the Père David's deer hinds and this was associated with an earlier peak in intake and earlier onset of the breeding season by 2-3 months. Coat changes also took place earlier in the year in the Père David's deer. Differences in plasma T3 values reflected differences in intake in the adult deer of both species, but there was no obvious relationship between T3 and intake in the juveniles. The comparative timing of these cycles in the adults of the two species strongly suggests that the cycles are linked. However adults and juveniles do not appear to respond to photoperiod in the same way.

The juvenile Père David's deer showed a similar seasonal pattern of growth to the red deer, but gained on average 120 g/day more live weight, so that by the middle of March the liveweight of the Père David's deer was over 70% greater than that of the red deer. Hybridisation between the two species is being investigated with a view to producing an improved deer for meat production with potentially greater growth potential and an earlier calving deer.

Contact names: **John Milne, Angela Sibbald**

The effect of sward surface height on the growth of yearling red deer

Sward surface height has been shown to be positively related to sheep performance over the range 3-6 cm and to cattle performance over a wider range. The extent to which such relationships exist for yearling red deer has not been previously established, although observations on hind and calf performance suggested positive relationships between sward surface height and liveweight gain were likely to exist.

An experiment was conducted over 2 years in which sward heights were maintained at 4, 6, 8 and 10 cm from 1 June until 17 September by a

'put-and-take' system. There were 16 yearling stags per treatment in each year and the swards received 250kg N/ha over the season. The results are shown in Table 5. Live-weight gains of individual animals generally increased with sward surface height with the greatest increases occuring between 4 and 6 cm. Live-weight gains per hectare differed slightly in 1986 and 1987, reflecting the differences in herbage growth between years, but overall the highest outputs per hectare were obtained on the 8 cm swards. Since individual animal live-weight gains were also high at 8 cm it would appear that such a height would be suitable for obtaining both efficient live-weight gains per animal and per hectare. A similar conclusion has been reached for cattle.

		Sward height (cm)			
Live-weight gain		4	6	8	10
g/day/animal	1986	90	163	169	179
	1987	99	163	169	157
kg/ha	1986	275	421	419	285
	1987	199	419	454	512

Table 5. Effect of sward surface height on the performance of yearling red deer stags.

Contact name: **Bill Hamilton**

ANIMAL PRODUCTION FROM GRAZING RUMINANTS

Effect of ewe body condition and level of food intake on hypothalamic activity and pituitary sensitivity to LH-RH

Effects of ewe body condition and level of food intake on plasma gonadotrophin concentrations and associated ovulation rates have been demonstrated previously. These differences in gonadotrophin concentrations could reflect differences in hypothalamic activity or differences in pituitary sensitivity to LH-RH released from the hypothalamus. The activity of both organs is influenced by ovarian steroids and in order to examine the effects of nutritional factors on hypothalamic/pituitary activity in the absence of steriodal feedback, ovaries were removed from ewes prior to study in 2 separate experiments (Figure 1).

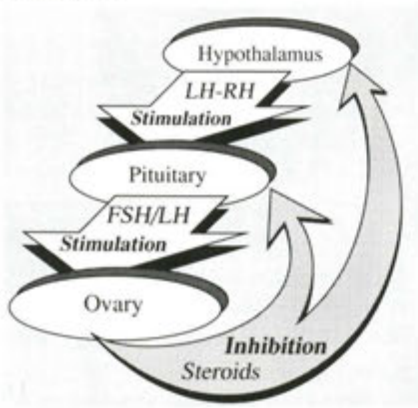


Figure 1. Hormonal influences on hypothalamic/pituitary activity.

The results of these experiments suggest that hypothalamic activity and LH-RH secretion were reduced in ewes in low body condition compared with ewes in high condition scores. There was no evidence that body condition altered the sensitivity of the pituitary to LH-RH.

Level of food intake, on the other hand, did not apparently affect hypothalamic activity. Gonadotrophin concentrations were found to be higher in ewes with moderate intakes than in ewes with high intakes but this was attributable to a greater pituitary sensitivity to LH-RH. It is suggested that the higher level of LH pulsatility observed previously in high intake ewes during the follicular phase of the cycle was attributable to effects of level of intake on steroid feedback or on the sensitivity of the hypothalamus to steroid feedback.

There is evidence that the nutritional control of hypothalamic activity and ovulation rate could be mediated through changes in endorphin concentrations in the brain. This has been investigated in a further experiment in which the effects of manipulating endorphin activity with the antagonist naloxone have been investigated. Untreated ewes with a high food intake had a higher mean ovulation rate than ewes with a moderate intake (1.63 v 1.00, $P < 0.05$) but following treatment with naloxone, differences in ovulation rate were reduced (1.33 v 1.20, $P > 0.05$).

Naloxone increased circulating LH concentrations, LH pulse amplitudes and, in the absence of elevated progesterone levels (i.e. during the follicular phase) LH pulse frequency. However, the increases were transient and so the possibility remains that a more sustained increase at the appropriate time of the cycle would have induced an increase in ovulation rate. This requires to be determined. Contact name: **Stewart Rhind**

Premating feed supplementation in ewes

It is known that the ovulation rate of ewes in moderate body condition is increased by improvements in food intake prior to mating and effects of level of intake on gonadotrophin secretion have been demonstrated in several experiments. However, increased intake will increase both energy substrate and amino acid supply to the tissues and either of these could be responsible for altering gonadotrophin secretion. An experiment was designed to establish which component of the feed affected gonadotrophin secretion.

Ewes on a control treatment were fed a basal diet which provided 80% of the daily energy requirements for maintenance of liveweight. A second group was given a diet containing 20% of a rumen undegradable protein source, white fish meal; this treatment (high protein) was designed to be isocaloric with the control treatment but to provide twice as much amino acid for absorption. A third group was given a diet containing volatile fatty acid salts (high energy treatment); this was designed to provide twice maintenance energy requirements but it necessarily also provided additional absorbed amino acids.

The high protein treatment did not significantly increase ovulation rate compared with that of the control treatment (1.48 v 1.41) but the high energy treatment resulted in a significant increase (1.75 v 1.41; $P < 0.05$).

Mean circulating follicle stimulating hormone concentrations (ng/ml) were slightly lower in ewes fed the high energy diet than in control ewes (23.5 v 28.5; $P < 0.05$) in the luteal phase but the opposite trend was observed during the follicular phase (16.3 v 13.1; NS). Mean concentrations and pulse frequencies were not significantly affected by nutritional treatment at either period but during the follicular phase, the high energy diet was associated with a higher mean lutenising hormone pulse amplitude (ng/ml) compared with control ewes (2.68 v 1.83; $P < 0.05$). This was associated with similar but non-significant trends in mean lutenising hormone concentrations (1.44 v 1.07) and pulse frequencies

(0.70 v 0.54 pulses/h) at this time. Protein supplementation had no effect on any of the hormones studied.
It is concluded that the increased supply of absorbed amino acid alone prior to ovulation does not affect gonadotrophin secretion or increase the ovulation rate. The observed effects of level of nutrition are likely to be attributable to the increase in the amounts of absorbed energy substrates.
Contact name: **Stewart Rhind**

Effect of declining liveweight at mating on ewe reproductive performance.

The reproductive performance of 252 Greyface ewes which had their food intake restricted from 14 days before mating until slaughter at 11 to 26 days after mating (LL) was compared with that of ewes which had only a restricted intake from mating until slaughter (HL) or were not restricted at any time (HH). The endocrine status of ewes of each group was investigated during the follicular phase of the cycle prior to mating and on 3 occasions during the first 10 days after mating.

LL ewes had a lower mean ovulation rate than HH + HL ewes (1.81 v 2.16; $P < 0.001$) and this was reflected in their lower mean potential lambing rates per ewe pregnant (1.58 v 1.79; $P < 0.01$) and per ewe put to the ram (1.37 v 1.65., $P < 0.01$) compared with HL ewes. There was no significant difference in the lambing rates of HL and HH ewes but the proportion of ova not represented by viable embryos was greater in HL ewes (0.27 v 0.13; $P < 0.01$).

In ewes slaughtered at day 11, there was a higher proportion of small conceptuses in HL + LL ewes than HH ewes (0.77 v 0.27; $P < 0.01$) but the size was not additionally affected by the period of restricted feeding before mating.

There was no effect of premating nutritional treatment on mean FSH or LH concentrations during the follicular phase prior to mating when ovarian follicles were developing rapidly prior to the formation of progesterone secreting corpora lutea which are then sustained by LH secretion.

LH and progesterone secretion at days 2, 6 and 10 after mating were investigated. While mean LH concentrations were not affected by treatment at any of these times, mean progesterone concentrations (ng/ml) were slightly higher in restricted ewes at day 6 (HL + LL: 2.95, HH: 1.92; s.e. = 0.272; NS) and significantly higher at day 10 (HL + LL: 6.87, HH: 4.82, s.e. = 0.354; $P < 0.01$).

While restricted ewes had a lower LH pulse frequency during the follicular phase ($P < 0.05$) and at days 2 ($P < 0.01$) and 10 ($P < 0.05$) post mating, there was no effect of treatment on progesterone pulse frequency at any time. (Figure 2).

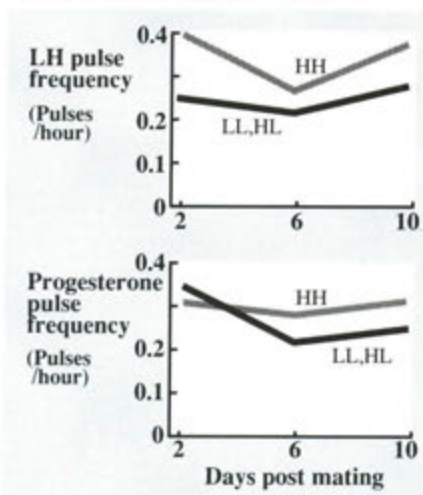


Figure 2. Mean LH and Progesterone pulse frequencies of ewes with restricted (LL, HL) or unrestricted (HH) food intakes.

The increased incidence of embryo wastage in ewes with a restricted food intake was not attributable to a deficiency in circulating progesterone concentrations but could be due to asynchrony of progesterone secretion and embryo development which may have resulted in restriction of embryo growth and embryo loss.
Contact name: **Stewart Rhind**

Application of ultrasonic scanning in sheep, deer and goats

The technique of real-time ultrasonic scanning, which was pioneered in the UK by the MLURI to determine foetal numbers in pregnant ewes, has more recently been applied to other species of farmed livestock. It has been shown that it can be used in beef cattle to diagnose pregnancy accurately and safely from 30 days of gestation which is substantially earlier than is possible by the normal method of rectal palpation.

Scanning has also played an important role in the Institute's goat breeding work. This involves the use of artificial insemination and embryo transfer techniques to multiply the number of superior cashmere goats, and the early and accurate diagnosis of pregnancy which scanning affords has made a valuable contribution to the efficiency of this work, allowing

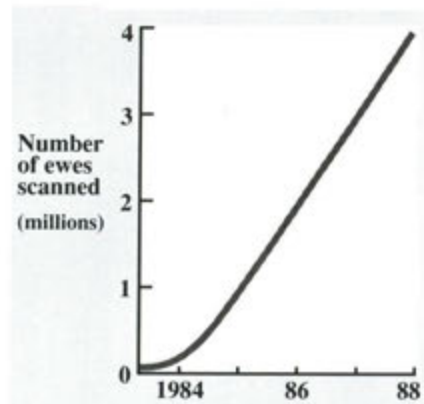


Figure 3. The number of ewes in the UK diagnosed for pregnancy using ultrasonic scanning.

non-pregnant individuals to be reprogrammed and used more than once in the same breeding season. The technique has been adopted widely by commercial and pedigree goat breeding enterprises.

The technique has been used successfully to diagnose pregnancy in red deer and other deer species. Work currently in progress is designed to establish relationships between foetal size and age in deer to provide information on foetal growth and

enable calving dates to be accurately predicted.

The use of the technique by the sheep industry has continued to expand rapidly. It is estimated that there are now considerably more than one hundred scanning contractors offering a commercial service and that some four million ewes, equivalent to approximately 25% of the national flock, were scanned during the 1987-88 winter (see Figure 3). The adoption of scanning by sheep farmers has enabled earlier work on the nutrition of the pregnant ewe to be applied in practice. The consequent reductions in lamb and ewe mortality and the savings in feed and labour are conservatively estimated to be worth £12 million per annum to the sheep industry.

Contact names: **Angus Russel, Iain White**

Reproductive efficiency in beef cows

Reproductive performance is a major determinant of efficiency and profitability in beef cow enterprises. Although detailed investigations are being carried out into the components of the reproductive process in cows, data from past experiments can be used to assess gross reproductive performance. Records from 321 spring calving cows have been analysed. Cows calved predominantly in March and April and were turned out to pasture in mid-May. Mating usually started within one week of turnout and continued for 9-10 weeks. The effects of body condition, cow breed, cow age and date of calving have been examined.

Body condition at calving had a major effect on calving interval (Figure 4). Cows which were at body condition score 2 or less at calving had a calving interval of 374 days while those with a body condition score of 3 or more had a calving interval of 363 days. Body condition at the start of mating was related to calving interval,

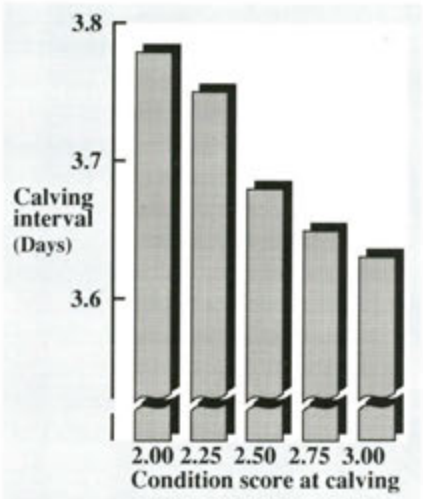


Figure 4. The effect of body condition score at calving on calving interval.

but was less important than body condition at calving. Body condition at the end of mating was not related to calving interval.

As cow age increased, the probability of cows becoming pregnant decreased. Also Blue Grey cows showed a greater probability of becoming pregnant than did Hereford x Friesians (0.90 v 0.83). Time of calving also affected the probability of becoming pregnant. Cows that calved within 36 days of the start of mating had a lower probability of becoming pregnant (0.73) than those calving 36 days or more before the start of mating (0.86).

Contact name: **Iain Wright**

The effects of nutrition and body composition on the duration of post-partum anoestrus in beef cows

A long anoestrous period after calving can be a major cause of low reproductive efficiency in beef cow herds. A number of factors which are thought to be important in influencing the duration of the post-partum anoestrous period are being examined, such as body condition at calving, feed intake, genotype and calf suckling. In addition measurements are being made of the profiles of the important reproductive hormones.

To date it has been established that each unit increase in body condition at calving decreases the length of the post-partum anoestrous period by 43 days. Level of feed intake has a smaller effect, but there is some evidence that it is more important in thin cows. In one experiment half the cows which were thin at calving and

	Body condition score at calving			
	2.08		2.82	
Feed intake (MJ ME/day) :	56	111	56	111
Non-cycling	6	2	1	0
Cycling	6	10	10	11

Table 1. Numbers of cycling and non-cycling cows at the end of one experiment.

which were on a low level of feeding after calving were still not cycling at the end of the experiment (Table 1). This aspect is currently being examined further.

It has also been demonstrated that cows in better body condition at calving have higher luteinizing hormone (LH) pulse frequencies, and it is considered that this may be responsible for their shorter anoestrous periods.

Separating cows from their calves for 48 hours was shown to increase LH pulse frequency at the time, but when the calves returned to their mothers LH pulse frequency returned to previous levels, and temporary calf separation had no effect on the length of the post-partum anoestrous period.

Contact name: **Iain Wright**

Half-lives of ovine anti-testosterone antibodies in cattle when injected subcutaneously or intraveneously

Results of attempts to induce multiple ovulations in cattle by passive immunisation against steroid hormones have been equivocal; in some experiments, some animals have had multiple ovulations while in others there has been no response. One possible cause of the discrepancy in results is the mode of antiserum

administration i.e. by intravenous or subcutaneous injection. This could affect profiles of circulating antibody concentrations and so ovarian response.

In order to determine the effect of mode of administration on circulating antibody titres, 8 cows were injected with 0.5 units/kg liveweight of ovine anti-testosterone antiserum, either subcutaneously or intravenously, and residual free antibody titres were assessed at 5 minutes and 1, 2, 4, 6, 8 and 10 h after injection and at intervals of 12 or 24 h for a further 3 weeks.

In cows injected subcutaneously, titres rose much more slowly to a peak at about 4 days after injection and then declined gradually so that there was a broad peak of maximal titres over a period of about 4 days. Cows injected intravenously on the other hand had maximum antibody titres within 2 h of injection and concentrations then declined rapidly over the first 2 or 3 days. They then fell much more slowly over the experimental period.

The preferred injection route may depend on the physiological process that is to be manipulated but the results indicate that subcutaneous administration is likely to be preferable because it results in more sustained levels of immunoreactive antibody i.e. it exerts its effects over a longer period and is also a safer and easier route of administration. This work was conducted in conjunction with Dr B. Morris, University of Surrey.

Contact name: **Stewart Rhind**

Uses of real-time ultrasonic scanning in diagnosis of pregnancy in beef cows

Real-time ultrasonic scanning of cows has been developed in the Institute for the past five years, and has been shown to be a reliable and accurate technique for pregnancy diagnosis in cows. Relationships have been developed between foetal age and the size of various foetal parts which allows the prediction of foetal age and hence calving.

The accuracy of the technique for prediction of calving date was assessed from records of 300 cows in 6 herds. Cows were scanned between 35 and 120 days of gestation and measurements made of foetal parts, the measurements made being dependent on the position and orientation of the foetus. Foetal ages were estimated from the equations relating age to size and calving date predicted. These predicted calving dates were then compared with actual calving dates.

Predictions were based on four different foetal measurements. 71.6% were based on trunk diameter, 22.3% on head diameter, 4.6% on uterine diameter and 1.3% on nose diameter. Overall the mean difference between predicted and actual calving date was 0.9 day with a standard deviation of 9.0 days. 80.5% of cows calved within 10 days of the predicted date, 67.5% within 7 days and 38.7% within 3 days. The best prediction was given by measurements of trunk and head diameter.

Even if foetal age is known exactly then calving date can never be predicted exactly because of variation in gestation length. Taking this into account the degree of precision offered by this technique is relatively high and its adoption could be of considerable value in the late pregnancy and calving management of cows.

Contact name: **Iain Wright**

The lifetime performance of red deer

One of the major contributors to the biological and economic efficiency of animal production systems is the replacement rate of female breeding animals. In the farmed red deer lifetime performance, the major determinant of replacement rate, of 70 hinds born in 1970-72 has been followed. The hinds have been managed such that they have been grazed predominantly on a heather hill with some access to sown swards at calving and mating.

	1970-86	1987
Number of hinds	70	50
Mortality rate per annum (%)	1.2	10
Weaning rate of calves (%)	85	73

Table 2. The lifetime performance of red deer.

Table 2 shows the performance of the hinds up to 1986 with mortality rates of about 1% per annum and weaning rates approaching 90%. However in the last year mortality rate of hinds has increased and weaning rate has decreased. Approximately a third of the hinds have lost some teeth and the mean growth rate of calves in 1987 from hinds born in 1971 was 224 g/day compared to a mean of 270 g/day over the period 1973-1978. The results to date would suggest that red deer hinds have a productive life of at least 15 years. This implies a replacement rate of about 7% per annum compared to 20-25% in sheep and 10-12% in beef cows.

Contact name: **Bill Hamilton**

Hybridisation between the red deer and Waipiti

Most of farmed red deer meat is produced from animals slaughtered at 16-18 months of age in the period from September to December. The use of a larger hybrid, such as that between the red deer and Waipiti, would allow the possibility of animals being slaughtered at an acceptable carcase weight at less than a year of age in the period from January to April, thus spreading the supply of deer meat on to the market over a longer period. The extent to which this may be possible depends upon the feasibility of hybridisation and the growth rate of calves. These issues have been explored with the Waipiti x red deer hybrid.

With natural service, pregnancy

rates of red deer hinds mated to a Waipiti male have been approximately 50%. The calving date has been on average 10 days later than for control hinds but this can be brought forward by the use of melatonin given to the hinds, since the Waipiti male is actively rutting in September. The incidence of dystokia and assisted births was reduced to 26% by management of the nutrition of the hind in late pregnancy with a mortality rate of calves of 7%, similar to that observed with pure bred red deer.

The live-weight gains of hybrid calves were 20% greater than red deer calves until weaning. During the winter housing period intakes per kg metabolic live weight were similar but growth rates of the hybrid calves were greater than those of the red deer, implying that the efficiency of utilisation of nutrients was greater in the hybrid. By the end of the winter housing period the hybrid calves were 20 kg heavier than comparably managed red deer. These results suggest that the F1 hybrid has potential for out of season deer meat production, although improvements in reproductive performance would be desirable and carcase acceptability has yet to be examined.

Contact name: **Bill Hamilton**

Cashmere production

Skin samples collected at monthly intervals from different ages and sexes of pure and cross-bred cashmere goats have been examined histologically to study the pattern of growth of cashmere throughout the year. The results show that the main period of activity of the secondary skin follicles which produce the cashmere fibres is from the summer solstice to the winter solstice, i.e. from the longest to the shortest day. It was noted, however, that some follicles were active before daylength began to decrease, and some remained active after daylength began to increase. Thus, although cashmere growth appears to be controlled to a large extent by change in daylength this may not be the sole factor involved. This in turn suggests that cashmere production might be increased by identifying and breeding from these animals which grow most fibre outwith the June to December period.

Cashmere fibres are shed from the secondary skin follicles in the early months of the year, and, if it is not harvested at that time, it will be lost as the animal casts its undercoat. Cashmere can be harvested by shearing in January or February but the animals then have to be housed for several months, which adds considerably to the costs of production. The fibre can also be harvested by combing in February or March but this is labour intensive, taking 15-20 minutes per goat. An alternative method which is being investigated is to put coats on the goats in January, not to protect the animals from the weather, but to contain the cashmere as it is shed and prevent its being lost. Preliminary trials have shown that combing following the removal of the coats in May can be as rapid as shearing. The main problems are in perfecting the design of the coats and in identifying the cause of felting of the fibre which occurs in a small proportion of the animals.

Contact names: **Angus Russel, Margaret Merchant**

Breeding Better Cashmere Goats

The Institute has played a major role in the establishment and early development of Cashmere Breeders Limited - a group constituted in May 1986 to establish and maintain selected herds of goats, to upgrade the farm production of cashmere and goatmeat, to operate a breeding scheme which will lead to improved cashmere production and quality and to market quality cashmere goat breeding stock on behalf of its members. The Institute is a member of Cashmere Breeders Limited and also acts as its managing agent. The group currently comprises 10 members with some 1,500 female goats kept specifically for the breeding of improved cashmere stock.

The breeding programme is being pursued in two stages. The first, now in its second year, involves the crossing of superior imported cashmere goats with indigenous feral stock. Native feral goats are hardy and well adapted to the climatic conditions in this country. They produce high quality cashmere (mean fibre diameter of 14 microns), but levels of production are low, averaging about 80-100 g per animal. To improve levels of production they have been crossed with superior stock as described below.

In the second stage of the programme the best crossbred stock will be brought together to form an elite herd in which further improvements in production and quality will be sought by genetic selection.

In the autumn of 1986 frozen semen from two bucks was imported from Tasmania; at the same time two bucks and four does were imported from Iceland. As it was essential to spread the genetic merit of these four males over as great a number of the indigenous female stock as possible a programme of laparoscopic intrauterine insemination was carried out, and the best of the female stock used as embryo donors in an embryo transfer programme. One hundred and eighty three feral females were inseminated in mid December 1986, 90 using frozen Tasmanian semen and the remainder using Icelandic semen collected fresh on each farm. Conception rates were 33% and 45% respectively; figures which do not compare unfavourably with the 50% conception rate habitually achieved in feral does naturally mated in their first season of domestication.

Eighty-three embryos were collected

from feral donors and transferred to 43 domestic recipient goats; 35 (81%) became pregnant and produced 53 Tasmanian x Feral kids.

During the 1987-88 breeding season the artificial breeding programme has continued to expand through the importation of live animals from Tasmania and Iceland and frozen embryos from New Zealand. Five Tasmanian cashmere bucks have been used as semen donors for a laparoscopic AI programme involving some 500 feral and feral-cross does. Based on initial scanning results approximately 60% of these does have conceived to artificial insemination, the results being significantly better in feral x domestic animals than in pure feral does.

Ten imported females were used as embryo donors; 106 embryos were collected from these animals and transferred to 48 recipient does of which 40 (84%) became pregnant and, on scanning, are carrying 70 (66% embryo survival) kids.

Contact names: **Angus Russel, Bill McKelvey**

SITES

The Institute is currently based at two sites, in Aberdeen (Craigiebuckler) and Edinburgh (Bush) but will eventually be consolidated on the one site in Aberdeen.

Craigiebuckler

The facilities comprise a Victorian (unlisted) mansion house (1200 m^2) used for the Land Use Division, for meetings and for recreational use; a main building of some 5700 m^2 housing laboratories, offices, library and technical service areas; various glasshouses, sample handling and storage buildings, garages and a canteen block, all set in an area of 20 ha in the south-west of Aberdeen. Some of the land on the site is used for small plot experiments by the Plants Division and other parts are in pasture grazed seasonally by cattle.

Bush

The main laboratory building of about 3000 m^2 accommodates laboratories and offices, and out-buildings of 2300 m^2 provide facilities for animals, plants, sample handling and includes garages and workshops. It is situated on a 5 ha area in the grounds of Edinburgh Centre of Rural Economy which is located on the Bush Estate some 6.5 miles south-west of the City of Edinburgh. The Institute has use of about 25 ha of policy fields adjacent to the animal house and of the 255 ha House O' Muir farm, one mile from the main building, on the Pentlands. The buildings on the latter farm provide winter housing for cattle and sheep used by the Animals and Grazing Ecology Division. The land rises from 210 to 450 m and the annual rainfall is about 800 mm. The soils on the upper slopes are freely draining brown earths of the Sourhope series derived from rhyolite, trachyte and andesitic lavas. On the lower slopes there are imperfectly drained soils derived from carboniferous shales and Old Red Sandstone.

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*, 8 ha of reseeded acid grassland and 30 ha of sown grassland.

The farm carries over 500 Scottish Blackface ewes and about 50 suckler cows.

FIELD RESEARCH STATIONS

In addition to the two main sites the Institute has use of three field research stations in Scotland (Sourhope, Hartwood and Glensaugh) and shares use of a station in Wales (Bronydd Mawr) with the AFRC Institute of Grassland and Animal Production.

Sourhope

Sourhope Research Station, 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 land rises from 210 to 608 m in altitude, and the annual rainfall is around 940 mm.

Soils

The soils are developed on locally derived drift from andesitic lavas of Old Red Sandstone Age. Acid Brown Forest soils characterise 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 *Molinia* (Flying bent) and *Nardus* (White bent) dominant grass heaths.

There are 40 ha of rough grazing which have been reseeded and there is a further total of 45 ha of enclosed grassland, of which 20 ha is capable of being conserved.

Livestock

1200 Scottish Blackface ewes and 1000 North and South Country Cheviot ewes. 50 Suckler cows - spring calving.

Buildings

Inwintering accommodation for 50 cows, 660 ewes and 150 hoggs. Hostel with nine rooms, office and laboratory accommodation for 3 scientific staff and visting scientists.

Research

Conducted on trace element deficiency in lambs, grazing Nardus by cattle, foraging strategy of sheep on hill vegetation, productivity and breeding of goats and sheep production systems.

Glensaugh

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

Soils

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

North of the fault the soils are of the Strichen association derived from schistose rock. The area has been extensively glaciated, and deep deposits of glacial drift cover the lower slopes. 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 derived from Old Red Sandstone. On Finella Hill iron humus podzols dominate the lower slopes and stony peaty podzols occur at higher elevations.

Land Resources

The farm 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 glacial soils and lower hill slopes. Bracken (*Pteridium aquilinum*) also occurs on the lower slopes.

The free draining land is dry heather (*Calluna vulgaris*) moor with blaeberry (*Vaccinium myrtillus*), wavy hair grass (*Deschampsia flexuosa*) and bell heather (*Erica cinerea*)

locally important. On the deeper peats at higher elevations crossleaved heath (*Erica tetralix*) and cotton sedge (*Eriophorum vaginatum*) become co-dominant.

Livestock

500 Scottish Blackface ewes, 400 Greyface ewes and 250 crossbred ewes of a range of genotypes, 50 spring calving suckler cows (Blue Grey).
300 breeding red deer hinds and stags with associated 250 Yearlings and calves.

Buildings

Loose housing accommodation and experimental cattle shed for cows and calves. Winter housing for 600 ewes. Accommodation for the housing of 150 red deer calves, office and laboratories for 3 scientifc staff and visiting scientifc staff.

Research

Research is conducted on agroforestry, deer, ewe efficiency and reproduction, and sheep production systems on heather moorland.

Hartwood

Hartwood Research Station which extends to over 300 ha, is located near Shotts in Lanarkshire, 30 miles from the Institute's Bush Site. 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 some 1100 mm.

Soils

The soils are heavy textured, imperfectly drained gleys of the Rowanhill series, and are typical of 400 sq miles of heavy soils running from Stirlingshire southwards into Ayrshire. The heavy wet soils contribute significantly to the marginal nature of the farming.

Land Resources

The research station has 220 ha of sown grassland, 20 ha of woodland strips, 28 ha of indigenous hill vegetation, and 25 ha of forage crops, mainly rape.

Livestock

There are 800 Greyface ewes, 230 Scottish Blackface ewes and 180 Suckler cows (135 Hereford x Friesian and 45 Blue Grey cows split between autumn, winter and spring calving herds).

Buildings

Winter housing for 660 ewes. Two cattle sheds each for 120 cows and calves. Silage capacity for 1500 tons. Experimental sheep and cattle metabolism facilities for 50 sheep and 15 cows respectively and cattle surgery facilities. Laboratory and office space including deep freeze and oven facilities for 5 scientific staff based at Hartwood and visiting scientists.

Research

Research conducted on grazing ecology of sown swards, plant nutrition in grass/clover swards, cattle reproduction, sheep and beef cattle grazing systems on upland sown swards.

Bronydd Mawr

Bronydd Mawr Research Centre, which is jointly managed by MLURI and the Institute of Grassland and Animal Production, 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 1400 mm.

Soils

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

Land Resources

There are 260 ha, most of which has 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.

Livestock

There are 1025 Brecon Cheviot, 600 Beulah Speckleface and 160 Welsh Mule ewes. There is also a spring calving herd of 60 suckler ewes of Welsh Black, Hereford x Friesian and Aberdeen Angus x Friesian genotypes.

Buildings

Cattle and sheep sheds for housing 60 cows and 600 ewes respectively in winter are available. There are offices and laboratories for 4 permanent scientific staff and visiting scientists.

Research

Research is conducted on lamb growth and ewe reproduction in relation to pasture conditions, effect of early-life nutrition on life-time performance of ewes, genotype x environment interactions with beef cows by MLURI. Pasture studies on the evaluation of grass and clover varieties, on N cycling in grass/clover swards and on agroforestry are conducted by IGAP, and the Welsh Plant Breeding Station, and joint studies by both Institutes on sheep systems research are conducted.

ANALYTICAL EQUIPMENT, INSTRUMENTATION AND FACILITIES

New analytical potential and instrumentation

During 1987 there were several new developments which significantly increase the Institute's analytical potential. The principal items are detailed separately in this section which also includes a summary of existing facilities that can be used on problems with potential for commercial exploitation.

Thermal Ionization Mass Spectrometry (TIMS)

The isotope analysis of Zn, Cu and Fe in human and animal samples from nutrition studies, Sr in soil and water samples from weathering studies. Pb in environmental samples and K in plant uptake studies.

Technicon Traacs 800 Autoanalyser

Routine determinations of N and P in soil, plant and water samples. It has a sampling rate of over 100 per hour for each channel and an automatic dilution facility. The Traacs is fully computer controlled (IBM Personal Computer) and results are presented in a final form with base, drift and carry over corrections.

Light microscopes

A controlled temperature stage for light microscopes suitable for observing the effects of temperatures between +40°C and -190°C on soil micro-organisms has been developed in the Department of Microbiology. This equipment could also be used for cryopreservation of tissue culture cells, ova, sperm, etc. in the future.

Densitometer

Software for the semi-automated densitometer has now been developed to allow photographic plates from the spark source mass spectrometer (SSMS) to be read and peak masses and intensities to be assigned.

Calorimeters

Four open-circuit calorimeters with continuous measurement of gas flows have been installed at the Bush site for the measurement of gaseous exchange and energy expenditure of sheep and deer. They will be used in research programmes concerned with the significance of shelter to sheep in farm/forestry and agroforestry systems and with the development of seasonal rhythms in deer.

Ultra-trace analysis

Development of graphite furnace atomic absorption spectrometry for the rapid determination of ultra-trace amounts of a number of trace elements has been completed and applied to the analysis of water samples.

Nebuliser/spray chamber for ICP analysis

A new Conespray nebuliser has been designed to convert liquid samples into an aerosol for injection into an inductively coupled plasma (ICP) source. This has been patented and a contract awarded by the British Technology Group for the development of commercial prototypes.

Other new equipment

The Institute has taken delivery of a MicroVAX 3600 computer. The MicroVAX 3600 is a 32-bit machine with 32 Megabytes of memory and an operating speed of 3 million instructions per second. It will also have 1.2 Giga bytes of on-line storage provided by two disk drives and will have a fast 1/2 inch tape drive for import and export of large volumes of data. The operating system will be VMS, the standard multi-user DEC system. However, the hardware is also capable of running other operating systems, which are independent of any manufacturer's hardware.

Programming will be in either FORTRAN or PASCAL and software that will be immediately available on the new computer comprises:

ORACLE - a very powerful, relational database package

GENSTAT - the multi-purpose statistical package developed at Rothamsted

MINITAB - a general, easy-to-use statistical package

NAG routines - a package of scientific, mathematical and statistical subroutines which can be incorporated into users' own programmes

UNIRAS - a graphics software package

Communications - a comprehensive communications package will also be available, enabling transfer of information, data files, electronic mail etc. around the world.

The relational database package will be used to set up a comprehensive database of existing soils information. The database will have the location of each entry as the relational element of its record. This will enable, for example, data from all sources to be extracted for a particular area or for all areas satisfying a particular set of criteria to be identified. The database package will also have application in other areas of the Institute's work, for example in setting up and manipulating animal records. The anticipated database load is the reason for the substantial on-line storage capacity of the new system.

Analytical facilities which have economic potential

The current analytical and instrumental facilities which have economic potential are listed below. The fields of interest are identified first, followed by the instrumentation used in their investigation.

Soil Survey

Soil characterisation, classification and mapping; land capability assessments for agriculture and forestry; land restoration; vegetation recording, classification and mapping; micro-morphology; air-photo interpretation; classical and digital cartography.

Equipment and facilities available include cartographic drawing office; Calcomp flat bed plotter; thin section preparation; National soil inventory database; soil, vegetation and landscape databases.

Remote sensing and geographic data handling facilities

The Institute is the Scottish Regional Remote Sensing Centre and carries out work involving remote sensing; geographic data handling; digital image processing; resource assessment; airborne video photographic techniques; crop monitoring using radiometers; peat survey and nutrient studies; palaeobotany; N and P transformation studies in peat; nutrition and nutrient cycling in trees; fertiliser requirements of trees; acid deposition effects; catchment studies and development of field instrumentation.

Equipment and facilities available include a PRIME 250 mini-computer, image processing system (GEMS system 33); video digitiser (512 x 512 6 bit resolution) with flatbed high resolution tablets and wild stereo and flatbed Plotters, colour graphics display (Tektonics 402); colour graphics plotter (integrex); 35 mm video film recorder (Ramtrek), peat samplers; sectioning facilities; automated ion chromatography and data handling; field monitoring equipment including loggers etc.

Clay and mineral studies

Chemical and physical characteristics of soils; clay and soil mineralogy; soil organic matter; structure and texture of soils; characterisation of surface properties; ion exchange; and forms of iron.

Techniques used to include x-ray diffraction; x-ray fluorescence; gas chromatography, thermal analysis; pyrolysis/mass

spectrometry; particle size analysis; scanning and transmission electron microscopy; Mossbauer spectroscopy; infra-red (and ultraviolet/visible) absorption spectrometry.

Elemental and speciation analysis of soils and plants

Multielement analysis (for major, trace and ultra-trace elements in biological materials); trace element speciation; stable isotope tracer studies; isotopic fingerprinting; heavy metal pollution studies; soil/plant trace element studies; nebulisers and spray chambers; forms of iron and copper in materials; characterisation of soil mineral structures and soil organic matter; free radicals in biological tissues.

Techniques used for elemental analysis include flame emission; flame atomic absorption, graphite furnace atom ic absorption; inductively coupled plasma emission; direct current arc emission; spark source and thermal ionisation mass spectrometry. Also electron paramagnetic resonance; Mossbauer; infra red and ultraviolet absorption spectroscopy for determination of the forms of elements in materials. Equipment for sampling; preparation and dissolution of samples prior to trace analysis are also available.

Organic and microbiological studies

Nitrogen, phosphorus and sulphur cycling; micro-organism/oplant interaction; Allelopathy; soil carbohdrate chemistry; plant residue decomposition; soil microbiology; mycorrhizas and their importance in plant nutrition; microbiological assessments of soil and water quality.

Techniques used include gas/liquid and high performance liquid chromatography; sutoanalysers; UV-visible spectrometers; ultrasonics; dissolved carbon analyser; carbon, hydrogen, nitrogen analyser; microbiological laboratory; growth and glasshouse facilities, sophisticated light microscopes with video-enhanced microscopy and image analysis; particle size analysis with Coulter counter; Chemostats for cultivation of micro-organisms; O2 and CO2 gas analyser; time lapse and video equipment for detailed studies of microbial cells.

Plant studies

Nitrate and ammonium uptake by plants; nutrient uptake and transport; effects of environmental factors on plants; nutrient cycling; assessment of crop nutrient requirements; crop and soil analysis; agricultural and forest field trials; crop water supply; plant root growth studies; growth refulators; environmental impact of cropping systems; agroforestry and farm-forest systems; amino-acid analysis of plants; levels of radiation in the environment.

Techniques used include controlled environment cabinets and glasshouses; UV-visible spectrophotometers; Aminco-Bowman spectrofluorimeter; Tecator Kjeltect digestion and distillation equipment; sterilisation/autoclaving facilities; field plot experimentation; TV camera system for root growth studies; neutron moisture meter; gamma soil density meter and recording soil penetrometer; equipment for physical measurements on soils; chromatography; plant and soil drying and grinding facilities; Technicon Traacs autoanalyser.

Animal studies

Facilities are available for the large-scale field testing of supplementary feeds, feed aditives and veterinary products for use with sheep, cattle, deer and goats. The facilities are suitable for animal production experimentation with grazing animals, indoor digestibility and metabolism measurements and there are analytical facilities to provide a wide range of analyses used in such testing and experimentation.

Technical Services

Workshop facilities are available for precision turning, milling, precision grinding, engraving, sheet metal working, welding (gas, arc, tig ac/dc), plastic welding and fabrication, and spray painting.

There is a comprehensively equipped electronics section for analogue and digital fault diagnosis including work in microprocessor based equipment, full program development aids for the Intel 8065 and 8044 families of microprocessors/controllers, and the fabrication of printed circuit boards, both single and double sided.

The photographic section provides photographic material in the form of record, publication, poster, exhibition and reproduction, line and colour slide for lectures and colour transparancies for publication.

New Field Analytical Equipment

Design and contruction of control and data logging equipment for field studies

Discrete daily and hourly samples of inputs, vegetation and soil throughflows, and outputs have been collected during selected rainfall and snowmelt events using event sampling equipment driven by custom-built control modules.

Volumes of water through selected systems, previously monitored using electro-mechanical counters, are now being monitored using MLURI designed and constructed solid state loggers. These digital, eight-channel loggers are normally pre-set to accumulate data in 20 minute periods over 28 days.

Analogue eight-channel loggers were also designed and constructed using similar micro-processor based circuitry to record soil temperature data from assembled thermistor probes. These probes have been installed at a range of sites to monitor air, snowpack and soil profile temperatures. The data collected by these analogue and digital loggers will illustrate typical input and throughflow hydrology along with related changes in temperature.

Further storm and snowmelt event sampling along with improved monitoring are planned to take place using reduced sampling periods, particularly at onset of events. This data will be used to improve the understanding of the possible processes leading to potential surface water acidification.

SCOTTISH AGRICULTURAL STATISTICS SERVICE

A unified statistical service for the Scottish Agricultural Research Institutes and Colleges was set up by DAFS on 1 April 1987. The Scottish Agricultural Statistics Service, SASS, is centred in Edinburgh with units in Aberdeen, Ayr and Dundee. It comprises 20 consultant statisticians, plus computer specialists and support staff, 7 staff are based in Aberdeen.

Statistical consultants are located at most institutes and run regular consultancy clinics at other sites. Additionally, some statisticians are assigned responsibility for supporting broad areas of application across all DAFS institutes. Thus, special emphasis is being placed on coordinating and initiating work on chemometrics, environmental studies, image processing, systems modelling and variety and crop system trials. To increase the statistical awareness and skills of scientific staff, a coordinated training programme in statistical techniques and associated computer programs has been started. This will assist scientists to analyse their data and to identify when statistical advice should be sought.

At present MLURI (A) is supported by staff based at Craigiebuckler and MLURI (B) by staff from the SASS centre in Edinburgh. The staff at MLURI (A) , who are also responsible for coordinating the statistical work on environmental studies, have two consultant and two support statisticians. Besides the support provided by these two teams it is expected that MLURI staff will make considerable use of the SASS expertise on systems modelling, image processing and surveys.

Soil science, its development and contributions to agriculture

T.S.West

When I look back on the previous eleven Macaulay Lectures, I realize that not only is this occasion a great honour for me but also a very considerable challenge. John Eadie, the previous lecturer spoke from the position of an unsurpassed knowledge of agricultural research and development as indeed did many of the previous speakers, eg Sir William Henderson, Sir Kenneth Blaxter and Sir Leslie Fowden. Professor John Bowman, now Secretary of NERC, under the admirable title of "Ill Fares the Land", gave the series an economic background while Professor David Finney made it numerate with an equally attractive title of "Agricultural Research Counts". Sir John Mason discussed meteorological inputs; somewhat curiously just before a storm of another kind struck the two institutes. Mr Ian Smith discussed achievements in Scottish Agriculture and gave us insight into policy inputs. Then there were those

lectures which were particularly relevant to the contributions of soil science from Professor E.W. Russell, Dr George Cooke and Professor Joseph Tinsley, all giants on the soil science scene. The last three and indeed Sir Leslie Fowden who talked on "Nitrogen from Soil to Seed', have left little for me to say and as a mere chemist I should not attempt to compete with them.

Instead, I propose to discuss soil science from the viewpoint of the provenance of soils and their ability to provide essential mineral nutrients, other than the big three; N, P and K, and thus to support plant, animal and human life on planet earth.

In some respects the world of soil science is curiously akin to that of medical science. The medical scientist can look at our blood cells and tissues and characterise our ethnic origins, our life style, our health, our general status as a human being and so on - and even the history of our tribe and the human race. Similarly the soil scientist can study soil particles and tell us their terrestrial origin, their previous history and general state of health, their probable ability to withstand stress or insult and so on.

So, like the greatest of all the English speaking poets - Dylan Thomas - I would like to "Begin at the Beginning".

Whether you believe in the biblical story of the creation of the Earth and the Universe or in the cosmologists' presently fashionable Big-Bang Primordial Atom theory of the origin of the universe - which incidentally does not speculate on the origin of the primordial atom - it is safe to assume that we can begin the prehistorical stage of soil science with the ball of molten magma that cooled down to form the planet. That is speculation. What now follows can be substantiated by experimentally verified fact - mainly from spectroscopic evidence.

The minerals which crystallised first from the molten magma were those of highest melting point the ferromagnesian alumino-silicates which aggregated to form the ultrabasic or basic rocks, eg the Gabbros, rich in ferromagnesian minerals such as olivine (Figure 1), plagioclase and clinopyroxine.

These were followed by the intermediate rocks such as andesites, rich in minerals such as garnet, biotite, feldspar and hornblende. The last to crystallise rocks were the acidic ones such as granite rich in silica and in minerals such as tourmaline and zircon.

These are the igneous or primal rocks from which all other rocks (and subsequently soils) were formed. These igneous rocks, with which I will classify metamorphic rocks, constitute 95% of the earth's present crustal material. The remaining 5% are sedimentary rocks. Agriculturally these sedimentary rocks, which may be regarded as physiochemically reprocessed primary rocks, are much more important than their 5% presence suggests because they lie near the earth`s surface. Of the sedimentaries 80% are shales, 15% sandstones and 5% limestones.

The physicochemical process is weathering involving chiefly hydrological, biological and glacial

Figure 1. Olivine. Thin section in cross polarised light

action. The relative influence of these varies from one part of the world to another and from one geological time period to another. In Scotland glacial action has given much of our landscape its characteristic appearance of U-shaped valleys and rounded bare mountain tops; fluvioglacial action has modified the valley floors. Tectonic plate movements of the Earth`s crust have shifted the rock strata with respect to each other on either side of the Midland Valley as shown in the geological map. North of the Highland Boundary Fault, Moine and Dalradian schists predominate with Old Red Sandstones in the east and

Torridonian sandstones in the west. There are numerous volcanic intrusions of granite. The north of the Midland Valley is dominated by Old Red Sandstone and carboniferous rocks. South of the Midland Valley, Ordovician and Silurian shales predominate with volcanic intrusions. It is also important to bear in mind that glacial movements shifted soils away from the underlying rocks from which they were weathered. In N.E. Scotland there were three different vectors for such movement in the most recent glacial period (ice age).

Figure 2. Glen Feshie. The flood plain of the river shows fluvial action - sorting of gravels and pebbles.Remnants of ancient Caledonian Forest can be seen on the river plain.

Mineral Contents of Soils are determined by Weathering

The basic and ultrabasic rocks are the first to weather so that soils derived from them are rich in the ferromagnesian mineral elements and also those minor elements of ionic radius ca 0.08 nm similar to Fe and Mg which coprecipitated by processes such as isomorphous crystallisation as the rocks congealed. Some examples of these minor elements are Co, Cr, Ni and Zn.

In soils derived from these rocks the Ni/Co ratio is frequently greater than unity. Such a ratio can cause toxicity problems, but otherwise, generally, such soils are well-endowed with the bio-essential trace or minor elements and are agriculturally fertile.

Intermediate rocks also produce fertile soils with good contents of most mineral elements e.g. Cu, Mn, Co, Ni, V, Zn, and generally with Co/Ni ratios greater than unity so that such soils are rarely toxic.

The minerals of the acidic rocks crystallised from a melt which was now depleted of these bioessential elements but rich in less desirable ones such as Pb, Ba, Rb and Cs; and these easily co-crystallized with the constituent major elements of ionic radius ca 0.13 nm. Thus the weathering of acidic rocks such as the granites frequently produces soils of low inherent fertility wuth a poor capability of retaining added fertiliser elements.

In most cases the weathering process completely breaks down the crystal lattice of the primary minerals and secondary minerals are formed; for example illite, montmorillonite and kaolinite; which subsequently are much more easily weathered. In the process those elements of ionic potential < 2, eg sodium show a distinct tendency to remain in the hydrosphere which is why the oceans are rich in sodium chloride and to a lesser extent magnesium chloride. However, most of the bioessential elements have higher ionic potentials and consequently remain with the major rock hydrolysate matrices containing Al, Si and P. These secondary minerals of the argillaceous rocks which are the predominant sedimentaries are the layered clay minerals such as montmorillonite. They incorporate the bioessential minor elements such as Fe, Mg, Co, Cu, Zn and Mn by replacement of Al in the layer lattice. But they also have large specific surfaces (i.e. large surface per unit mass) which also adsorb these same elements in a position where they can easily pass into the soil solution. Thus the clay-mineral rich sedimentary rocks such as shales produce particularly fertile soils.

The sandstones or arenaceous rocks which constitute 15% of the sedimentaries are formed from the silica-rich acidic rocks. Soils formed from them are generally of low fertility because of their poor content of bioessential elements and poor retentive capacity for added fertilisers. The remaining 5% of the sedimentaries i.e.the limestones, also tend to have low bioessential element contents.

Metamorphic rocks which have been classified above with igneous rocks are formed usually from sedimentaries under the influence of extensive heat and pressure, much of northern Scotland is composed of them. We have to be aware that those that are formed from argillaceous sedimentaries such as shales, may have much of their secondary minerals recrystallised back to primary minerals. Thus slates, schists and the gneisses tend to produce less fertile soils. In the process of heat treatment they may also lose valuable volatile elements such as zinc and boron.

Boron is an unusual element in that it is plant-essential, but plays no known role in animal life. Within the plant it plays the role of transporter of sugars because of its ability to form complexes with polysaccharides. It has a rather narrow range between essentiality for crops such as turnips and toxicity for others such as cereals.

Organic Matter

Were it not for the organic matter content of terrestrial soils they would be like marine sands and of little or no agricultural use. The organic matter dictates to a large extent what an agricultural soil looks like and what it feels like texturally. The organic matter derived from biological, chemical and physical transformation of plant and animal materials constitutes the humic component of soils. In passing I should perhaps stress that the most important transforming agency is the microbiological population of the soil. Each gram of soil is reckoned to contain more microbes - including bacteria than there are humans on planet earth. I should also stress that organic matter is in constant dynamic equilibrium and is reckoned to have a half-life of anywhere from a few years to several thousand years depending on the nature or degree of humification. It should be noted that plant life obtains its carbon almost entirely from the atmosphere by the process of photosynthesis and that all soil organic matter therefore has an invaluable built in time-clock because of the nuclear transformation of ^{12}C to radioactive ^{14}C in the upper atmosphere. Once the ^{14}C has been bound up in plant or animal residues in the soil this radiocarbon decays at a steady rate of about a half every 5700 years. Thus we can date soils containing organic matter well back (ca 25 000 to 50 000 years) into the prehistoric period of mankind. Man first appeared in Northern Scotland about 9 000 years ago.

The soil organic matter, as it were, fleshes out the mineral skeleton of soil particles. Most of it is bound up in the organo-silica gel layer that coats most soil particles. It forms much of the store of major elements such as N, P and S which can be worked over and progressively fixed and released by microbial transformation which is why it is so important for the soil to have a good organic content and also an active microbial population and why the study of soil organic matter and soil microbiology is so critically important in agricultural soil research. The organic matter also is important in modifying the water retention capacity of soils, their ability to intercept and convert solar energy, their 'plant friendliness', crumb structure and so on.

It is perhaps not often realised that microbes are themselves soil formers. Thus lichen associations attack and dissolve rocks whilst the well known organism *Aspergillus Niger* attacks and dissolves the clay, silt and sand fractions even of granite soils. Microorganisms also exude organic complexing agents in the rhizosphere of plant roots, eg 2-ketogluconic acid, which dissolve minerals such as apatite. The biological message from the soil is "microbes make soils fertile".

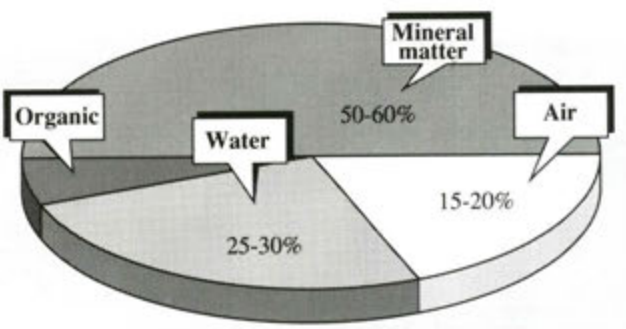


Figure 3. The proportions of the main soil components.

A useful picture of the overall gross chemical composition of soils in general is shown in Figure 3. The soil water contains micronutrients such as Cu and Co at levels down to less than one millionth or even one hundredth of a millionth of a mole per litre and major nutrients such as K and Cu, at much higher levels. The air in the soil is generally richer in carbon dioxide than the atmosphere above ground, it also carries important levels of hydrocarbons such as ethylene which act as plant growth regulators.

Some soils such as the peats may be almost entirely organic in nature. Peat covers roughly 16% of the land mass of Scotland and I need scarcely mention further its important properties as a conditioner of agricultural and horticultural soils in particular. Pollen grains survive for thousands of years in peat deposits and tell us much about the vegetation and hence climate of the prehistoric period of soils and the abundance of various forms of plants in past ages.

Soil Availability for Agriculture

Two thirds of the surface of our planet are covered by water and, therefore, unavailable for agriculture

leaving ca 5 hectares per person. Of these 5, one is too cold, one is too dry, one is too mountainous and one is too barren, this leaves one hectare per head of human population on which to raise plants and manage other forms of agriculture. At the present time we utilise only one half of this hectare for agriculture and the oceans supply each of us on average with food equivalent to the yield of land of the size of a quarter of a tennis court (about 0.007 Ha). In Scotland we utilise about 16% of the land mass for crop production and rotation grass, 5% for permanent grass and about 59% for rough grazing. If we exclude the rough grazing component, the yield of which is difficult to reckon, we are using about 0.3 ha each for food production.

Agricultural Significance of Minor Nutrients from Soils

The supply and function of the "big three" nutrients N P and K is a well known story which will be mentioned no further in this discussion, but we should perhaps remember that their extensive and controlled systematic use emerged only during the period of the second world war. The contribution made by utilisation of knowledge worked out by soil scientists in the previous part of the century was absolutely crucial to this isolated island's ability to feed itself during those war years. Since then the yields of arable and other crops have increased enormously. Very often the credit for this is quite mistakenly given almost entirely to the plant breeder without recognition of the invaluable contribution of soil scientists. The nature of the fertilisers to be applied, how much, when and how and the manner of application to different soils is just as crucial as the plant species or variety.

Boron, magnesium and sulphur are three key mineral elements. Boron has been mentioned already, it is easily washed out of soils, particularly freely drained mineral soils, because it exists chiefly as free borate ion in solution. It is well known that magnesium plays a central role in photosynthesis in plants via chlorophyll, but it is also important in binding the pyrophosphate end of ATP or ADP to the phosphorylating enzymes. In animals, the phenomenon of hypomagnesemia in cattle is also a problem in some soils particulraly in upland pastures. Sulphur, which is important in amino acid and protein synthesis and in the energy cycle for photosynthesis in plants, used to be no problem in arable areas where superphosphate fertilisers were used because the sulphur came inadvertently with the phosphate. The change to use of triplephosphate has now altered the situation and sulphur deficiency long forecast and demonstrated by the former Macaulay Institute has now been recognised. The clean-up of sulphur from generating station emissions and the decrease in use of fossil fuels should now be breaking through into sulphur deficiency symptoms in upland and other swards, showing up as reduced and less nutritive grass yields.

It is now well recognised in animal and human nutrition that trace element supply from soils and ground water is a vital and important factor. Sheep and cattle fed on cobalt deficient pastures generally show poor bodily development. Cattle fed on Cu-deficient pastures also show poor bodily development with characteristic symptoms of grey body hair, swollen joints and very poor reproductive fertility. The synergic effect of molybdenum-induced Cu deficiency is even more marked. Copper deficiency also occurs in humans and is sometimes an inherited syndrome as in Meinke's disease and zinc deficiency is not uncommon in some parts of the world.

It is perhaps less well known that some crops may also need trace element fertilisation. For example the cultivated oat *Avena sativa* grown on copper deficient soils - of which there are many - is a poor yielder. But the application of a small amount of copper sulphate to the soil, doubles the yield and the fertilisation effect can last as long as 20 years. It is sometimes pointed out that in other cases fertilisation with trace elements lasts only for a few years, for instance Se, 1-2 years, deficiency of which causes muscular dystrophy; Co, 2-4 years depending on the soil. This observation is curious since most farmers put tons of major fertilisers on to their fields every

	Removed in crop (kg/ha)	Total content in 20cm (kg/ha)
Se	0.00002	0.1-2
Co	0.001	2-100
Cu	0.1	2-200
Zn	0.2	20-500
Mn	0.5	100-10,000
K	100	5,000-50,000

Table 1. Amounts of trace elements removed from an arable soil by an average crop yielding 5 tha^{-1} compared with the estimated total content in the top 20cm of the same soil

year. However, the introduction of trace-element amended NPK fertilisers may now be providing the answer. It would appear that fertiliser manufacturers realise how they may get an edge on those of their competitors who do not use trace element amendment.

Table 1 on the preceding page shows the mineral elements, which an average crop yielding only 5 tons/ha will remove from the soil annually. It may be seen that continuous cropping can lead to deficiency in major elements such as P & K in a very short period of time and that there may be problems with some of the minor elements such as Co, Cu and Zn on a longer time-scale. A mass spectrometric study of the total element contents of 10 representative Scottish soils shows marked deficiencies in bioessential elements such as Cu and Co and intriguing enrichment

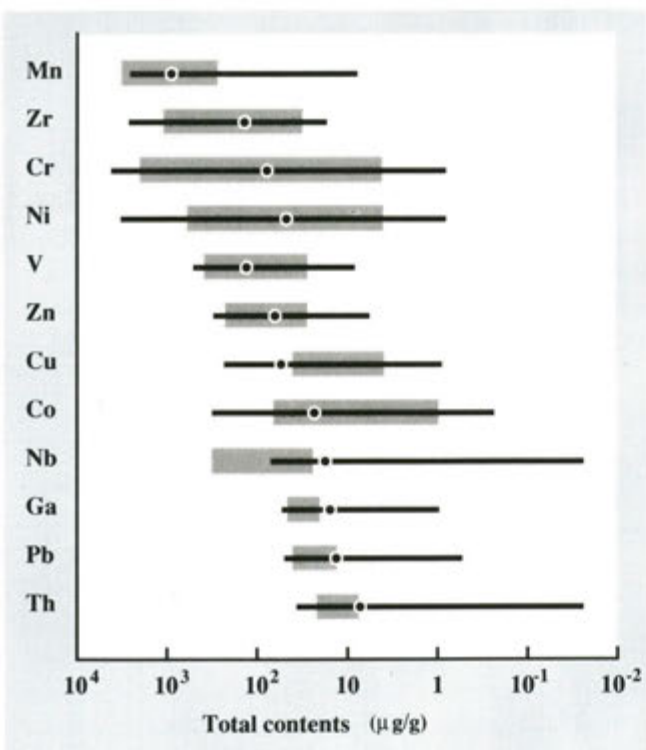


Figure 4. Range of 12 trace elements in 10 representative Scottish soils (rectangles) compared with the range (bars) and means (dots) in the earth's crustal rocks

of non-bioessential elements such as Nb, Ga, Pb and Th. The latter ions may perhaps be drawn up in the transpiration stream of the vegetation, not translocated above ground by the root, and they may be subsequently fixed by the organic matter in the upper horizons of the soil.

Quantity - Intensity Relationships

Of course it is not the total content of mineral elements in the soils that is of immediate importance to the growing plant or the grazing animal but that which is available in dissolved form or in colloidal solution in the soil water, (Figure 5). Most of the soil`s store of mineral nutrient is locked up in unavailable primary minerals which only release them over periods of tens of thousands of years. The material in the soil's secondary minerals may be released over a period of a few years or months. Those elements that are adsorbed on the surface of clay particles may, in contrast, be released over a period of days and thus become available to the plant in a growing season. The ions or colloids in solution are instantaneously available. This labile or instantaneous part of the total constitutes the intensity factor and simulating this interaction of the soil and the plant is one of the biggest problems facing the soil scientist.

Various techniques such as electro-ultrafiltration have been investigated but without much success. We still have to adopt an empirical procedure for chemical extraction.

However, the achievements of modern soil science over a fair number of years in research institutes such as the old Macaulay and Rothamsted and in the Universities have been considerable and I hope some impression of this has been conveyed.

At this point I would like to pay a special tribute to the work of the Soil Survey and the Peat Survey, work which is of absolute significance for the past, present and future success of research in soil science. They have categorised and classified virtually all the soils and peat deposits of the entire land mass of Scotland from the surface down to one metre wherever the soil depth has been sufficient. In conjunction with mineralogists and chemists they have made inventories of,

Parent Materials
Minerals
Major and Minor Nutrient Status
Organic Matter Content
Various Physical Properties

of Scotland's soils and produced soil maps which show where all the resources are. More recently they have begun to develop a comprehensive Soil Data Bank, a computerised inventory which can be accessed to produce an enormous wealth of information for a wide range of purposes from

agriculture to civil engineering and also for basic soil-related research.

This detailed knowledge of the chemical and physical properties of soils is supplemented by meterological and topographical information, it thus represents a very detailed account of what soils we have, where they are, how much there is and how they will behave. This achievement of the Soil Survey of Scotland and of the Peat Survey is scarcely equalled anywhere else in the world and provides soil research scientists in Scotland and Scottish agriculture with opportunities and prospects unequalled anywhere else.

Climatic maps have been produced, vegetation maps, peat maps, land capability for agriculture maps, land capability for forestry maps. And now with the enormous flexibility of the computerised data bank, the surveyors, in conjunction with their colleagues in soil chemistry and mineralogy, are able to produce single factor maps for characteristics such as soils suitable for direct drilling, cobalt maps, stoniness maps and so on.

The continuing presence of a strong, active and viable soil survey for Scotland has made possible most of the work I have been describing. In the future, faced with the new tasks of land use, its presence and vitality will be even more essential.

Several years ago the Peat Survey evolved a Unit of Remote Sensing which uses aerial photography, satellite imagery and the surveyor on the ground to produce a three level system for ground truthing and validating satellite imagery as a routine but enormously flexible tool for surveying all terrain features. This not only permits agricultural surveillance, but also monitors all other land uses including environmental aspects, and, allied to the other in-house capabilities of the Institute`s scientific disciplines has provided the new Macaulay with yet another enormously important, significant and flexible tool for research, development and everyday practical application.

Future Problems

Society is posing the soil scientist many complex new problems eg the disposal on land of urban sewage sludge and other urban wastes, industrial wastes, acid precipitation, radioactive fall out from nuclear power station incidents such as that from Chernobyl and the long term disposal of high-level radioactive wastes from the nuclear industry. We are aware of these problems but it is probable that the hills and uplands of the less densely populated areas of Northern Britain will face particularly difficult situations in this respect.

The agricultural industry itself is causing new problems for soil science - and here it is not so much the obvious ones of the disposal of sludge from intensive animal husbandry but rather some of the new cultivation practices that may cause severe problems.

The increasing use of monoculture, for example, means the intensive extraction of particular nutrients in the same fields year after year with none of the rest periods associated with rotation agriculture and with the varying demands of different crops not allowing particular nutrients to recover via theQuantity/ intensity mechanism outlined in Figure 5. Monoculture also tends to intensify problems from soil-borne diseases.

Minimum cultivation techniques further aggravate the problem though they may be more cost effective in the short term. However, decaying roots leave soil channels that next season`s roots will tend to use again and over a period of years there will be established a series of channels surrounded by zones of nutrient-deficient soils and those will no doubt be well colonised by root pathogens. Arable crops may suffer by having been bred not to depend on mycorrhizal associations, unlike long standing crops such as trees which have adapted to the problems.

There certainly was considerable wisdom in the policy of annual stirring of the soil through ploughing developed by our long departed forefathers.

The introduction of winter sown crops also

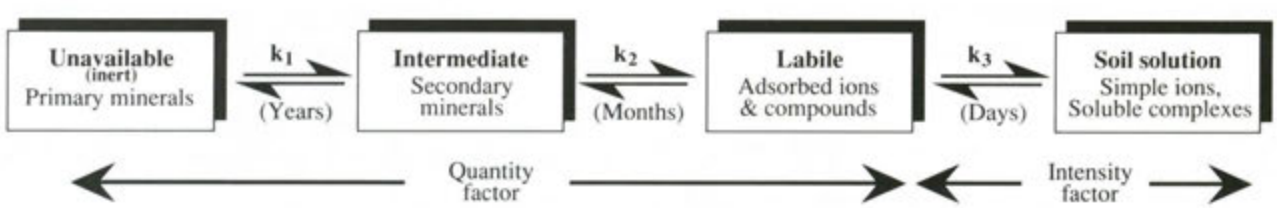


Figure 5. Availability of nutrient elements from the soil's store

places a greater demand on the soil for yet more nutrients and it is significant that already we recognize that generally, winter sown crops need even greater applications of major fertilisers - with all that that implies for the environment.

Conclusion

Soil Science has solved many problems in practical agriculture today and yesterday. It is a somewhat academic, intensive and extremely interesting and rewarding branch of scientific research which has a great deal to do with the planet being able to easily feed its steadily increasing population and improve the quality and quantity of life for man and animal alike.

It is, however, an apparently unspectacular type of science to the casual observer such as the modern breed of politician and perhaps even to Mr & Mrs John Public . It is also a long-term type of research that produces results that have little or no immediate shop window value and because it does not have the facility of immediacy of result it is not favoured in these days of pursuit of short term returns on investment in scientific research. Soil Science has been hit harder by recent reductions in expenditure than most other branches of scientific endeavour in the agricultural research sector. This is so short sighted that it must be regarded as sufficiently myopic perhaps for those in charge of science policy not to see the spectre of a planet which could mirror the desert image they fear from nuclear holocaust? The death of grass could be just as devastating. It is with us in too many small areas of the world at present.

However, *Homo sapiens* has always been a curiously versatile character, foolish and squandrous of life and precious resources in the short term but, to date at least, wise and intelligent in the long term. I am confident that in due course wiser counsels will prevail. To the beleaguered soil scientist at the present time in the gales of economic winter I would like to tender the advice given to me many years ago by an old North Sea fisherman,----"Don't bend with the wind, bend into it". The soil endures, so do those who work with it.

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Miss K.A. Robertson

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D.A. Elston B.Sc., M.Sc. (to Dec 1987)
G.Wetherill B.Sc., M.Sc. (from December 1987)

STAFF WHO HAVE LEFT MISR/MLURI SINCE PUBLICATION OF LAST ANNUAL REPORT

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R.E. Wheatley - 31.3.87
C.J. Wilkinson - 31.3.87

VISITING RESEARCH WORKERS

* Miss J.A. Armstrong, B.Sc., M.Sc. (Department of Forestry, University of Aberdeen)

Dr L. Battaglini, (Instituto di Zootecnica Speciale, Corso Svizzera, Italy)

Miss L. Crone, B.Sc. (Royal Commission of Ancient Monuments, Scotland)

* J.P.J. Dicks, B.Sc., Scotch Whisky Research Studentship

* M. Hayden, B.Sc. (Durham University)

* C. Hepp, Ing. Agr. (I.N.I.A., Chile)

* Miss P. Lynch, B.Sc. (Edinburgh University)

* R. McMahon, SWAP Studentship

Dr A. Mannelli, (Universita di Pisa, Pisa, Italy)

Dr W. Masayna, (Khon Kaen University, Thailand)

Dr A.R. Mantecon, (Universidad de Leon, Spain)

Dr P. Nadeau, (Dartmouth College, Hanover, New Hampshire, U.S.A)

Dr A. Nicol, (University College of Agriculture, Canterbury, New Zealand)

Dr G. Nielsen, (Agriculture Canada, Research Station, Summerland, B.C., Canada)

Dr D. Nielsen, (Agriculture Canada, Research Station, Summerland, B.C., Canada)

Dr K. Osoro-Otadui, (Centro de Experimentacion Agraria, Villaviciosa, Spain)

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Dr K.B. Zwart, (Institute for Soil Fertility, Haren, The Netherlands)

* Ph.D. Student

VISITS ABROAD

J. Anderson
Snowmelt Event Sampling, SWAP at Høylandet, Nord, Trøndelag, Norway, 30th April - 4th May 1987.

R.H. Armstrong
6th Meeting of the European Workshop, Rome, September 1987.

D. Atkinson
International Botanical Congress, Berlin, FDR, July 1987.
University of Michigan Biological Research Station, Pellston, Michigan, August, 1987.

D.C. Bain
6th Meeting of the European Clay Groups, Seville, Spain, 7-10 September, 1987.
Presentation at SWAP Weathering Seminar, Royal Institute of Technology, Stockholm, Sweden, 3-4 December, 1987.

J.R. Bacon
lst Meeting of the International Society for Trace Element Research in Humans, Palm Springs, California, USA, 8-12 December, 1986.
Laboratories of Dr J. Turnland, USDA, Albany and San Francisco, 15-16 December, 1986.

M.L. Berrow
European Community Bureau of Reference Meeting, Brussels, Belgium, 24-25 November, 1987.

J.M. Bracewell
Rapporteur at the International Dahlem Workshop on Humic Substances and their Role in the Environment, West Berlin, FDR, 29 March - 3 April, 1987.

S.J. Chapman
Lecture at the 8th International Symposium on Environmental Microbiology, Nancy, France, September, 1987.

J. Darbyshire
International Symposium on the Role of Organisms in Nitrogen Cycling, Perspectives and Challenges, Swedish University of Agricultural Sciences, Uppsala, Sweden, 9-12 June, 1987.

M. Davidson
Symposium on Advanced Techniques in Microscopy-Applications in Biological and Agricultural Research, Agricultural Research Centre, Melle, Ghent, Belgium, 12-13 May, 1987.

A. Edwards
Plant-Soil Interactions at low pH, Grande Prairie, Alberta, July, 1987.

R.C. Ferrier
Snowmelt event sampling, Høylandet, Nord, Trøndelag, Norway, 20th April - 4th May, 1987.
Soil Survey of event sampling, Høylandet, Nord, Trøndelag, Norway, 28th September - 10th October, 1987.

W.J. Hamilton
Lectures on Deer Farming, Irish Republic, April, 1987.

N. Hutchings
Riso Laboratories, Foulum Research Centre, Denmark.

D. Jones
Scanning Electron Microscopy Meeting, Hamilton, Ontario, 3rd - 8th May, 1987.

A. Lilly
Visit to CSIRO Division of Soils, Brisbane, Australia, 9th June 1987.
Lecture on the Soils and Land Capability of Scotland, CSIRO Division of Soils, Brisbane, Australia, 22nd June, 1987.
Fieldwork with CSIRO Division of Soils in northern NSW, 22-28 June.
Fieldwork, Brisbane, 3 July, 1987.
Visit to Land Resources Branch, Queensland Department of Primary Industries, Indooroopilly, Australia, 6 July, 1987.

A.E.S. Macklon
Poster presentation at 3rd International Symposium on Structure and Function of Roots, Nitra, Czechoslovakia, 3-7 August, 1987.

J. Miller
Field meeting at Høylandet, Nord, Trøndelag, Norway, September, 1987.

J.A. Milne
FAD/IAEA 2nd Research Coordination Meeting on Improving Sheep and Goat Productivity with the Use of Nuclear Techniques, Kuala Lumpur, Malaysia, 23-27 February, 1987.

P. Newbould
Conference on Ecology of Arable Land: the Role of Organisms in Nitrogen Cycling. Perspectives and Challenges, Uppsala, Sweden, 1987.

A.J.F. Russel
Second International Cashmere Conference, Lincoln College, New Zealand, May, 1987.
European Association of Animal Production Annual Meeting, Lisbon, Portugal, September, 1987.

A. Sibbald
Paper at Seminar Multiple Uses of Woody Species in the Arid Mediterranean Zones, Zaragossa, Spain, 25-26 September, 1987.

R.J. Thomas
Seminar on Diversity in Agriculture (Europe), Dept. of Agriculture, Brunei Darussalem, April, 1987.
Poster presentation at the International Symposium on Advances in N Cycling in Agricultural Ecosystems, CSIRO, Brisbane, Australia, 11-15 May, 1987.
Visit to CSIRO research stations in Queensland, April-May, 1987.
Seminars at Department of Soil Science, Lincoln College, Christchurch, and Department of Agronomy, Massey University/DSIR Palmerston North, New Zealand, May, 1987.
Visit to Whatawhata Hill Country Research Station, MAF Ruakura, Hamilton, New Zealand, April - May, 1987.

D. Vaughan
Visits to Institut für Radioagronomie, Jülich, Bodentechnologisches Institut, Bremen, Bundesanstalt für Geowissenshaften, Hannover, Institut für Pflanzenernahrung, Braunschweig, FDR, 24-29 September, 1987.

M.J. Wilson
S.W.A.P. Mid-term Conference, Bergen, Norway, 22-26 June, 1987.
6th Meeting of European Clay Groups, Seville, Spain, 7-10 September, 1987.

I.A. Wright
Paper at Annual Meeting of L'Association Francais pour la Production Fourrageres, Paris, France, March 1987.

STAFF ACTIVITIES

R.H. Armstrong
Member of British Standards Institute Committee (LEL/105/1) on electric fencing.

R. Aspinall
Member of Biogeography Study Group Committee of the Institute of British Geographers.

D. Atkinson
Vice-Chairman of the Programme Committee of the 1987 British Crop Protection Conference.
Member of the Committee of SCI Agriculture Group.
Member of the Editorial Board of 'Plant and Soil', 'Tree Physiology' and 'Communications in Soil Science and Plant Analysis'.

D.C. Bain
Honorary Secretary of the Clay Minerals Group of the Mineralogical Society.
Assistant Editor of 'Clay Minerals'.

M.L. Berrow
Technical Secretary of DAFS Consultative Committee for the Development of Spectrochemical Work.
Working Group 4 member of DOE Standing Committee of Analysts.
DAFS representative on DOE Potentially Toxic Elements sub-committee on the Use of Sewage Sludge on Agricultural Land.
Honorary Research Associate, University of Aberdeen. Member of Technical Programme Committee, 3rd International Conference on Environmental Contamination.
Member of Scientific Committee of lst Soil Residue Analysis Workshop, Winnipeg, Canada.
Member of MISR/COSAG Liaison Group.

R.V. Birnie
Member of Land Applications Panel.
Columbus Utilisation Research Fellow in Geography at the University of Aberdeen.
Honorary Lecturer in Physics at the University of Dundee.

C.J. Bown
Member of BSI sub-committee EPC/48/1-terminology and classification, EPC/48/2-sampling, of technical committee EPC/48 on soil quality.
Member of the Organising Committee of BSSS autumn field meeting, held at the West of Scotland Agricultural College, Ayr.

J.M. Bracewell
Associate editor of the 'Journal of Analytical and Applied Pyrolysis.
Member of the AFRC Spectrometry Panel.

J.C. Burridge
Chairman of the Association of Scottish Industrial Analysts.
Member of editorial board of 'Atomic Spectrometry Updates' and the 'Journal of Environmental Science and Health. Part A'.

M.V. Cheshire
Member of the advisory editorial board of the 'Journal of Soil Science'.
Honorary Research Associate of the University of Aberdeen.

J. Darbyshire
Member of BSI committee on biological methods for determining soil quality.

L. Dawson
Member of the British Soil Science Grants Committee.

C.C. Evans
Member of DAFS Consultative Committee for the Development of Spectrochemical Work.
Member of Committee and Working Party on Trace Element Dose Response Trials.

R.C. Ferrier
Project reviewer for the National Science Foundation, USA.

B.A. Goodman
Member of committee of Mossbauer Discussion Group, Royal Society of Chemistry.

S.A. Grant
Associate Editor of 'Grass and Forage Science'.
Member of the Steering Committee of the Reconciliation Project.

R.G. Gunn
Honorary Secretary of the British Society of Animal Production.

W.J. Hamilton
Member of Morvern Deer Management Group.
Member of East Grampian Deer Management Group.
Member of the Council of the British Deer Farmers Association.

P.D. Hulme
Member of Organising Committee of International Peat Society/British Ecological Society symposium 'Peatland Ecosystems and Man - an impact assessment.

A.E.S. Macklon
Honorary Research Associate, University of Aberdeen. Referee for 'Physiologia Plantarum', 'Journal of Experimental Botany', and 'Plant, Cell and Environment'.

T.J. Maxwell
Chairman of SCPA
Member of SARDAC
Member of DAFS Hill Farming Advisory Committee
Convenor of ACLU
Member of Joint Management Board, DAFS.

J.A. Milne
Associate Editor of the 'British Journal of Nutrition'.
Chairman of Programmes Committee, British Society of Animal Production.

D.L. Nelson
Vice-Chairman, North of Scotland Grassland Society.
Chairman of Mearns District Agricultural Training Board Group.
Committee Member of Howe of Mearns Agricultural Discussion Society.

P. Newbould
General Secretary of the Association of Applied Biologists.
Member of the Editorial Boards of the 'Journal of the Science of Food and Agriculture', 'Agricultural Systems, 'Fourcages'.
Member of the Board of Management of ECRE.
Member of the Post Graduate Committee, ESA.
Member of the Scientific Advisory Committee for a Swedish project 'Ecology of Arable Land - the Role of Organisms in Nitrogen Cycling'.
Member of the Executive Committee of SPALDA.

M.F. Proe
Member of International Energy Agency/Bioenergy Agreement Project A3.
Member of committee on 'Nutritional Consequences of Intensive Forest Harvesting on Site Productivity'. U.K. Technical Group Contact.

STAFF ACTIVITIES

A.J.F. Russel
Vice-President, then President of the British Society of Animal Production.
Consultant to MAFF Chief Scientist's Review Group 'N Crops and Animal Enterprises'.
Member of Technical Committee on Responses to Nutrients (Goats).
Member of the Board of Directors, Cashmere Breeders Ltd.
Member of the Council of the British Boer Goat Society.
Member of Editorial Boards of 'International Sheep and Goat Science', and 'Small Ruminant Research'.

J.D. Russell
Associate Editor of 'Clays and Clay Minerals'.

B. Sharp
Member of the Editorial Boards of the 'Journal of Analytical Atomic Spectrometry', 'Spectrochimica Acta, B', 'Atomic Spectrometry Updates'.
Member of the DoE Standing Committee of Analysts, Working Group 4.

W. Shirreffs
Council member (Publicity Officer) of the British Cartographic Society.
Jury member for BCS John Bartholomew Award.

A. Sibbald
Secretary of Agroforestry Research U.K. Discussion Forum.
Secretary of the Research Councils and Treasury Supported Users Group, Edinburgh University Computing Service.

R.J. Thomas
Reviewer for USDA Competitive Grants Committee, N fixation section.

M.J. Wilson
Chairman, Clay Minerals Group, Mineralogical Society.
Council Member of the British Society of Soil Science.
Member of the Editorial Boards of 'Clay Minerals' and 'Applied Clay Science'.
Honorary Research Associate of the University of Aberdeen.
Elected Fellow of the Royal Society of Edinburgh.

PROGRAMME OF WORK 1988-1989

Programme Units and Research Objectives 1988-89

The programme of research which is primarily concerned with land use in the hill, upland and marginal areas is being developed under four main themes.

The first theme concerns land use assessment, evaluation, monitoring, the production of relational database information systems, production system modelling and validation, land use modelling, and related socioeconomic issues.

The second theme is concerned with environmental issues; the impact of external pollutants on agriculture and forestry and of agricultural and forestry management practices on long-term soil stewardship, vegetation and landscape will be investigated.

The third theme is concerned with developing systems of land management related to agriculture, forestry and farm forestry. These include systems concerning the use of sheep, cattle, deer, goats and camelids.

The fourth theme is concerned with improving the efficiency of the components of production systems and includes strategic research; on plant nutrient supply from soils; trace elements and heavy metals; plant nutrient uptake, growth and production; vegetation dynamics; grazing and foraging behaviour of animals; energy expenditure of animals and the effects of shelter on animals; reproduction; nutrient partition; growth and carcass composition and animal fibre production.

The Research Objectives (RO's) of the programme of research are organised within 9 Programme Units (PU's) the first eight of which are funded by the Department of Agriculture and Fisheries for Scotland (DAFS) and the ninth by a range of outside contracts.

01 Land resources and information systems

BACKGROUND

Factual descriptions and information of the land resources and land uses of Scotland will be obtained. Data will be collected on soils, vegetation and climate. Landscape evaluation techniques, improved methods of data acquisition and organisation, the statistical handling of data for interpretive and classification purposes, and a relational database will be developed. The PU provides the basic resource information and a context for research on land use modelling and systems research (PU 02), the environment (PU 03), soils (PU 04), plants (PU 05) and vegetation dynamics and grazing ecology (PU 06). It will improve understanding of inter-relationships between the components of land use systems. Importantly it adds the locational element that allows research findings to be used to aid land stewardship, errors in which are costly and damage the environment. Research assists management of assets in public and private sectors.

RESEARCH OBJECTIVES

Survey and sampling of soil and peat

(a) Surveys of mineral and organic soils.

Important agricultural areas in the uplands remain unsurveyed at an adequate scale. Baseline information for other research areas is a priority, both to explain variance and project results.
(b) Characterise the spatial and temporal variation in soil and environmental properties by geostatistical methods.

Soil maps now define small/medium scale property distributions. Within this framework geostatistical concepts will develop an economical sampling strategy and ensure sound data for detailed modelling applications expressing local and experimental site variance.
(c) Quantification of soil structure in relation to land use studies.

Soil structure has been assessed in field studies for many years. Validation of field observations by laboratory measurement is necessary, however, particularly to assess the robustness of various structures to differing land use.
(d) Quantification of the soil water regime with respect to its spatial and temporal variability.

Profile of soil moisture content throughout the year characterises soil and is crucial in determining land use patterns. The research seeks quantification of the resource and understanding of temporal variation.

Climate

(e) Compilation and development of an integrated climatic databank for Scotland.

Soil physical conditions and climate are closely related. In common with current EEC trends, this research concentrates on elucidating the agricultural significance of climatic and soil parameter interaction.

Vegetation

(f) To create a database of the distribution and agronomic significance of the major indigenous plant communities.
(g) Development and application of multi-level remote sensing techniques for assessing and monitoring vegetation biomass.

Semi-natural vegetation forms the major resource of almost 70% of Scotland's surface area. Two research objectives concentrate on (1) the nature and distribution of the resource and (2) quantification of biomass.

Land use change

(h) Evaluation of hill and upland landscapes.

Visual appearance of the countryside is of major importance. Researching landscape perceptions has significance for agriculturalists, conservationists and tourism (£1600M in 1986).
(i) To assemble a database on the soils, vegetation and physical character of the Scottish Environmentally Sensitive Areas.

Database assembly for Environmentally Sensitive Areas in Scotland is needed to enable progress to be monitored and land use effects assessed.
(j) Methodology for monitoring rural land use change.
(k) Development and application of a land use monitoring system based on statistical analysis of satellite imagery.

Although several attempts have been made to monitor land use change, methods are disputed and results in question. Research is intended to improve this situation, both methodologically and mechanistically.

Land use information systems

(l) Develop an integrated multi-level information system within a relational database structure.

Data storage and manipulation techniques are essential in examination of relationships within and between information sets. All data collection will focus on the development of a relational database using ORACLE and the VAX 3600 computer.

02 Land use systems and socio economics

BACKGROUND

To provide an objective basis for land use assessment, management and planning involves the integration of information and knowledge from PU 01 and PU 03, with the understanding derived from strategic research on soils (PU 04), plants (PU 05), vegetation dynamics and grazing ecology (PU 06), and the nutrition and production of grazing animals (PUs 07 and 08). This requires the development and testing of production systems and land use models; it also includes evaluating the socioeconomic and environmental consequences of land use options, and the impact of policy objectives on land use.

RESEARCH OBJECTIVES

Land use assessment

(a) Research and development of land evaluation systems.

Land evaluation seeks to compare the requirements of specific land uses with the physical and biological characteristics of land. Systems of land evaluation selecting options for a range of land uses are valuable tools in rural planning.

Modelling and testing production systems

Methods of developing land use potential identified above involve systems research, including model construction and field testing. Linking physical outputs and economic performance, systems research tests and evaluates knowledge emerging from strategic research in whole systems of production.
(b) Test and model hill sheep production systems.

Improvement of low input hill sheep production systems will enable agricultural populations to be sustained and the countryside to be better managed for landscape and conservation objectives.
(c) Test and model upland sheep production systems.
(d) Test and model upland cattle production systems.

The use of resources on upland farms require to be maximised in high or low intensity systems tailored to farm requirements for sheep and cattle.
(e) Test and model silvopastoral production systems.

Use of spaced trees as a form of productive diversification in upland sheep and cattle systems requires evaluation.

Evaluation of land use options

Within biological system frameworks, potential for diversification is dependent upon the availability of capital and labour. Diversification options will be evaluated for their impact on socioeconomy of land units. Information will be of value in formulation of support and incentive schemes.

1. Farm scale objectives

(f) Model the consequences of land use decisions with respect to farming and forestry in hill and upland areas.

Existing models of farm forestry will be enhanced to represent upland as well as hill farming conditions and calculation of labour requirement and cash flow.
(g) Determine the potential for and the economic effects of diversification on hill and upland farms.

Traditional farm enterprises can be described in terms of input of land, labour and capital. The potential for enterprise diversification depends upon the extent to which these resources can be diverted and distributed both in time and space throughout an annual production cycle to accommodate alternatives.

2. Regional policy objectives

(h) Develop and test a geographic information system for predicting land use mixes at a regional scale.

Systems of identifying significant data combinations within a spatial matrix are required. GIS methodology is being developed using an administrative region as a test area. (DAFS-IFS funded research).
(i) Model land use implications of alternative scenarios for farm incomes with reference to loss of farmland to forestry.

Economic and yield data are being assessed within a matrix stratified by land type determined from the soil data sets and maps. (DAFS-IFS funded research).
(j) Model the economic and social consequences of alternative land use policy objectives.

National policies are designed to influence land use by using either planning legislation, or statutory and fiscal controls. There is a need to provide more precise estimates of the effects of the introduction of a range of potential policy objectives designed to influence land use, on economics and employment in rural areas.

3. Environmental impacts

(k) Physical impact assessment of land use change in rural areas.

Increased multipurpose use of the countryside has visual impacts and longer term effects on resources. New methods of assessing environmental impact assessment may be possible using multidimensional techniques.
(l) The impact of changes in land use in scenic upland areas on soil, vegetation, wildlife and landscape.

The effects of countryside change are being assessed with ITE Banchory. (DAFS-IFS funded research).

03 Land use, land use change, soil conservation and pollution

BACKGROUND

As a result of the over-production of a number of agricultural commodities, it is inevitable that land will be taken out of agricultural production and put to alternative use. In the hills and uplands there is likely to be a further increase in the land devoted to timber production. The research in this PU will assess and predict the likely consequences of changes in land use on soil and water quality. In addition, the separate but possibly interacting effects of external pollutants from the atmosphere and as a result of waste disposal, will be investigated.

PROGRAMME OF WORK 1988-1989

RESEARCH OBJECTIVES

Impact of land use and land use change on soils and waters

(a) Determine inputs and outputs at a series of long-term environmental monitoring sites.

It may be anticipated that changed land use in the hills and uplands will impinge upon soil properties, nutrient supply and hydrology, but for the effects to be fully understood it is necessary that long-term base line input/output data are acquired, both as a means of identifying and assessing short-term variations and of providing background information for other research objectives.
(b) Quantify the effects of different land uses on hydrology and hydro-chemistry.

Research is aimed at quantifying the effects of pasture improvement, afforestation and clear-felling, and agroforestry (see PU 9 RO c) on surface water quality in a variety of easily manipulated sites. The effects of vegetation and soil on the chemistry and volume of throughput waters will enable clarification of the processes involved.
(c) Determine the effects of afforestation of blanket peat on water quality.

The expansion of forestry on to the deep blanket peat of Sutherland and Caithness has aroused fears that stream water quality will deteriorate and that fish stocks will decline or disappear. There is, however, little information available as to whether stream water acidification is inevitable in these circumstances and, in conjunction with the Forestry Commission, the effects of peatland afforestation in the associated surface water network will be monitored at Rumster in Caithness.
(d) Assess the effects of drainage on the vegetation, structure and hydrology of peat soils.

A related study will attempt to quantify the effects of drainage on the peat itself, in order to determine the extent and rate of change in its structure, surface morphology and vegetation, as well as the hydrological implications.
(e) Determine the ameliorating effects of selective liming on acidified catchments.

The amelioration of acidified forested catchments by liming would be prohibitively expensive if applications had to be made over extensive areas. However, heavy applications to selected stream source areas could be a much more cost-effective procedure and it is proposed to determine the practicability of this treatment in an already acidified catchment where the dominant vegetation type is Sitka spruce growing on peaty soils.

Soil Conservation

The choice of future land use options must take soil conservation factors into account, so that the full cost and consequences of proposed changes, which may ultimately include land rehabilitation, can be more precisely established. Soil erosion not only reduces productivity on the sites where it occurs but through sediment damage can result in deleterious effects much further afield.
(f) Determine long-term changes in soil conditions under defined systems of land use.

The physical, chemical and biological characteristics of soils are continuously evolving, so that it will be necessary to obtain first a set of base-line data from representative hill and upland sites under long-established land use regimes. The effects upon the soil that are brought about by changes in agricultural and forestry practices can then be more easily evaluated.
(g) Soil wettability and its influence on erosion and run-off losses in hill and upland soils.

A particular problem in the uplands is that soils that are disturbed by cultivation prior to afforestation or by vegetation burning may become unstable, leading to the risk of erosion. The increased suspended material in run-off waters represents a loss of potential nutrients from the soil as well as a threat to water quality. A factor not previously investigated, and which may be important in the relationship between infiltration and run-off, is the water repellancy of organic matter.

Heavy Metals and Waste Disposal

The pollution of soils by the disposal of heavy metal-contaminated wastes at particular sites, remains a source of public concern. There is a need to quantify the amounts of heavy metals that are accumulating in different types of soils, to understand the factors that control their movement within ecosystems, and to develop ways and means of disposing of metal-contaminated wastes more safely.
(h) Identify forms of metals in industrial and farm wastes and characterise their reactions with organic absorbents.

The safe disposal of heavy metal-contaminated wastes depends upon a full understanding of the processes involved in the retention or mobilization of the heavy metals. Strategic research is required into the ways that these metals react with and are absorbed on the organic components of soils and associated materials.
(i) Assess the retention or movement of heavy metals in polluted soils and their availability to herbage.

Concomitant with this work will be the setting up of field experiments aimed at understanding the fate of various heavy metals within the ecosystem, and in particular the relative quantities retained within the soil, taken up by herbage or lost to groundwaters.
(j) Identify soil types appropriate for the disposal of sewage, farm animal and industrial wastes.

Insufficient consideration has been given to the type of soil on which waste applications are made. The long-term effects on soils need to be clarified so that suitable guidelines with respect to the selection of soil types suitable for this kind of waste disposal can be formulated. The information derived from the above two ROs will allow the long-term effects of waste disposal to be more clearly defined.
(k) Devise means for the use of farm, sewage and distillery wastes in different production systems.

Attempts will also be made to devise novel methods, using widely available, inexpensive organic materials, to reduce the harmful effects of heavy metal-contaminated wastes, so enabling them to be more effectively used as nitrogen and phosphorus fertilisers in agricultural or forestry production systems.

Atmospheric Pollution in the Hills and Uplands

The possible widespread and persistent pollution of soils and vegetation by pervasive atmospheric deposition of heavy metals, particularly lead, from industrial emissions or vehicle exhausts, of organic pollutants, such as polychlorinated biphenyls (PCBs) from industrial wastes, or of radiocaesium from atomic weapons tests, or accidental and controlled release, remains an area of serious public concern. These pollutants may be extensively distributed in upland ecosystems, where they are associated initially with soil organic matter and, through plant uptake, accumulate at higher trophic levels of food chains.
(l) Characterise the amounts and sources of lead deposited from the atmosphere.

Previous studies have shown that high concentrations of lead can occur in the top soils of the Scottish uplands, but the relative roles of natural geochemical cycling versus inputs from atmospheric sources have not been established. Such a differentiation can be made, however, by isotopic methods, and the proposed study should provide an unambiguous indication of the extent to which upland soils are being contaminated by aerial pollution.
(m) Examine prevalence, distribution, fate and significance of poly-chlorinated biphenyl congeners in hill and upland environments.

The uplands may be particularly susceptible to soil accumulations of PCBs because of higher rain washout, lower turnover and greater absorption efficiency by peaty organic matter. There is therefore a requirement to examine the actual concentrations of organic pollutants such as PCBs in the upland environment and to investigate their fate.
(n) Effect of organic matter content of soil on the cycling of radio-caesium and its availability to various upland plant species.
(o) Factors affecting the uptake of radiocaesium by sheep.

Models have been developed to predict the transfer of radiocaesium to ruminant tissues. However such models have recently been demonstrated to be inadequate. In order to improve the models, more information is required on the significance of different pathways of radiocaesium transfers between the soil, plant and animal. Furthermore, a greater understanding of the factors affecting caesium in sheep metabolism is necessary. The work proposed is done in conjunction with research contracts funded by NERC, MAFF and CEGB.

04 Plant nutrient supply from soils

BACKGROUND

The objective of the programme is to determine the quantities, rates and times at which nutrients are released from the relatively infertile soils of the hills and uplands so that the sustainability of the supply of nutrients from different soils can be assessed and any inputs of fertiliser to improve plant production can be used more efficiently. In the hills and uplands a large proportion of the important plant nutrients is locked up within soil organic matter. The availability of nutrients, especially nitrogen, phosphorus and sulphur is, therefore, very dependent upon the rate at which this material decomposes. The PU will aim to characterise the size and nature of the pools of these elements, to identify the processes that govern nutrient transfer, and to quantify the rates at which these processes occur within different soil types. The factors determining the availability of trace elements, and ways of ameliorating deficiencies will also be investigated, as will the effects of mineral weathering, ion-exchange and acidification on nutrient supply.

RESEARCH OBJECTIVES

Carbon Turnover

(a) Quantify the relationship between carbon turnover and availability of N, P, S and other nutrients.

Organic matter is an especially important source of nitrogen, phosphorus and sulphur on the acid, wet soils of hill and upland areas which receive little or no fertiliser inputs. The rate of release of these nutrients depends on the rate of transformation and oxidation of organic matter, most of the transformations being mediated by micro-organisms. The release of even a small fraction of these nutrients would significantly raise the overall level of fertility of the land.
(b) Influence of chemical structure and soil conditions on the decomposition rates of plant residues and soil micro-organisms.

Knowledge of the mechanism of mineralisation would be essential in understanding how to harness these reserves in plant production and would also greatly aid the formulation of nutrient cycling models.

These ROs underpin work in PU 05 which involve the effects of uptake of major nutrients by plants from the soil (for example ROs a, c, d and e).

Nitrogen Turnover

Accurate predictions concerning the mineralisation of organic N to plant available forms are essential to an understanding of how to make more efficient use of the levels of fertiliser N that are likely to be justified for hill and upland plant production. Even where fertiliser-N inputs are low or absent, as in rough grazing and in conventional or on-farm forestry, the effects of management practices on N-mineralisation are only poorly understood. A series of interrelated research objectives is proposed to quantify the nitrogen pool in hill and upland soils, the rates at which this pool is mineralised by soil micro-organisms, including protozoa and nematodes, the rate of N transfer from N-fixing plants to other species and the possibility of enzyme-mineral interactions in reducing N availability in mineral soil pastures. Many of these ROs will provide information that can be used in modelling work on N cycling (PU 05 RO n).
(c) Role of organic forms of N in providing mineral N for plant growth.

Quantification of the predominant active forms of organic N and understanding of the dynamic processes governing these pools will increase the prospects of being able to manipulate the soil nitrogen reserves and of managing the supply of available N in a range of land uses and management practices.
(d) Nitrogen flux through soil microbial biomass in upland grass and tree production systems.

Both the processes of mineralisation of soil organic matter-N and the immobilisation of inorganic N from the soil solution involve the flux of N

through the soil microbial flora. Microbial biomass N is considered to constitute a relatively labile form of organic N and is potentially available to plants. It will be important, therefore, to quantify the size of this pool and the flux through it.
(e) Importance of soil protozoa, nematodes and earthworms in the mineralisation of N from soil organic matter.

Recent research suggests that protozoa and nematodes in soils can make important contributions to nitrogen fluxes in many ecosystems by their excretion and their feeding on soil microflora. Earthworms are also known to influence the mineralisation of N but the mechanisms involved are uncertain.
(f) Decomposition of nodules, roots and stolons of nitrogen-fixing plants and the release of biologically-fixed nitrogen.

The release of nitrogen from N-fixing plants followed by transfer to other species is a flux of great agricultural significance, but there are as yet few reliable estimates of this flux that could be used in simulation models.
(g) Interaction between soil enzymes and clay minerals in relation to nitrogen availability in pastures.

Soil enzymes play a key role in breaking down N-containing organic materials into forms which are readily available for plant uptake and utilisation. Associations of enzymes with clay minerals could modify their activities and lead to sorption and immobilization of their breakdown products. Mineral soils in upland Scotland contain clay minerals capable of actively absorbing enzymes, and have been found to immobilise major fractions of applied N. Research is required to determine the extent to which these observations are linked.

Phosphorus Turnover

The amounts of phosphate available for absorption by plants are extremely low in hill and upland sites. P fertiliser is a finite resource and is relatively expensive. Thus, it is necessary to use the small amount of available P well and to use the amount applied as fertiliser with optimum efficiency to benefit the growth of legumes in particular, but also grasses and possibly trees, and to avoid escapes to water which could be environmentally damaging. Information is needed on the sources, sinks and transfer processes affecting P in soils and the factors influencing these, so that biologically efficient and environmentally kind strategies for the use of P fertiliser can be devised. Research in this group of ROs will focus upon the organic and mineral P status of hill and upland soils and on the effects of grazing and leaching on P dynamics and cycling, aspects that will relate directly to plant uptake of P in PU 05, ROs c and d. A more quantitative understanding of the transfer processes involved will result from concomitant research into ion exchange (ROs q and r) and microbial weathering (RO t) phenomena.
(h) Phosphorus dynamics in soil organic matter and microbial biomass.

In highly organic soils with intrinsically low P, the supply to plants depends largely on the mineralisation of organic matter. Microbial biomass, which can contain as much as 30% of total P is regarded as a source of available P and as a sink for residual fertiliser phosphate. Quantitative information is required on the rate of P mineralisation and the dynamics of microbial P under different soil conditions and management regimes.
(i) Soil factors influencing the availability of phosphorus.

The availability of phosphorus is related to a variety of soil factors, but particularly to soil type, pH and initial P status. It is important that these factors are quantified so that the P that is actually available for plant uptake over a range of soil types and chemical characteristics can be more readily assessed.
(j) Comparison of soil P dynamics between areas of indigenous and improved vegetation on grazed organic-rich soils.

The possibility for increased retention of P as a result of greater plant uptake and higher nutrient cycling, including return of waste from grazing animals on grazed sites with indigenous or improved vegetation requires investigation. The net effects of these processes in upland soils need to be more closely defined.

Sulphur

Most sulphur in hill and upland soils is associated with the organic fraction and in areas of low atmospheric input, the mineralisation-immobilisation cycle which is driven by microbial activity, will control the rate of supply of sulphur for plant growth. Even in areas with considerable atmospheric sulphur inputs, the S-status of topsoils can be unsatisfactory. Areas of sulphur deficiency have been reported in certain areas of Scotland and yield responses of herbage to S applications have been noted. An assessment of the general situation requires more comprehensive data on the S-status of organic soils, combined with further quantitative information on atmospheric inputs and soil translocation losses.
(k) Assess the sulphur status of soils in the hills and uplands and the effect of this and applied S on plant growth.

The ability of organic soils to provide plant available S will be evaluated, so that in S-deficient areas the effectiveness of various forms of fertilisers can be assessed.
(l) Quantify atmospheric inputs and leaching losses of sulphur and other elements in hill and upland pastures.

Central to this work will be the concurrent quantitative determination of atmospheric S inputs, in both wet and dry deposited forms, taking seasonality factors into account. Calculation of detailed sulphur budgets will also be useful in studies of surface water acidification, because sulphate is thought to act as a mobile anion that effectively transfers H ions from soils to surface waters.

Trace Elements

Several trace elements in hill and upland pastures have been shown to be in short supply and to limit animal performance, with significant consequences for animal health and loss to the industry (around £10 million per year in Scotland). Cobalt and copper deficiencies are quite common, particularly in sheep confined to improved reseeded pastures, and selenium deficiency can lead to various clinical and sub-clinical disorders resulting in the loss of animal production. The aim of this group of research objectives is to characterise

the soil factors controlling trace element release, to devise and test ways of improving the cobalt and selenium contents of herbage in deficient areas and to develop a soil-plant trace element database (from existing information) that can be used to model the effects of management practices on trace element cycling.
(m) Investigate factors which affect trace element contents of hill and upland sown pastures in relation to nutrient supply to animals.

Increased levels of herbage production brought about by pasture improvement can cause trace element deficiencies. It is important to investigate the soil factors responsible for the release of Cu, Co and Mo in a variety of hill and upland environments, and to quantify uptake by herbage throughout the growing season, so that strategies can be adopted that either avoid or ameliorate deficiency symptoms.
(n) Determine factors controlling the availability of selenium from soils to plants.

It has been calculated that one tenth of Scotland's land area, much of it rough hill grazing, is mildly deficient in selenium , and pastures and fodders grown in these areas will contain insufficient selenium for animal health. Soil treatment can increase the selenium content of herbage but the margin between deficiency and toxicity is narrow. There is a need to devise a slow-release form of selenium suitable for application to soils, and to develop soil tests enabling identification of those soils that produce selenium-deficient herbage.
(o) Investigate ways of extending the persistence in plant-available forms of cobalt applied to deficient mineral soils.

Similarly, cobalt-deficient pastures are wide-spread in Scotland and although this situation may be ameliorated by the application of cobalt sulphate solutions to the soil, the cobalt generally becomes immobilised and unavailable to plants within a few years. Even for this limited effect, unnecessarily high cobalt contents have to be accepted in first year herbage. Methods are sought to extend the period for which applied cobalt is available to plants, so enabling soil treatment costs to be reduced.
(p) Development of relationships between trace element status of soils and plants and management practices.

The construction of a relational database on soil-plant trace element contents from well-defined field experimentation conducted over a period of 40 years, should enable the effects of management practices to be identified and could lead to a reduction in input costs.

Ion Exchange

The concentration and mobility of nutrient ions in soil solution is largely controlled by the partition of solutes between aqueous and solid phases. In combination with rates of water movement, this partition also controls leaching from the root zone to sub-soils and ultimately to surface waters. Two complementary research objectives will investigate nutrient dynamics between the liquid and solid phases and will relate to work on phosphorus turnover (ROs h, i, j) and plant uptake (PU 05 ROs c and d).
(q) Dynamics of nutrient status in soil solutions in relation to water potential, soil pore size and root growth.

The availability of nutrients to plant roots is governed largely by the chemical activity of the nutrients in the rhizosphere solution as modified by ion exchange and soil hydrology. The composition of soil solutions will be examined in relation to root development in grass/clover swards, soil hydrology and pore size distribution, with particular emphasis on wetting/drying cycles.
(r) Distribution of exchangeable nutrient ions between organic and inorganic components of upland soils.

The exchange and sorption characteristics of upland soils with respect to major organic and inorganic components exert a major influence on the mobility of nutrients and their availability to plants. The partition of phosphate and ammonium ions between these components will be studied so that fertiliser strategies, as well as potential hazards to ground water quality following heavy fertiliser applications during land use changes, can be more critically evaluated. The information obtained will relate directly to ROs h and i.

Mineral Weathering

A full understanding of terrestrial nutrient cycling requires knowledge and quantification of the processes involved in the release of mineral nutrients from inorganic soil components, particularly by microbial action, and the rates at which these processes operate. The primary aim is to quantify the release of P, K, Ca and Mg from decomposing soil and fertiliser minerals on different types of hill and upland mineral soils. Another important aspect of the mineral status of the hill and upland environment is the rate at which nutrients are removed by podzolisation processes under different vegetation.
(s) Inorganic nutrient inputs from mineral weathering in hill and upland ecosystems.

The precise role of the weathering of soil minerals as direct nutrient inputs to soils and plants on a short-term basis need to be assessed. The amounts and rates at which Ca and Mg are released and taken up by herbage during different times of the year will be calculated.
(t) Quantify the release of mineral nutrients from hill and upland soils by microorganisms.

P, K, Ca and Mg may be directly solubilised by the microbial decomposition of minerals in the nutrient-deficient hill and upland environment, although the mechanisms involved and the rates of release are unknown. Particularly active organisms will be sought so that they can be used as innoculants of selected plants that can better utilise the upland environment.
(u) Influence of different plant communities and their litter on translocation processes in upland soils.

Podzolisation is the major soil-forming process in the hills and uplands and results directly in the impoverishment of mineral nutrients in surface horizons. However, the process proceeds at different rates according to the dominant vegetation, and some plants may even be capable of reversing podzolisation.

Experiments will be made, aimed at quantifying podzolisation rates under different plant communities. This will enable the most appropriate decisions to be taken where a change of land use involving

vegetation change is envisaged.

Proton Turnover

Soil acidity is one of the major limitations to pasture production in the hill and upland areas of Britain. Low soil pH levels influence plant growth directly by affecting the mobility and plant availability of nutrients such as phosphate and by increasing the levels of toxic elements like aluminium. This group of research objectives addresses questions concerning the proton balance of hill and upland soils in relation to plant productivity, the role of organic matter in acidifying soil and transferring this acidity to surface waters, and the possible exacerbating effects of atmospheric acidic inputs in the form of "acid rain" in lowering soil pH.
(v) Assess the role of individual soil properties on the relationship between soil acidity and aluminium.

High exchangeable aluminium levels in soils can restrict root development and can severely disrupt the nutritional and plant uptake aspects of certain elements such as phosphorus. However, there is a need to increase understanding of the relationship between soil type, aluminium concentration and pH, because the pH values at which plant problems develop vary widely. The quantity of lime necessary to maintain the pH of a soil rised sharply with an increase in the required pH, so that it is important to understand what actually is an adequate soil pH.
(w) Assess the organic contribution to the acidity of soils and surface waters in hill and upland sites.

Isolation and characterisation of organic acids from soils and drainage waters will allow an assessment of their contribution to soil acidification in organic topsoils. Knowledge of the seasonal variations of these acids under different management regimes could benefit the timing of fertiliser inputs especially if nitrogen applications coincide with high organic anion contents and result in accelerated nitrate leaching.
(x) Assess the extent of acidification of Scottish soils in hill, upland and marginal areas in recent decades.

It has long been assumed that the inherent buffering capacity of soils ensured their virtual invulnerability to the effects of acid deposition but studies in certain areas of Europe, based on comparisons of modern and historical data, show that this assumption may not be justifiable. These studies suggest that acidification of soils by "acid rain" has occurred and has resulted in severe environmental consequences. Thus it is important to determine whether Scottish soils have been similarly affected.

05 Plants - Nutrient uptake, growth and production

BACKGROUND

The objective of the programme in conjunction with PUs 03, 04 and 06 is to determine the sustainability of plant production in hill and upland environments in which the supply of nutrients from native soils is low and the justification for fertiliser inputs has to take account of their efficiency of use and their long term effects on soils and water. This requires a strategic understanding of the important factors and processes which affect the uptake and cycling of nutrients, and growth of plants in these environments, specifically in relation to indigenous and sown grassland, and trees. These plant communities are essential components of the land resources and land use management and production systems under investigation in other programme units viz. hill and upland sheep and cattle, deer and goats, PUs 02, 07 and 08, silvopastoral systems, PU 02, and farm woodlands and forestry.

RESEARCH OBJECTIVES

Indigenous and sown grassland

Herbage production from indigenous and sown swards in hill and upland environments is limited by the availability of nitrogen and phosphorus, low soil pH and low temperatures. The means whereby plants adapt to these environments require to be understood in order to predict the ability of plants to sustain production and how this ability might be influenced by adjustments to pH, nutrient inputs and the inclusion of clover. The effects of grazing on plant production are dealt with in PU 06 - Vegetation Dynamics and Grazing Ecology. The emphasis in this PU is placed on the carbon, phosphate (see also PU 04) and nitrogen economies of indigenous and sown plants and how these may be affected by pH, temperature and photosynthesis, root morphology and dynamics of root growth, the rhizosphere, the storage and internal cycling of nutrients, inputs of fertiliser and clover N, the transfer of nutrients from the grazing ruminant and plant litter to the soil, and to and from, the soil/plant to the atmosphere.

Carbon Economy and Photosynthesis

(a) Role of energy and nutrients in limiting growth responses of hill grasses to defoliation.

The scope for manipulating the botanical composition and nutritive value of indigenous plant communities by grazing control is being investigated on a limited number of field sites (PU 06 ROs a, b and c). To extrapolate from these findings and predict amounts of utilizable DM of particular vegetation types across the range of sites they occupy, requires that the work should be underpinned by autecological studies and investigations of the modifying influence of edaphic and climatic factors on the carbon economy of some of the more important indigenous plant species.
(b) Develop methods for manipulating and extending the period of production for sown swards.

Interactions between temperature and nutrition will affect the photosynthetic performance of sown upland swards by altering their ability to partition carbon and nutrients to leaves in the autumn, and internally cycle nutrients for storage over winter to support spring growth. The exact physiological mechanisms by which some grass genotypes are better suited for spring and autumn growth than others are unknown. These mechanisms need to be described and quantified to understand how to manipulate sward productivity at either end of the growing season particularly in relation to the use of N.

Forms of P and availability of P and N as affected by pH

(c) Influence of plant uptake on P depletion, repletion and speciation in the soil solution.

Highly organic hill and upland soils are likely to have much of the small amount of total P in the soil solution as organic combinations. Knowledge of which different organic and inorganic forms of P are present and the extent to which they are available for uptake by grass is crucial for assessing the P economy of upland soils and determining the need for fertiliser P.

(d) Influence of soil phosphorus concentration, pH and aluminium on uptake of phosphorus by grass.

The ability of grasses to extract P from marginal soils and the extent to which P uptake is affected by soil solution chemistry also requires to be understood.

(e) Effect of N supply and soil acidity interactions on nutrient uptake and pasture growth.

Acidification can be accelerated by nitrogen fertiliser use and nutrient uptake by vegetation. An understanding of the effects and quantification of acidification in N-fertilised and non-fertilised pastures on N uptake is necessary so that management strategies can be developed which reduce the risk of further acidification, maintain productivity, and minimise the potential for environmental pollution.

Fertiliser N, Clover N, and N Transfers

N fertiliser inputs remain a major management tool for the manipulation of herbage production from the grass and grass/clover pastures which form an integral part of grazing systems in hill and upland areas. There is a continuing need to develop management strategies which improve the efficiency of N fertiliser use, maximise the inputs of N derived from clover and minimise environmental pollution. These management strategies have to take account of the root system development of pasture species on N uptake, internal plant storage and cycling of N and transfer of N between the various components of the grazing system, including the atmosphere. Information derived from these studies can be used to model N-cycling in upland pastures.

(f) To achieve the efficient use of N fertiliser on sown pastures.

The efficiency with which fertiliser applications are used may be limited by factors such as high soil water and organic matter contents. These may result in a reduction in the amounts of available N as a consequence of leaching, denitrification or immobilisation. To utilise fertiliser N more efficiently, N supply must be closely matched to herbage demand; this will also minimise environmental pollution.

(g) Quantify root system development of pasture species.

Root length, radius, branching patterns, the rates and relative timing of root growth and root distribution in the soil profile in relation to nutrient supply are critical to the plant's ability to absorb nutrients from the more difficult uncultivated soils and continuously stocked pastures of the hills and uplands. In a mixed grass and clover sward, the root systems have different characteristics and abilities to take up nutrients. Soil type and grazing intensity and soil compaction also has an effect on rooting characteristics; the influence of soil structure, soil water status and soil temperature on root development need to be examined.

(h) Availability of nutrients and internal nutrient cycling for regrowth of cut grass.

Grass plants recycle N from roots and leaf bases to shoots during regrowth after grazing or cutting, to augment the available N from the soil. The effect of fertiliser timing and supply on uptake and remobilisation of stored reserves and the consequences for plant growth require to be quantified.

(i) Determine importance of mycorrhizal connections in the transfer of nutrients between clover and ryegrass plants.

Vesicular-arbuscular mycorrhizal connections exist between plant roots of different species, and may act to transfer nutrients between plants, thereby by-passing the soil. Understanding the mechanism of N and P transfer between plants, and determining the significance for plant productivity is essential to our understanding of nutrient cycling in grass/clover swards and for the manipulation of sward nutrition.

(j) Quantify the contribution of fixed atmospheric N_2 in upland sown swards. In sown swards white clover can provide an input of low cost fixed N_2 and thus reduce reliance on N fertiliser. Previous work in hill and upland swards indicated that inputs of 50-120 kg N/ha could be achieved. However, further work is required to quantify seasonal patterns and annual inputs of fixed N_2 in continuously grazed swards. Furthermore, there is a particular need to quantify the input of fixed N_2 from clover in mixed swards under trees.

(k) Effect of N fertiliser on clover performance in grass/clover mixtures.

Under some systems of management, the use of fertiliser N to manipulate herbage production may reduce N_2 fixation by clover and the clover component in the sward. It is necessary to understand the interactions of mineral N supply with clover N_2 fixation in order to develop N fertiliser strategies which will maintain the content of clover in the sward.

(l) Quantify the role of animal excreta and plant litter in nitrogen cycling.

In grazed swards nutrients are recycled to the soil via excretal returns from grazing animals and plant litter. Ingestion of herbage and subsequent excretion results in a spatial and temporal redistribution of nutrients, which can result in changes in soil fertility. The rates of flux of nutrients via excreta or litter depend on the partitioning of herbage between consumption and senescence. The magnitude of recovery and loss of nutrients cycling via the animal is poorly defined for UK conditions. Data on the rates of nitrogen flux via the animals and its subsequent recovery by herbage will be used to assess the effects of excreta on the nitrogen requirements of sown pastures.

(m) Nitrogen transfers between pasture, water and atmosphere.

Atmospheric inputs of nitrogen occur through wet and dry deposition and through gaseous exchange with plants. Outputs occur through soil denitrification, plant respiration and localised losses from animal excreta. The fluxes of nitrogen associated with these processes are not quantified in the hill and

upland environment and therefore the net nitrogen budget with respect to the atmosphere is unknown.
(n) Modelling N cycling in upland pastures.

There is a need to draw information on the availability, uptake and partition of nitrogen in pasture production systems in the upland environment together, to identify gaps in information and mathematical modelling to allow predictions of the consequences of given management or input strategies on herbage production to be made.

Trees and other Woody Perennials

It is anticipated that a major change in land use in the hills and uplands will involve a range of forestry systems developed in integration with existing agricultural land use, as farm forestry, agroforestry, and, on the more extensive hill areas, as forestry. There are specific aspects of the biology of these potential systems which require research to provide quantitative relationships which will form the basis of models and produce the management protocols whereby predictable levels of output can be increasingly achieved.

Agroforestry

Models of silvopastoral systems (widely spaced trees with an understorey crop of grass or grass/clover) have been and will continue to be modelled, there is a need to improve the relationships describing the effect of tree shade on pasture growth and root growth and development, competition between grass and trees for water and nutrients, and the effects of N fertiliser and N recycled through the animal, and the role of allelopathy on the growth and quality of both plant components. Effects of silvopastoral systems on the environment are the subject of an EEC contract.
(o) Evaluate factors affecting energy capture and plant production in silvopastoral systems.

Incoming radiation to the understorey grass crop will be affected by tree spacing, tree height and canopy structure in silvopastoral systems. These factors will also affect temperature, precipitation, humidity, air flows though the canopy and evapotranspiration of the grass crop, and thus photosynthesis, respiration and herbage production.
(p) The nitrogen and water relations of grass and trees when establishing a silvopastoral system.

Implications for water and nitrogen in the establishment phase of a silvopastoral system are being investigated under the auspices of a DAFS-IFS award in collaboration with Prof D. Atkinson (Aberdeen University) and Prof P. Jarvis (Edinburgh University).
(q) The effect of allelopathic interactions on nutrient uptake by trees and grass.

The role of allelopathy, which is usually inhibitory, is potentially of most importance in systems where there is a diverse mixture of species, as in silvo-pastoral systems. It is essential to understand allelopathic interactions between the different components of a silvopastoral system in relation to nutrient uptake, and the manner in which they may be modified by species selection and fertiliser application, to minimise growth inhibition.

Farm Forestry and Forestry

The potential for increasing the intensity of tree production exists where land of better quality in the marginal/upland areas is released from agriculture and used for farm forestry, (small scale farm plantations of broadleaved or conifer woodland). Early cash returns from high rates of growth, combined with better quality timber is a possibility; another is biofuel production. Alteration in the rates of tree growth can be brought about by manipulating inputs of fertilisers. Matching nutrient supply to plant demand, and obtaining information on the dynamics of root distribution and root/soil interactions on nutrient uptake and of how the tree partitions and stores nutrients through an annual cycle of production will lead to improved efficiency of fertiliser use and minimise pollution effects. There are additional factors which have to be taken into account when developing efficient fertiliser strategies for second rotation forests : these will be investigated.
(r) Effect of nutrient supply on internal nutrient cycling and seasonal growth of trees.

The annual bill for fertilising current forestry systems in the UK exceeds £5M and may increase dramatically under the government's extensification scheme if land is released and used for farm forestry. Most fertilisers are applied to trees during their establishment when demand for nutrient uptake is greatest. Both deciduous and ever-green trees recycle N, P and K to maintain seasonal growth. Before field measurements can be made, identification of the mechanisms of nutrient turnover within trees is essential.
(s) Quantification of root systems and mycorrhizal associations of tree species in relation to nutrient supply.

Information on the dynamics of root distribution and root/soil interactions is essential to understand the potential of tree species to extract nutrients and water from the soil and allow timing of nutrient application to be improved. Root system dynamics are a major component of nutrient cycles in tree plantations since, in addition to supplying above-ground tree components with nutrients, the root system itself may represent a substantial reservoir. There is also a need to determine the dynamics of root infection by mycorrhizal fungi and their role in soil/plant nutrient transfers. Difficulties inherent with tree root system studies necessitate further development of a range of techniques including the minirhizotron, root coring and electron microscopy.
(t) Effect of nutrient supply upon nutrient uptake and partition of growth in trees.

Careful matching of nutrient supply to plant demand can lead to dramatic increases in productivity and may be one method by which rotation lengths in farm forestry may be shortened. In order to manage plantations in this way it is essential to understand nutrient demands of different tree species in relation to both seasonal growth and partitioning of resources within the tree. Knowledge of the physiological mechanisms by which plant growth rate is regulated by timing and level of nutrient supply will enable efficient fertiliser strategies to be developed.
(u) Factors affecting nutrient

source/sink relations during the establishment of second-rotation tree plantations.

Limited experience of second rotations in forest systems suggest that fertiliser requirements may be reduced and it is widely assumed that this phenomenon is due to the supply of nutrients released from decomposing harvest residues together with their effect of depressing weed competition. The physical presence of these residues increases the cost of replanting. Options to reduce costs include burning or whole-tree harvesting. The longer-term nutritional consequences of such actions remain unclear. Research into the cycling of nutrients during this critical stage in stand development will enable the consequences of these different management practices to be assessed. Particular attention will be paid to the potential supply of nutrients from soil reserves and how this may be altered by the removal of whole trees. This work is to be carried out in collaboration with the Forestry Commission and results will be of direct relevance to on-farm forestry where shortened rotations coupled with whole-tree utilisation may increase nutrient removals still further.

There are a number of ways, in addition to fertiliser management, which have the potential to influence timber production and improve the efficiency of farm forestry systems. The choice of species, spacing and root system characteristics in relation to soil type, and shelter effects (PU 07) the potential for incorporating N_2-fixing shrubs and trees, and introducing ways of increasing the supply of N in nutrient poor soils by planting mixtures of appropriate trees are some of the strategic issues which require to be explored.

(v) Performance of contrasting tree species under farm-forestry management.

The potential for manipulation of spacing and nutritional inputs to different species under intensive production systems on sites of good quality require to be investigated.

(w) Variation in tree root systems and its consequences for the use of different genotypes for farm forestry.

Information on the dynamics of tree root distribution and root/soil interactions is important to understand the potential of tree species to extract nutrients and water from the soil and allow timing of nutrient application to be improved. Root systems of different species vary in range of physiological and morphological characteristics but the extent of variation within a single species is unknown. Matching the root characteristics of different plant genotypes to soil physical properties is particularly important for perennial plants such as trees, where the root system is active for many years in a single crop rotation. An understanding of the morphological diversity of root systems will allow the selection of biotypes which optimise nutrient uptake and plant growth in different soils and provide a strategic base to the development of efficient farm forestry and agroforestry production systems.

(x) Assess potential productivity and use of N_2-fixing shrubs.

N_2-fixing shrubs and trees can be beneficial as an additional source of N especially during establishment. There is the potential for increased cycling of N and other nutrients as a consequence of decreased losses through run-off and erosion and increased rates of plant litter and nodule decomposition. Fertiliser requirements are likely to be less and some shrubs will be suitable for grazing by ruminants. Knowledge of the potential for the use of N_2-fixing plants in on-farm forestry is sparse.

(y) Plant nutrient transformation and availability beneath pure and mixed tree species.

The supply of soil nitrogen to crops of Sitka spruce planted on nutrient poor soils is enhanced by planting in mixture with pine or larch. The mechanisms of this effect and the processes involved have not been identified but enhanced mineralisation of nitrogen is implicated. The soils where mixed species are prescribed are frequently poor in P and K and for pure stands regular applications of P and K fertilisers are required. The effects of planting mixed tree species on the availability of P and K have not been ascertained. The possible role of allelopathy in this effect has not been investigated.

06 Vegetation dynamics and the ecology of grazing systems

BACKGROUND

Indigenous Vegetation

The hills and uplands of the UK provide a unique environment in which a number of land use objectives require to be satisfied. Important for their achievement is an understanding of the inter-relationships between the grazing domesticated ruminant and indigenous vegetation. The objectives of the research are to provide a quantitative understanding of the response to grazing of plants and of grazing behaviour. This information is required so that land management systems can be developed which are compatible with the requirements of sheep, cattle, wildlife and recreation, and with enhancing the landscape and amenity value of the hills and uplands.

RESEARCH OBJECTIVES

Plant Responses

This requires a knowledge of how plant communities respond to grazing in interaction with soil and edaphic factors, how plant dynamics within and at the boundaries of communities alter the composition of the vegetation and how management protocols can be developed to meet specific requirements. An adequate understanding of plant responses to defoliation, diet selection and intake exists for dry heather moorland, blanket bog and species-rich Agrostis-Festuca. Knowledge of the responses of the three other most important communities, viz. Nardus, Molinia and species-poor Agrostis-Festuca, is not available.

(a) Control of the amount of Nardus in acid grassland by grazing using different animal species.

In several plant communities there have been large increases in the proportion of Nardus stricta which has been attributed to changes in both farming practice and sheep to cattle ratios. Nardus is undesirable both because of its rejection as a feed by sheep but also because of its poor contribution as a habitat for

wildlife and its unattractive scenic value. Control of Nardus by herbicides is expensive and undesirable and investigation of grazing management protocols for control using sheep, cattle or goats as the most feasible approach, is needed.
(b) Scope for manipulation of the floristic composition and nutritive value of Molinia grassland by grazing.

Molinia is currently under-utilised in extensive grazing systems because sheep appear to preferentially graze adjacent Agrostis-Festuca communities. The uneaten leaves accumulate as litter and impede growth in subsequent years so that periodic burning is required to maintain Molinia dominance. Molinia has a relatively high nutritive value and has potential as a feed for grazing cattle. However, it is known to be sensitive to heavy grazing, and to develop protocols for the management of Molinia communities, a knowledge of the extent and patterns of defoliation by cattle that can be sustained by Molinia is required. The nature and role of the plant communities which develop when Molinia is overgrazed also need to be evaluated.
(c) Effects of sward conditions on the composition and productivity of species-poor Agrostis-Festuca grassland.

Species-poor Agrostis-Festuca communities are very important to sheep productivity in Wales, the North of England and the wetter parts of upland Scotland. There is considerable concern that they are becoming degraded with the ingress of undesirable species such as mosses. A balance between productive Agrostis-Festuca and other communities is necessary if wider conservation objectives are to be realised using sheep as a management tool.
(d) Approaches to aiding the rehabilitation of degraded heather stands.

In several parts of the UK, e.g. Wales, North Yorkshire Moors and Shetland, the area occupied by heather moorland is declining significantly with deleterious consequences to local economies through reduced grouse numbers and a reduced landscape value. The decline in these areas has been related to mismanagement of sheep grazing, winter feeding and burning. The re-establishment of these areas to heather dominance will require strategies of burning and grazing management, which have yet to be developed.
(e) Environmental and management factors controlling the cover of Calluna in wet moorlands.

Sufficient knowledge exists about the effects of burning and grazing on well-managed dry heaths in the east of the UK to allow effective management of these heaths. This is not the case for the wetter western moorlands, which cover about a third of Scotland and which consist mainly of variations of Calluna/Molinia vegetation. Soil and environmental factors in interaction with burning and grazing management practices are thought to be important in determining the stability and productivity of these communities.
(f) Mechanisms of interspecific competition in the spread of bracken.

Bracken is currently spreading at a rate of 1% per annum in Scotland and Wales and its spread involves interactions between grazing, burning and edaphic factors, as they influence above-ground canopy changes, and root processes, such as allelopathy and nutrient competition. Whilst herbicides are reasonably effective, the fact that bracken is still spreading suggests that more cost-effective means of non-chemical control based on a greater understanding of the circumstances leading to the spread of bracken is necessary. Not only will there be economic but also conservation benefits through increased habitat diversity by reducing the spread of bracken.

Grazing behaviour

(g) Develop and test foraging strategy theories for ruminants grazing mixed indigenous hill vegetation.
(h) Assessment of diet composition and behaviour of ruminants grazing indigenous hill vegetation.
(i) Manipulation of ruminant foraging strategy to influence dynamics of hill vegetation communities.

A major deficiency in our ability to manage hill vegetation is our lack of understanding of foraging strategy by sheep and cattle. This understanding is necessary so that the consequences of where sheep and cattle graze on the productivity of plant communities and on the performance of these species can be predicted. It has particular current relevance to the setting of stocking rates within designated Environmentally Sensitive Areas to meet both environmental and agricultural objectives. A first stage is the development of an experimental approach to the validation of models derived from foraging strategy theory together with the development of suitable measurement techniques. This is a necessary prerequisite to the testing of models in a series of plant community combinations of increasing complexity. The approach can then be used to examine practical means of manipulation to meet specified agricultural or conservation objectives.

Sown Swards

The efficient utilisation of the relatively small proportion of improved sown grassland in the hills and the more extensive areas in the uplands is vitally important in sustaining much of the agricultural activity in these areas.

Considerable progress has been made as a consequence of describing the relationships between sward height, sward productivity and herbage intake. This has had a direct practical application in improving grassland management of the adult ewe and cow grazing perennial ryegrass swards during the summer.

There is now a need to define the relationships between lamb performance and sward parameters and develop objective criteria for the management of swards in the autumn. In management systems which rely less on inputs of N fertiliser it is crucial that the factors which influence clover content of the sward and the achievement of predictable levels of animal performance from perennial ryegrass/white clover swards are described and understood.

An improvement of 5% in the efficiency with which herbage is utilised could lead to an increase of £5M per annum to the UK sheep industry through increased revenue and reduced costs. The research described to be undertaken in the next five years is designed to achieve such an improvement.
(j) Spatial heterogeneity and persistence of clover in

relation to edaphic and management factors.

The ability to successfully manage grass/white clover swards under upland conditions is limited by the unpredictability of white clover performance, both within and between growing seasons, and the uneven distribution of white clover within swards. A combination of climate, physical properties of soils, nutrient supply from soils, plant responses to grazing and animal returns determine the spatial and temporal heterogeneity of clover. An understanding of these factors will lead to the development of management systems which encourage the clover component of the sward.

(k) Morphology of ryegrass and white clover in relation to climate and grazing strategies.

(l) Effects of grazing management and sward canopy structure on intake by suckling and weaned lambs on ryegrass/clover swards.

Previous research has shown the importance of canopy structure and light interception in determining the performance of white clover. Sward conditions also have a major impact on the clover content of diet which may influence nutrient supply from herbage and milk in the suckling lamb and herbage intake by the weaned lamb. These observations have led to the development of two new approaches to the management of grass/clover swards. The first approach is based on the possible synergism between grass varieties with different heading dates and white clovers of different morphological type. The second approach is based on the development of non-continuous grazing systems with low N fertiliser inputs and with greater sward heights in the July/August period.

(m) Relationships among stock density, sward structure, grazing behaviour and herbage intake by lambs on sown pasture.

Relationships between sward height and herbage intake developed for ewes have been found not to apply to lambs aged 10-14 weeks of age. Lamb growth rates at this age can influence subsequent carcass composition and there is a need to grow lambs at specified rates in the pre and post-weaning periods to meet marketing requirements. In consequence, it is important to be able to predict herbage intake of lambs from sward parameters.

(n) The effect of sward structure on sward productivity and ingestive behaviour of sheep grazing sown swards in autumn.

Although information is held on the sward profile to adapt to provide adequate pasture production and nutrient supply to ewes for the period from spring until August, less information has been obtained for the autumn period, which has important consequences for subsequent reproductive performance of ewes and for growth rates of lambs. Moreover, this information refers solely to swards that have been continuously grazed. In most systems silage aftermaths provide one-third to one-half of the grazing available in the autumn and these swards are likely to differ in their morphology and density compared to continuously grazed swards. These differences are likely to lead to differences in the responses of the plant to grazing in terms of herbage growth rate in the autumn and in the following spring and to ingestive behaviour and hence nutrient supply.

(o) Grazing strategies with goats to reduce the vigour of weed species in sown swards.

In upland sown swards grazing by goats has been found to have potential for the control of certain weed species. Goats are likely to be kept in upland areas for the production of cashmere and meat and consequently the cost-benefit of their use as a weed-control species is likely to be high. Research is needed to determine both short-term and long-term means of control through stocking density manipulations with goats.

(p) Intake, grazing behaviour and performance of goats grazing sown swards.

Little is known about the ingestive behaviour of goats grazing sown swards. Indirect evidence suggests that intakes may be lower than would be predicted on an inter-species basis. To provide sufficient nutrient supply for cashmere production and adequate live-weight gains, relationships between herbage intake and sward parameters requires to be described.

(q) The complementarity of sheep, cattle and goats grazing sown swards.

Complementary grazing of ruminant species has considerable potential to produce biologically and economically efficient systems. Indirect evidence suggests that facilitation may occur between goats and either sheep or cattle. Research which showed that there were only small benefits of grazing cattle and sheep together requires to be extended in the light of new knowledge on the relationships between sward height and herbage intake.

07 Nutrition of grazing animals

BACKGROUND

Systems of land management for animal enterprises in the hills and uplands are largely determined by the fact that between 50% and 100% of the nutrients ingested by ruminants are obtained from grazed herbage. The objective of research is to predict nutrient intakes from grazing herbage more precisely and quantify the relevant underlying digestive and metabolic processes which determine animal production responses and the efficiency of use of feed inputs. Environmental conditions in hill and upland areas are such that the efficiency with which nutrients are used is modified by increased energy expenditure: these effects will also be quantified.

RESEARCH OBJECTIVES

Adult sheep

(a) Improved prediction of herbage intake by sheep grazing summer and autumn sown swards from a study of behavioural and physiological factors.

The proportion of variation in herbage intake by ewes from sown swards that can be explained by sward and animal variables currently measured is about 50%. Research has concentrated recently on sward parameters and has tended to ignore physiological and social behavioural variables. The objective is to improve the precision of prediction of herbage intake; an increase of 10% in the accuracy with which intake can be predicted is estimated to reduce annual costs of the UK sheep flock by £2m.

(b) Effect of size of dam

and litter size on the efficiency of resource use by sheep grazing sown swards.

The efficiency of sheep meat production from grassland in upland environments is influenced not only by feed provision but also through the choice of ewe genotype. Maternal genotypes differ in a number of economically important characteristics such as lactation and reproduction. Both ewe and ram size influence energetic efficiency and a simulation model has indicated that output per unit area and energetic efficiency are affected by the interactions between maternal size, sire size and litter number. Advances in the ability to predict nutrient supply from sward parameters allows for the first time an objective means of testing genotype/environment interactions. The objectives are to improve the efficiency of land use for upland sheep production and to devise the principles and objectives for future genetic manipulation.

Lambs

The objective of research on lamb growth is to predictably produce a lean carcass from a range of genotypes of desired size and conformation to meet market requirements and provide a supply of lamb to these markets over an extended period of the year. This takes into account changes which are likely to take place in the EEC sheep-meat regime and future market demands. Important issues are how patterns of nutrient supply influences carcass composition of lambs and how nutrient supply can be predictably achieved from grazed grass herbage and forage brassica crops. Research which will lead to more precisely meeting consumer demand to the spreading supply of lamb over the winter, together with reduced costs, through greater efficiency in use of feed resources, is estimated could benefit the sheep industry by £2.5m per annum over the next 10 years.

(c) Effect of pattern of nutrient supply on the carcass composition of lambs of different genotypes.

Relationships have been developed between carcass composition and live weight for a number of breeds and crossbreds. Recent research has indicated that current relationships between carcass composition and live weight of lambs grown continuously cannot be applied to lambs when different patterns of growth in the pre- and post-weaning period are applied. These aspects will be examined with the aim of describing the patterns of nutrient supply to achieve desired carcass compositions for a range of breeds and crossbreds over the autumn and winter.

(d) Nutrient supply from grazed upland swards for weaned lambs in the autumn.

In the post-weaning period, nutrient supply to lambs is principally derived from grass/clover swards. Our ability to predict growth rate of lambs from nutrient supply from grazed herbage in the autumn is currently poor. Increased precision would allow the more efficient use of often limited feed resources from grassland.

(e) Factors influencing the growth rate and carcass gains of lambs grazing forage brassicas.

(f) Role of glucosinolates in affecting the voluntary intake of forage brassicas by sheep. (DAFS IFS award).

The use of forage brassica crops to finish lambs in the autumn is likely to increase in the future as the supply of lambs to the market is spread over a longer period after weaning. They are a source of potentially inexpensive nutrients but it has not proved possible to predict lamb growth rates, which are usually low and variable, with any precision. S-containing compounds and trace elements have both been implicated in these effects. As well as the effect that S-containing compounds may have on the efficiency of nutrient utilisation, they have also been implicated in the low and variable voluntary intakes reported for forage brassicas. The identification of the reasons for these low and variable intakes will allow lamb performance to be more precisely predicted. Since the level of S-containing compounds is amenable to variation by genetic selection and cultural practice and possible prophylactic approaches to adjusting trace element levels exist, there are a number of approaches to improving the efficiency of utilisation of forage brassicas.

(g) Nutrient supply from forage brassica crops suitable for efficient utilisation by sheep in the winter.

To spread the supply of lamb onto the market until the late winter requires the use of alternative forage brassicas, which are winter-hardy and accessible during frosty and snowy weather. Potentially suitable material is available from plant breeders but its nutritive value and potential for grazing in situ have not been investigated.

(h) Effect of grazing management practices on the trace element nutrition of lambs.

Lamb growth on some reseeded swards in upland areas has been reduced by a lime-induced copper deficiency associated with the antagonistic effects of molybdenum and sulphur on copper availability. Cupric oxide needles have been shown to be a satisfactory prophylactic treatment in some circumstances. Only one equation for predicting copper availability has been developed for part of the grazing season to identify the circumstances when such a treatment is necessary and these require to be developed for the whole of the grazing season. The inclusion of indigenous vegetation in the diet may be a cheaper and simpler means of achieving the same objective under some circumstances. Since cobalt and selenium deficiency is thought to occur under similar conditions, these trace elements also require study.

Goats

(i) Trace element nutrition of goats grazing sown and indigenous swards.

Goats, as an alternative species for upland areas for fibre and meat production, have been found to have low plasma levels of copper when grazing swards on soils which are likely to lead to herbage with low availability of copper. Copper is known to be important to fibre growth and this gives an added significance to its study in upland areas.

Cattle

(j) Effect of grazing management strategies on cattle performance and floristic composition in Nardus-dominated swards.

Interim results of research (see PU 06) on the grazing of Nardus, which is

considered to be an undesirable species in most indigenous communities, have indicated that Nardus can be effectively controlled by grazing by cattle. It is unclear to what extent this can be achieved without inflicting undue penalty on cattle performance. For both conservation and agriculture objectives to be met, it is necessary to quantify levels of animal performance that can be achieved when Nardus is controlled by cattle grazing.
(k) Econometric model of land and feed resource use for growing beef cattle.

Relationships between the interactions of winter and summer nutrition and growth rate of growing beef cattle have been developed, but the resource utilisation implications of these relationships have not been examined. The development of a computer model will provide the agricultural industry with a valuable aid to farm management decision-making with a possible saving in costs of £0.5 m per annum.

Deer

(l) Nutrient supply from sown swards in the summer and autumn for deer calves and yearlings.

Relationships between sward height and animal performance have been developed for sheep and cattle grazing systems. In the development of systems of deer farming where numbers have increased rapidly to 30,000 in the last few years, these relationships are of similar importance to the economic efficiency of deer grazing systems as to those of other species. In particular, relationships for calves in the post-weaning period and for yearlings prior to finishing or entering the breeding herd are required.
(m) Seasonal cycles of deer in relation to nutrient supply.

Red deer have a pronounced seasonality in their biological rhythms of growth, intake, reproduction and coat growth. Our understanding of these rhythms is incomplete, particularly of their interaction with availability of nutrients from pasture and of the inappetance of the young animal in its first winter. The period of low growth and appetite in the winter limits the ability to market deer-meat economically throughout the year and this will become a major constraint, unless overcome, to the development of the farmed deer industry in the future.

Shelter and Farm/Forestry Systems

The anticipated increase in the use of hill and upland areas for forestry, farm/forestry and agroforestry systems could have an important modifying role on the energy expenditure of sheep through changing shelter provision. No quantification of these effects is currently available. Whilst model systems can be used to predict energy expenditure, they cannot take into account behavioural aspects which are considered to greatly modify energy expenditure; furthermore, a large-scale use of resources is required to validate these models.
(n) Measurement of energy expenditure in grazing sheep.

A more direct approach with a strong probability of success is to directly measure the nutrient intake and energy expenditure in detailed small-scale studies. Techniques for the measurement of nutrient intake are available and methods for the measurement of energy expenditure are at an advanced stage of development.
(o) Impact of shelter in agroforestry systems on energy expenditure, animal behaviour and nutrient supply in sheep.

The approach will initially be used to examine the effect of spacing density on energy expenditure and nutrient intake in agroforestry stands when the intimate mixture of sheep and trees are likely to lead to specific benefits to the sheep particularly in the spring, autumn and winter periods. Information on the effect of forestry systems on animal shelter will have an economic benefit in reducing feed costs and will encourage the uptake of such systems by the livestock sector of the farming industry.
(p) Modelling the shelter effects in agroforestry stands through study of mass, heat and water transport. (DAFS IFS award).

Spacing density in agroforestry stands will also influence air flow and through turbulence and vertical component effects affect temperature and water conservation. These in turn will influence grass growth and nutrient intake and energy expenditure by sheep. The same variables will have similar effects on shelter belts in farm/forestry systems.
(q) Effect of weather on grazing behaviour, nutrient intake and energy expenditure of sheep in farm/forestry systems.

Shelter belts may have their largest benefits in reducing fluctuation in weather conditions and thereby avoiding sudden changes in grazing behaviour, intake and energy expenditure. This may be particularly important for adult ewes in the autumn where stress effects on reproductive performance have been reported.

08 Animal production from grazing ruminants

RESEARCH OBJECTIVES

Sheep

In sheep production systems in the hills and uplands of the UK two of the major determinants of biological and economic efficiency are reproductive performance and the matching of nutrient supply to animal demand. Research is aimed at developing an understanding of how to control the reproductive rate of sheep relying on grazed herbage as their main feed source: it aims also to understand the way in which additional nutrient inputs and the utilisation of adipose tissue can be used to achieve predictable levels of animal performance.

The endocrine control mechanisms whereby early life nutrition influences reproductive success, and how body condition and current nutrient supply regulates ovulation rate will be determined. This information, with that derived from investigations concerning the factors influencing embryo loss, will provide the means of improving the predictability of reproductive performance and facilitate any developments in the use of exogenous means for controlling reproductive rate in the grazing ewe. Reducing between-year variation in lambing rate by 50% will reduce costs of production by £3 m per annum. The matching of lambing rate more closely to efficiency of resource use for a range of environments, could increase lambing rate in the hills and uplands by

10%, and increase income per farm by 15%.

The matching of nutrient supply to demand requires an understanding of the factors which determine the relative contributions to nutrient supply from grazed herbage (see PU 07), supplements and from the strategic use of adipose tissue reserves. An understanding of the mechanisms which favour the deposition of energy in adipose tissue and the ability to quantify deposition and utilisation in the grazing ewe will lead to significant improvements in the efficiency of sheep production systems.

(a) Effect of early-life nutrition on lifetime reproductive performance of sheep and the mode of action.

Reproductive rate of the ewe is known to be determined by growth and development in early life but the effect of nutrition at particular stages of development has received only limited attention in the sheep. The effects have not been quantified in a range of environments and the modes of action have not been identified.

(b) Endocrine mechanisms underlying the effect of body condition on ovulation rate of grazing ewes.

Effects of body condition on ovulation rate have been described for a range of genotypes. Differences in body condition have been found to be associated with differences in circulating follicle stimulating hormone concentrations during both the luteal and follicular phases. By a study of the underlying mechanisms responsible for the differences in circulating hormone levels, progress will be made in understanding how to make ovulation rate more predictable.

(c) Effects of nutrient intake by grazing sheep on their endocrine status and ovulation rate.

Effects of current nutrition on ovulation rate have been associated with changes in level of energy intake and in luteinising hormone pulse frequency in the follicular phase. Factors influencing luteinising hormone releasing hormone in relation to changes in intake, such as opioids, are not understood, nor is the relative significance of pituitary sensitivity to gonadotrophin releasing hormone and of sensitivity of the hypothalamus and pituitary to ovarian steroid feedback. Nutrition prior to the mating period will be able to be manipulated with more precision in the future. This, combined with an increase in understanding of mechanisms of ovulation rate control, will increase the precision of prediction of ovulation rate.

(d) Contribution of partial failure of fertilisation to ova wastage in sheep.

Ova wastage is attributed to partial fertilisation failure and loss of embryos. The relative importance of each of these effects has not been assessed under grazing conditions, although ova wastage of up to 25% has been reported in experiments under different conditions. Quantification of these effects will lead to a closer identification of the nature of the losses so that they can be minimised.

(e) Reproductive performance of sheep as influenced by sward conditions in the autumn and by supplementation.

Advances are being made in the prediction of nutrient supply from grazed herbage and when supplements are given in the autumn. This will allow the development of better decision rules about the allocation of land and feed resources to ewes of different genotypes over the mating period.

(f) Effects of genetically derived increased prolificacy on production efficiency under different nutritional environments.

The development of hill and upland genotypes with genetically determined high ovulation rates will allow the exploration of concepts of production efficiency in terms of land use in relation to nutrient supply from herbage in the autumn.

(g) Methods of describing change in body composition and utilisation of body reserves in grazing ruminants.

The seasonal pattern of nutrient supply to grazing ruminants in relation to nutrient demand enables nutrient energy to be stored as adipose tissue during the summer and utilised in the winter. It can be estimated in the breeding ewe that about one-third of metabolisable energy ingested in late summer is converted into adipose tissue and that about a quarter of the total metabolisable energy intake in late winter is derived from adipose tissue. Quantification of these effects in the living animal is important, particularly in relation to the possibility of manipulating the extent to which these processes can be used to economic advantage.

(h) Mechanisms controlling partitioning of nutrients between body reserves and milk in grazing ewes in late lactation.

The use of immunological approaches are one means whereby small changes in adipose tissue utilisation or deposition could be used to increase the efficiency with which feed resources are utilised and consequently produce savings in costs in sheep systems.

(i) Manipulation of lamb carcass composition by immunisation against fat cell membranes.

Immunological approaches to the reduction in fat content of some species have already been successful. The demand of the consumer for lamb meat with a low fat content is well appreciated and such an approach offers one, potentially rapid, means of achieving such an objective.

(j) Development of equipment to assess fat cover in live animals. (DAFS IFS award).

An alternative approach to increasing the leanness of carcass is to develop a method whereby producers can select live animals for slaughter within narrowly defined levels of fatness. Ultrasonics offer one means of measuring fat accurately in live sheep but there is a need to develop the technology for on-farm use.

Cattle

(k) Incidence and causes of reproductive failure in beef cows.

There is a continuing need to improve the economic and biological efficiency of hill and upland beef cow systems. The scope for achieving such improvements is largely limited to achieving improvements in reproductive performance and by the manipulation of winter feed inputs and adipose tissue. The factors that influence calving interval, and the successful use of exogenous means of producing twin ovulations in beef cows require to be identified and investigated. An understanding of the way that different genotypes respond by partitioning nutrients when subjected to variation in nutrient supply over the annual production cycle is also central to an understanding of how to

make the most efficient use of resources.
(l) Factors determining the length of post-partum anoestrus in beef cows and its endocrine control.
(m) Effects of post-partum nutrition and body composition on follicle development and ovulation in beef cows.

The initiation of ovarian cyclicity post-partum is under endocrine control but the factors known to influence the length of the post-partum anoestrous period and the modes of action are not understood. Understanding will allow management practices to be altered to reduce the period of rebreeding and may lead to the development of exogenous means of control.
(n) Endocrine control of follicle development and twin ovulations in beef cows.

The production of twins from beef cows is the means whereby the efficiency of suckler cow production could be most dramatically increased. In vitro fertilisation and embryo transfer techniques may have a role in the dairy cow industry but simpler techniques are likely to be required for the beef cow. Passive immunisation techniques offer the most potential because of ease of use and ability to induce twin ovulations. However, the conditions necessary for consistent induction of multiple ovulations remain to be elucidated.
(o) Effects of nutrient partitioning on the efficiency of resource use by beef cows of different genotypes.

The efficiency with which genotypes of differing productive characteristics utilise land and feed resources depends upon how nutrients are partitioned between productive processes and adipose tissue. Improvements in biological and economic efficiency will be made if genotypes are matched to suitable combinations of land and feed resources.

Alternative Animal Species

Agricultural land use in the hills and uplands is dominated by sheep and to a lesser extent by cattle. Self-sufficiency in beef in the EEC has already been achieved and it is generally assumed that self-sufficiency in sheep meat will take place within the next 10 years. There is likely to be a reduction in financial support for these commodities in the future, and land, which may be removed from cereal production in the marginal and lowland areas, may revert to grass, and sheep and cattle production. These factors could lead to a reduction in the competitive position and future viability of sheep and cattle in the hills and uplands. There are a number of possible alternative enterprises. Forestry and farm-forestry as alternatives may not always be acceptable options because of soil and climatic limitations, or detrimental landscape and environmental effects. There is, therefore, a requirement to identify and develop alternative ruminant livestock enterprises which are suited to the hill and upland environment and produce commodities likely to be in demand or have potential for market development.

Red Deer

Red deer have the advantage that they can utilise a wide range of sward types, produce very lean meat and there is the potential to increase numbers rapidly. Previous research has shown that it can be domesticated and that economic systems of production can be developed. The number of deer being farmed is increasing rapidly and it appears to be one alternative animal species that has some immediate potential.
(p) Performance of red deer in extensive and large-scale management systems.

Systems of deer production are being tested on a large scale in the Scottish Highlands but the relationships between stocking rate and sustainable productivity have not yet been established and some of the aspects relating scale of operation to biological and economic efficiency have not been addressed.
(q) Assessment of the lifetime performance of red deer hinds.

One of the advantages of the red deer would appear to be the lower replacement rate for female breeding stock than sheep or cattle. A long-term study is measuring the lifetime productive performance of the red deer.
(r) Development of hybrids between exotic deer and red deer and assessment of their potential for deer production systems.

Production systems presently developed for the red deer aim at marketing yearling animals for slaughter at approximately 16-18 months of age between September and December. It is important to develop an all-year-round market for deer meat and the means of achieving this are by altering the calving date and by increasing the rate of growth of the calf such that animals suitable for market requirements are produced at 8-14 months of age in the period from December until August. The hybridising of exotic deer species with red deer offers the possibility of increasing growth rates and altering calving date.

Goats

Feral goats have been shown to be adapted to UK hill and upland farming conditions and to have the potential to act as a biological controller of weed species in sown pastures. They are dual-purpose animals, producing cashmere fibre and meat. There is a strong UK demand for both products. Cashmere fibre worth £70 m is imported each year. There are difficulties in obtaining sufficient supplies from traditional exporting countries. Current annual consumption of goat meat in the UK is estimated to be 2,000 t. This does not meet UK demand which is estimated to be 3,000 t per annum and there is considered to be potential for increasing this amount further.
(s) Hormonal and nutritional manipulation of seasonal coat growth in cashmere goats and the harvesting of fibre.

Growth of cashmere fibre has been established to be seasonal with the period of shedding taking place in the late winter. Manipulation of fibre growth and shedding and improvements in harvesting techniques are prerequisites of the successful development of goat production systems.
(t) Cashmere production from goats and its improvement by cross-breeding and selection.

Yields of cashmere are currently low (80 g per annum), although of high value (£60-70 per kg). There is considerable variation about the mean cashmere yield and quality suggesting that rapid genetic improvement will be possible by selection.

However, a more rapid means of increasing cashmere yields is by the introduction of superior genetic material and this is currently taking place. To assist in the development of suitable selection indices for future use information on heritabilities and genetic correlations for fibre characteristics require to be obtained.
(u) Techniques of artificial insemination, super-ovulation and embryo transfer in goats.

Rapid improvements in genetic merit require the development of suitable techniques for multiple ovulation and embryo transfer and of artificial insemination.
(v) Growth and carcass composition of dual-purpose goats used for cashmere and meat production.

Income from cashmere fibre alone is unlikely to be sufficient to sustain the economics of goat production systems. There is an unsatisfied demand for goat meat in the UK but relationships between nutrient supply, growth rate and carcass composition have not been established in relation to the use of land and feed resources for upland-based systems.

Camelids

(w) Animal production and characteristics of fibre from camelids in upland environments.
(x) Techniques for oestrous synchronisation, artificial insemination and embryo transfer in camelids.

South American camelids have the potential to adapt to a range of sward types in the UK. Of the four camelid species, viz. llama, alpaca, guanaco and vicuna, the alpaca and guanaco appear to offer the most potential because of the quality of their fibre and their relative availability. However, there are only small numbers of the two species available in Europe and imports of semen and embryos are the most likely route whereby numbers can be increased. Hybridisation with the more common llama would be a slow means of introducing genetic material and there will be large benefits from the use of llamas as recipients for alpaca and guanaco embryos. Information on fibre quality and yield under UK conditions is not available and will be a prerequisite to progress being made in the development of camelids as alternative animals.

Semi-fine wool production

(y) Model the biological and economic possibilities of semi-fine wool production in the hills and uplands.

Sheep have several potential advantages, such as litter size and adaptability to the environment, over other ruminant species in the utilisation of hill and upland resources. They also have the potential to produce a combination of the food and non-food animal products. Currently wool contributes only 5-8% of the financial output of hill and upland sheep systems. However, there is a steady demand for semi-fine wool on the world market and there is a potential for an increase in the UK production of such wool. In consequence there is the potential to increase semi-fine wool production, which could be achieved from wether flocks on hill areas or from dual-purpose flocks in upland areas. Any sheep used for providing wool on low-ground areas are also likely to be bred on upland areas. To assess the biological and economical feasibility of such systems, a preliminary modelling exercise is required.

09 Outside Contracts

RESEARCH OBJECTIVES

(a) Soil properties and land use in relation to 1) mineral and 2) peat extraction.

Britain's landscape was once extensively scarred by the results of extractive mineral working. In recent years much remedial work has taken place and new planning applications must make provision for adequate remedial measures.
1) British Coal are responsible for major opencast workings : DAFS have a statutory responsibility for the successful management of restoration. MLURI, under contract to BC, provide soil surveys to assist in planning restorations and preparing proposals.
2) Scotland's land surface has over 25% of peat, parts of which are utilised as domestic and industrial fuel and as horticultural material. The quality and quantity of peat is important and special expertise in surveys of this material exist in MLURI and are utilised by the peat industry under contract.
(b) Land Capability Classification for Forestry.

Land Capability Classifications are becoming increasingly recognised as tools for assessing land resource potential. The Forestry Commission have commissioned a survey of Scotland based on research work developed at MLURI.
(c) Interpretation of air photographs and development of a database expressing land cover types in Scotland.

The potential of land is being studied and is expressed in a number of classifications : its actual use is a necessary adjunct to these studies and is also of great value in demonstrating the extent of change due to countryside pressures. The Scottish Development Department has commissioned interpretation of aerial photography flown in 1988 and the digitisation of the land cover maps.
(d) National Peatland Database for Scotland.

As part of a research contract entitled 'Combustion of peat with emphasis on reduced smoke emission and improved fuel feeding' MLURI have been contracted to produce a national peatland database for Scotland for the Energy Technology Support Unit (ETSU). The database will provide the spatial distribution of various peatland types of importance to the study.
(e) Use of satellite remote sensing of vegetation to map habitats of breeding birds.

NCC have contracted MLURI to analyse satellite imagery for a study of the general habitat of breeding birds at two sites, one in Scotland, the other in Northern England.
(f) Determine effects of soil water chemistry and vegetation type on acidification of streams.

In a number of areas in Scotland, Norway, Sweden and other countries, stream water and associated lakes are becoming more acidic. Some of this acidity has been attributed to the deposition in rainfall and acids derived from the burning of fossil fuels, but there is considerable disagreement about the extent of such depositions and about the effects they produce. These effects are likely to be strongly influenced by the nature of the vegetation and the nature and thickness of the soils through which the precipitation passes before entering the streams. The work is funded by the Royal Society Surface Water

Acidification Programme (SWAP) via research contracts.
(g) Relate mineral weathering to soil and fresh water acidification.

The replenishment of the acid neutralising capacity of soils and prediction of future changes in soil and water acidification are to a large degree dependent upon the quantification of mineral weathering rates. Such rates are being determined for different soil types in the area being studied under ROa. This work is also funded by SWAP.
(h) Assess the effects of agroforestry on soil condition and nutrient losses.

The current surplus of cereals within the EEC has lead to a search for cropping systems to produce products currently undersupplied within the Community. Both the Community and the UK import substantial quantities of timber and there is growing interest in increasing conventional forestry and agroforestry systems. The latter is likely to be established on soil types not previously used for tree production and research is needed into the effects on soil nutrient levels and soil physical condition. Aspects of this work will be funded by an EEC grant to study the environmental effects of agroforestry using the farm experiment at Glensaugh and will involve collaboration with Professor D. Atkinson at the University of Aberdeen.
(i) Devise practical methods to remove pollutants from distillery wastes.

The malt whisky industry produces wastes which contain appreciable quantities of copper. Two major effluents are produced in the manufacture of malt whisky. The first, pot ale which remains in the still after removal of "low wines" by distillation of the fermented mash, is reprocessed into animal feedstuffs. Distillation of the "low wines" leaves behind the second effluent, spent lees, which is either discharged directly into the environment, or treated on a biotower before discharge.

To meet the requirements of a recent CEC directive on the disposal of heavy metals in agriculture, the copper content of both whisky effluents must be reduced considerably before reprocessing or discharging into the environment.
(j) The dynamics of radio-nuclide uptake by sheep.

The growth of the nuclear power industry has created a need to study the effects of the accidental release of various radionuclides on entering the human food chain. The transfer quotients of ingested radionuclides by ruminants into meat and biological half-lives are not precisely known and these are required as components of the models. This work is funded by MAFF and CEGB and conducted in conjunction with ITE.
(k) Effect of sward conditions on radiocaesium cycling in hill and upland sheep systems.

Models developed for predicting the fate of radiocaesium in the human food chain were found to be inadequate following the Chernobyl incident. In particular, the prediction of the extent to which sheep grazing the hill and upland areas of the UK became contaminated was inadequate. The factors affecting the intake of radiocaesium by sheep grazing upland sown swards and indigenous hill vegetation growing on soils with a high organic content require to be better understood. The effect of plant biomass is considered to be of particular importance. This is joint work conducted with ITE and supported by NERC.
(l) Calluna vulgaris seed distribution, germination and establishment.

In areas of degenerate heather, where heather has been killed and ground cover lost or replaced by grass or has become bare peat, regeneration of heather will need to occur from seed. Information is needed to enhance and speed up regeneration by this means. The work is funded by the Joseph Nickerson Heather Improvement Foundation.
(m) The effect of controlled grazing on vegetation and tree regeneration in broad-leaved woodland.

Statutory agreements for the restriction of access for farm livestock to broad-leaved woodland under established conservation legislation require information on the impact of grazing animals on woodland vegetation and tree regeneration. Existing evidence is restricted to exclusion studies, and there is no information for woodland to which animals have controlled access. This work is supported by NCC.

EXTERNAL FUNDING BODIES

Department of Energy

Energy Technology Support Unit

European Economic Commission

Highlands and Islands Development Board

Central Electricity Generating Board

Pentlands Scotch Whisky Research Limited

British Gypsum

Statoil

British Coal Corporation

Forestry Commission

Argyll and Bute District Council

Joseph Nickerson Heather Improvement Foundation

Natural Environment Research Council

Pitlochry Knitwear

Ministry of Agriculture, Fisheries & Food

British Technology Group

Trident Feeds

Nature Conservancy Council

British Petroleum

Norsk Hydro

North East Scotland Development Authority

Grampian Regional Council

South of Scotland Electricity Board

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RESEARCH STATIONS

Sourhope Research Station, 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, the annual rainfall is around 940 mm.

Soils

The soils are developed on locally derived drift from andesitic lavas of Old Red Sandstone Age. Acid Brown Forest soils characterise 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 *Molinia* (Flying bent) and *Nardus* (White bent) dominant grass heaths.

There are 40 ha of rough grazing which have been reseeded and there is a further total of 45 ha of enclosed grassland, of which 20 ha is capable of being conserved.

Livestock

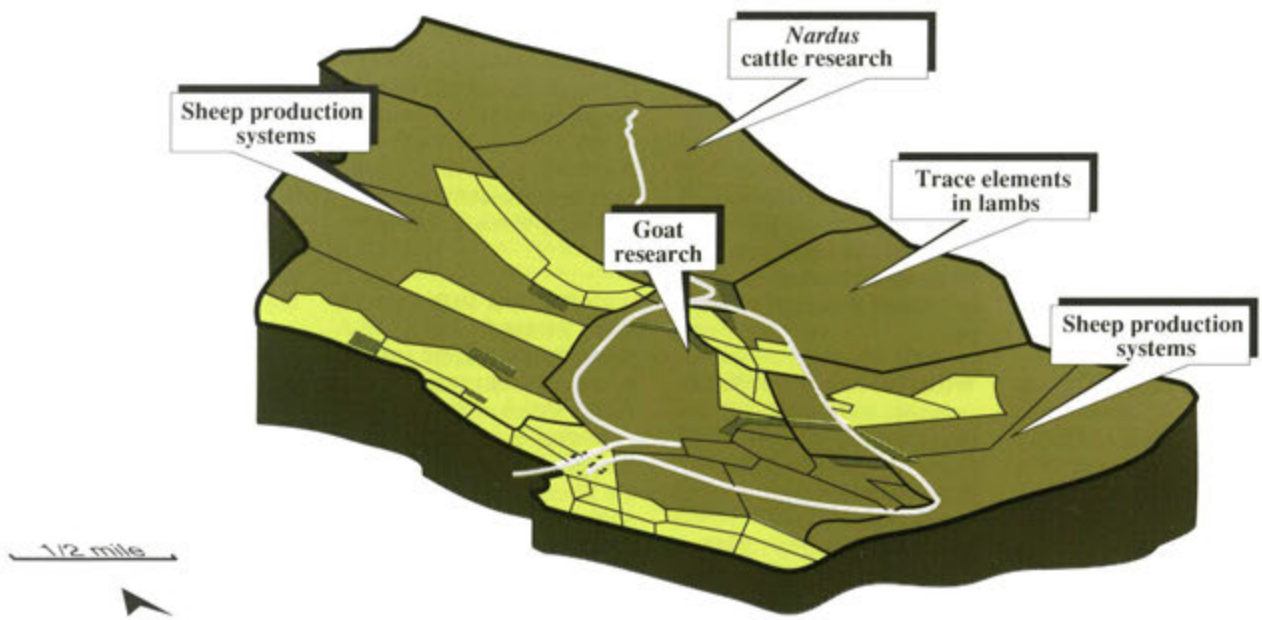
1200 Scottish Blackface ewes and 1000 North and South Country Cheviot ewes. 50 Suckler cows - spring calving.

Buildings

Inwintering accommodation for 50 cows, 660 ewes and 150 hoggs. Hostel with nine rooms, office and laboratory accommodation for 3 scientific staff and visting scientists.

Research

Conducted on trace element deficiency in lambs, grazing Nardus by cattle, foraging strategy of sheep on hill vegetation, productivity and breeding of goats and sheep production.



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

Soils

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

North of the fault the soils are of the Strichen association derived from schistose rock. The area has been extensively glaciated, and deep deposits of glacial drift cover the lower slopes. 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 derived from Old Red Sandstone. On Finella Hill iron humus podzols dominate the lower slopes and stony peaty podzols occur at higher elevations.

Land Resources

The farm 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 glacial soils and lower hill slopes. Bracken (*Pteridium aquilinum*) also occurs on the lower slopes.

The free draining land is dry heather (*Calluna vulgaris*) moor with blaeberry (*Vaccinium myrtillus*), wavy hair grass (*Deschampsia flexuosa*) and bell heather (*Erica cinerea*) locally important. On the deeper peats at higher elevations crossleaved heath (*Erica tetralix*) and cotton sedge (*Eriophorum vaginatum*) become co-dominant.

Livestock

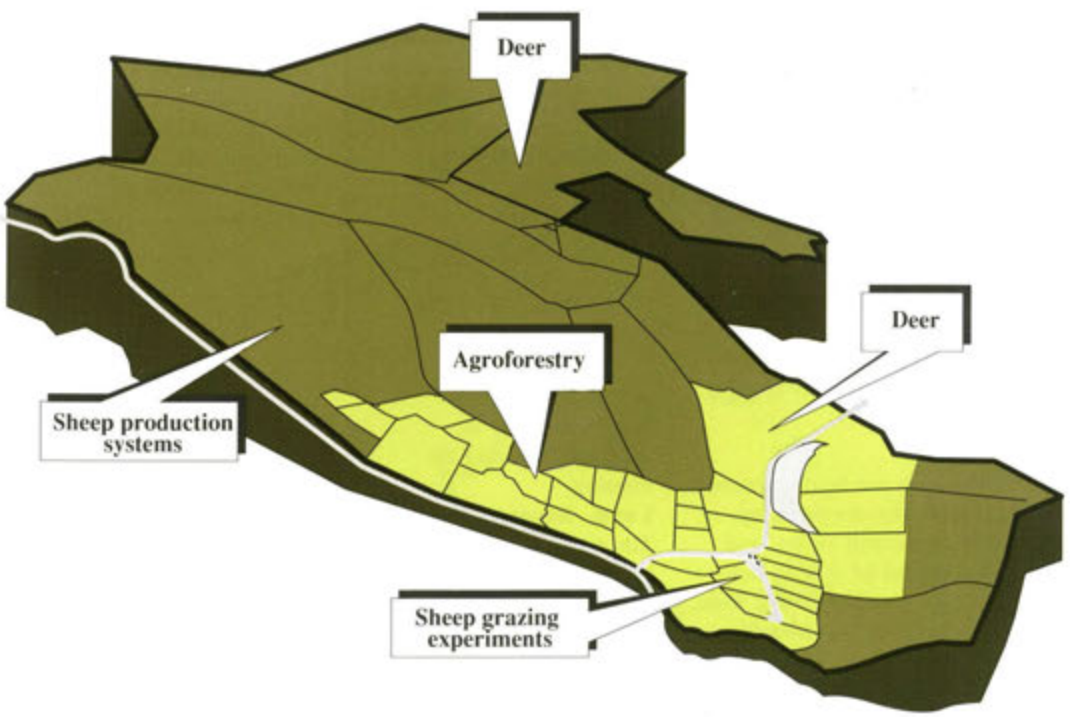
500 Scottish Blackface ewes, 400 Greyface ewes and 250 crossbred ewes of a range of genotypes, 50 spring calving suckler cows (Blue Grey). 300 breeding red deer hinds and stags with associated 250 Yearlings and calves.

Buildings

Loose housing accommodation and experimental cattle shed for cows and calves. Winter housing for 600 ewes. Accommodation for the housing of 150 red deer calves, office and laboratories for 3 scientifc staff and visiting scientifc staff.

Research

Research is conducted on agroforestry, deer, ewe efficiency and reproduction, and sheep production systems on heather moorland.

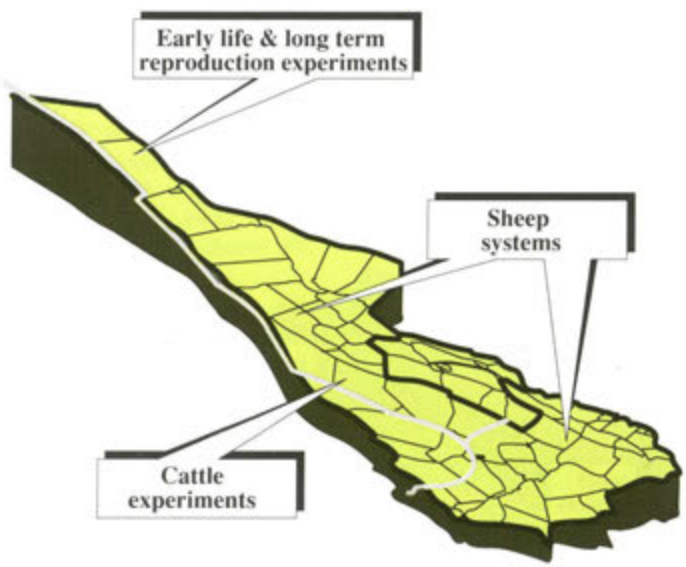


RESEARCH STATIONS

Bronydd Mawr Research Centre, which is jointly managed by MLURI and the Institute of Grassland and Animal Production, 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 1400 mm.

Soils

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



Land Resources

There are 260 ha, most of which has 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.

Livestock

There are 1025 Brecon Cheviot, 600 Beulah Speckleface and 160 Welsh Mule ewes. There is also a spring calving herd of 60 suckler ewes of Welsh Black, Hereford x Friesian and Aberdeen Angus x Friesian genotypes.

Buildings

Cattle and sheep sheds for housing 60 cows and 600 ewes respectively in winter are available. There are offices and laboratories for 4 permanent scientific staff and visiting scientists.

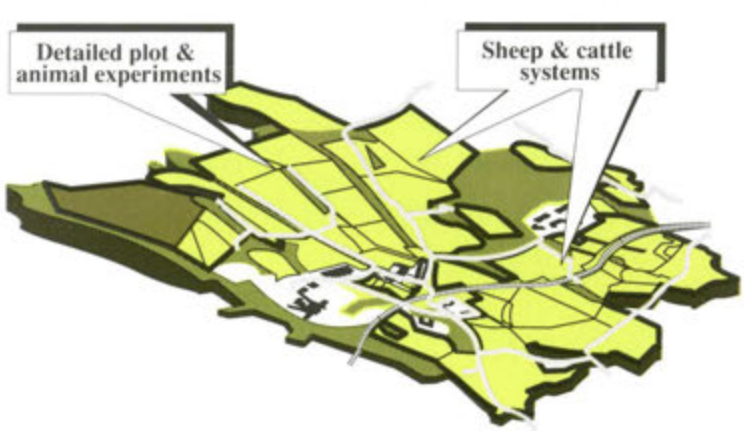
Research

Research is conducted on lamb growth and ewe reproduction in relation to pasture conditions, effect of early-life nutrition on life-time performance of ewes, genotype x environment interactions with beef cows by MLURI. Pasture studies on the evaluation of grass and clover varieties, on N cycling in grass/clover swards and on agroforestry are conducted by IGAP, and the Welsh Plant Breeding Station, and joint studies by both Institutes on sheep systems research are conducted.

Hartwood Research Station, which extends to over 300 ha, is located near Shotts in Lanarkshire, 30 miles from the Institute's Bush Site. 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 some 1100 mm.

Soils

The soils are heavy textured, imperfectly drained gleys of the Rowanhill series, and are typical of 400 sq miles of heavy soils running from Stirlingshire southwards into Ayrshire. The heavy wet soils contribute significantly to the marginal nature of the farming.



Land Resources

The research station has 220 ha of sown grassland, 20 ha of woodland strips, 28 ha of indigenous hill vegetation, and 25 ha of forage crops, mainly rape.

Livestock

There are 800 Greyface ewes, 230 Scottish Blackface ewes and 180 Suckler cows (135 Hereford x Friesian and 45 Blue Grey cows split between autumn, winter and spring calving herds).

Buildings

Winter housing for 660 ewes. Two cattle sheds each for 120 cows and calves. Silage capacity for 1500 tons. Experimental sheep and cattle metabolism facilities for 50 sheep and 15 cows respectively and cattle surgery facilities. Laboratory and office space including deep freeze and oven facilities for 5 scientific staff based at Hartwood and visiting scientists.

Research

Research conducted on grazing ecology of sown swards, plant nutrition in grass/clover swards, cattle reproduction, sheep and beef cattle grazing systems on upland sown swards.

Macaulay Land Use Research Institute in Upland Britain